PHYSICAL VARIABLES AND COMMUNITY STRUCTURE OF THE WHITE ROCKS CLIFF SYSTEM, CUMBERLAND GAP NATIONAL HISTORICAL PARK

A Thesis

By

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PHYSICAL VARIABLES AND COMMUNITY STRUCTURE OF THE WHITE ROCKS CLIFF SYSTEM, CUMBERLAND GAP NATIONAL HISTORICAL PARK.

(December 2007)

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Cliff-face ecology is the study of the patterns and processes which control cliff-face ecosystems (Larson et al. 2000). It is important to study cliff systems due to their cultural and biological significance. Cliff systems have been employed for shelter and concealment throughout humanities history. Presently, cliff systems are used primarily for recreation, which has had an increasingly negative effect on the sensitive vegetation which occurs on these systems. Cliff systems provide habitat for many threatened, rare, and arctic and boreal disjunct species which are restricted to cliff systems as a result of moderated environmental and physical conditions not found in traditional horizontal environments.

A vegetative survey of the White Rocks cliff system, located in the Cumberland Gap National Historical Park, was conducted during the summer and fall of 2005, and May, 2006. Vascular plants, mosses, and lichens were surveyed on the cliff top, cliff face, and talus using $1m^2$ plots spaced evenly along 12 randomly located vertical transects. Physical characteristics including transect position on the cliff, slope, aspect, soil volume, microfeature frequency and type, and total microfeature area were measured for each plot. Biotic characteristics including vascular, bryophyte and lichen species percent cover per plot, and presence or absence of each species per microfeature were also analyzed per plot. Microfeatures were classified in three categories including ledges, cracks and pockets. Transect and plot locations with respective biotic and abiotic characteristics were used to construct a GIS database of the cliff system to assess the potential impacts of rock climbing. Biotic and abiotic factors were analyzed using multivariate statistics to determine their impact on the vegetative community of the cliff top, cliff face, and talus.

The results indicated that slope, soil volume and surface heterogeneity significantly impacted the vegetative community of the White Rocks cliff system. Vascular species most frequently occurred on areas of the cliff system with shallow slope, greater soil volumes, and greater surface heterogeneity, while non-vascular species commonly occurred on areas with the opposite characteristics. Other measured variables were significant dependent upon vegetative type; specifically plot location on the cliff face impacted the lichen community, supporting the observations of vertical horizination of the lichen species observed in other cliff system studies in the southern Appalachians. The microfeature analysis indicated that although microfeature type did not impact the vegetative community, the physical and biological characteristics associated with the microfeatures did. Additionally, the survey identified several rare and threatened vascular plant species and several disjunct arctic and boreal lichen species in the cliff system. The unique assemblage of lichens and rare vascular plants found at this site warrant protection of this cliff system, as it serves as an interglacial refuge for these lichen species with more northerly main ranges.

ACKNOWLEDGMENTS

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INTRODUCTION

Cliff systems are found in virtually every environment around the world. Even in areas typically considered to have minimal geographical variation, one can find features which fit the characteristics of a cliff, which may be loosely defined as a high, steep, or overhanging mass of rock (Larson et al. 2000). Typically, a cliff system has a cliff edge, a cliff face, and talus. The cliff edge is the area of relatively level ground above the cliff face. The talus is the area below the cliff face, often formed as pieces of the cliff shear off, creating a field of rubble (Figure 1), (Larson et al. 2000). Although cliff systems are relatively common, they are very infrequently studied at the community level, in part due to the novelty of cliff system studies. Although there have been many studies involving individual organisms on cliff-systems, as well as geological studies, there have been very few studies which analyze the community composition and structure of cliff-face vegetation at the community level prior to 25 years ago.

Cliffs have had a significant impact on human activity for thousands of years. Humans have used cliffs for hunting purposes, and sought caves associated with cliffs for shelter. Native Americans, and much later moon shiners, also used caves as places of shelter and concealment. In addition, some ancient societies recorded their histories and lives on the rock surface, which we still see today as petroglyphs, a common management consideration in National Parks and preservation areas around the world (Larson et al. 2000). Cliff tops have been employed during times of war due to the strategic advantage they offer. In

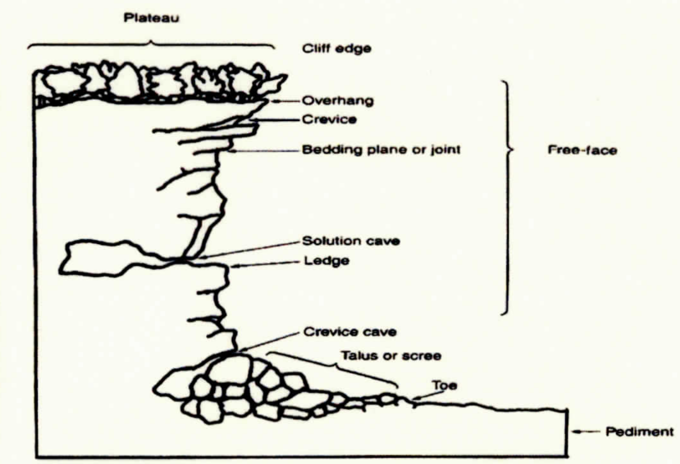

Fig. 1 Diagram of a cliff system. (Larson et al. 2000)

modern times, cliff systems have garnered great attention from the general public. The panoramic views which can be seen from high cliffs cause these structures to become tourist attractions. In response to this, many cliff systems around the world have been incorporated into National Parks or wilderness areas. Cliffs are important, in part, because the steep character of the land surrounding these features prohibits development, promoting wilderness. Due to the strong attraction to vertical features, cliff systems are used extensively in advertising as well. This can be seen in many magazines, especially those oriented toward the outdoor community (Larson et al. 2000).

Despite their widespread use and recognition to the general population, cliff systems may be the most attractive to the outdoor community. Outdoor enthusiasts use cliffs for many purposes, including hiking and back-packing, rock climbing and rappelling, and BASE (building, antenna, span, earth) jumping. Since the end of World War II, outdoor recreation has grown tremendously, especially in the areas of rock climbing and rappelling. As a result of this incredible growth land managers have become concerned primarily about the effect increased use is having on the land surrounding cliff systems, but do not typically consider the impact to the cliff systems themselves (Larson et al. 2000). Despite this rapid growth in interest in cliff faces and its associated impact, the scientific community has given the subject remarkably little attention. Cliffs offer biologists opportunities to study ecosystems that have been buffered from anthropogenic and natural disturbances such as fires because of their inaccessibility, (Larson et al. 2000), and also serve as interglacial refuges for regionally-rare glacial relict species (Clebsch and Walker, 1988).

Cliff-Face Ecology

Historically, biologists have considered cliff faces too difficult to sample, or too limited in terms of plant and animal life to be worth the effort or expense (Smith 1998). Only in the last 25 years has the scientific community begun researching the properties and processes associated with cliffs. Due to limited disturbance, cliff ecosystems act as refuges for many rare plant and animal species. The plant species present on cliff faces often grow extremely slowly, and are capable of surviving for hundreds or thousands of years (Larson et al. 2000; Smith 1998). Thus these plants, some of which are found only on cliff faces, offer the scientific community unparalleled information regarding local and global climate change, and nutrient availability via core analysis and dendrochronological studies.

In the last twenty five years, work has begun to delineate the patterns and processes associated with cliff-face ecology. Most work in the field has been conducted by a group of individuals working on the Niagara Escarpment of southern Ontario, Canada. The Cliff Ecology Research Group (CERG) is based at the University of Guelph, and headed by Dr. D.W. Larson. Their work was begun primarily due to interest in *Thuja occidentalis*, or Northern White Cedar, a tree that forms forest stands on cliff faces (Larson 1989). This work

has focused on the constraints associated with growth on cliff faces, the impact of recreation on vascular and non-vascular plants and communities on both the cliff edge and cliff face, and the factors contributing to the variation in species composition between the forests located on the cliff top away from the edge, and the cliff face (Bartlett and Larson 1990).

Some of the first published work was an analysis of the plant community of the Niagara Escarpment with a focus on *T. occidentalis*, the dominant woody cliff-face species on the Niagara Escarpment (Larson et al. 1989). The research showed that although the cliff edges and the cliff faces are dominated by *T. occidentalis*, species composition changes to *Acer saccharum* dominated forest with 5m of the cliff edge. It was also determined that in undisturbed areas, *T. occidentalis* declined in number as one moves away from the cliff edge with *A. saccharum* becoming the dominant canopy species (Bartlett and Larson 1990; Bartlett et al. 1991; Larson et al. 1989). In addition, the CERG discovered that cliff faces of the Niagara Escarpment supported individual *T. occidentalis* specimens of up to 1,032 years old (Kelly et al. 1992) which suggested the existence of old-growth forests on cliff faces (Kelly et al. 1994). Later studies showed that this occurs on cliff systems around the world, with many cliff systems supporting stands of old-growth forest of great age (Larson et al. 2000). More recently, the CERG has begun analyzing the epilithic lichen and endolithic organism communities of the Niagara Escarpment. It was found that species composition of microorganisms within the rock face were not evenly distributed along the cliff system (Gerrath et al. 2000; Matthes et al. 2000), and that substrate composition affects light attenuation through the rock surface, impacting the endolithic community (Matthes et al. 2001).

Further community level work found that although the available species pool influenced composition on the cliff edge, species composition was controlled by other factors on the cliff face. Later it was determined that seed rain does not control the species composition of mature cliff-face communities, but that this process is controlled at the seedling stage by various environmental filters (Booth and Larson 1998; Booth and Larson 2000). The group has published several reports explaining how the growth of *T. occidentalis* is controlled by environmental factors including water, nutrient availability and rooting space. They found that contrary to expectations, tree growth on cliff faces is not limited by water, but by nutrient availability, and that the tree roots grew primarily in cracks and crevices of the rock, penetrating only 9mm in solid rock (Matthes-Sears and Larson 1995; Matthes-Sears et al. 1995). This is due to the relative abundance of nutrients available in these features, or microhabitats, when compared to the remainder of the rock face. Additionally, these microfeatures allow for soil accumulation, which provide for water and nutrient retention, creating useable habitat for vegetation.

After several years, the CERG, as well as researchers from other parts of the world, began to analyze how climbing activity impacts the plant community at the cliff edge and on the cliff face. This was especially important considering the increase in individuals involved in high impact recreational activities. On the Niagara Escarpment, it was found that disturbance increased diversity of some species, but that the species which composed these communities were small, disturbance-tolerant species, which did not occur in unimpacted areas (e.g. crustose lichens in climbed areas) (Pampang et al. 1995). In the southern Appalachians, studies conducted in the Linville Gorge Wilderness area of North Carolina, indicated that climbing activity reduced the diversity and abundance of vascular plants,

mosses, and foliose and fruiticose lichens, while releasing crustose lichens from competition (which increased in both their abundance and diversity) (Smith 1998). Additionally, this study revealed that the cliff edge forms a community distinct from the cliff face and that lichen communities shift in composition from the cliff top to the cliff bottom. A new species of lichen also was discovered and named during the course of this study (Smith 1998). The findings in the southern Appalachians are supported by studies in Minnesota and Illinois (Farris 1998; Nuzzo 1996). Both showed that the total percent cover of vegetation on climbed cliff faces was significantly lower than on unclimbed faces, and that the lichen community was more diverse on unclimbed faces than on climbed faces (Farris 1998; Nuzzo 1996). Farris (1998) also found that the vegetative coverage of rock features commonly used for climbing was significantly lower than those on unclimbed faces. In Canada, the CERG found that the vegetation and the land snail populations of the Niagara Escarpment also were negatively affected by climbing activity (McMillan and Larson 2002; McMillan et al. 2003). New findings have recently been published by the CERG, which may impact the commonly accepted idea that climbing activity does negatively impact cliff-face vegetation exclusively. This study found that the majority of the areas chosen by rock climbers are lacking in vegetation prior to the introduction of climbing activity, as most participants seek out steeper, less featured areas for route development. The lower angle, highly heterogenous areas of the cliff system that climbers commonly avoid often provide habitat for far more vegetation than do steep, homogenous areas (Kuntz 2006).

All of this research suggests that cliff systems are extremely valuable to the general public, as well as the scientific community, and that they are extremely sensitive to human impact. The potential to employ ancient trees growing only on cliff-faces to analyze climate change over hundreds of years is invaluable, and the affect of human impact on the vascular, non-vascular, and micro-organismal communities of cliff faces have wide-ranging management implications. Studies again conducted by the CERG have shown that cliff communities on the Niagara Escarpment do not return to the pre-disturbance species composition. Restoration to this state takes significant time and must be facilitated by human intervention (de Gruchy et al. 2001; Matthes et al. 2003).

Although most cliff-face research has been conducted at higher latitudes, it is important to study cliff systems in other locations as well in order to delineate common processes and factors among regions. The southern Appalachian region is renowned worldwide for its high levels of biodiversity. Studies in the southern Appalachians have identified many arctic and boreal disjunct species at high elevation (Graham 2006; Walker 1987). One of these is *Thuja occidentalis*, a typically low-elevation boreal relict that has been the subject of many prior studies. Other vegetative surveys on cliff systems in the area have identified many additional arctic and boreal species which occur only on these cliff systems. These species are restricted to cliffs in the region as many are not adapted to exist in horizontal environments outside of their home range. In horizontal environments of the southern Appalachians, these disjunct species are easily outcompeted by native species, and are not physiologically adapted to handle many environmental conditions. Cliff systems provide habitats that are buffered from extremes of environmental variables including temperature and light, and provide competition and predation-free habitat. The high diversity of the southern Appalachians is due in part, to the lack of recent glaciation. As a result, many arctic and boreal species which migrated south through the Ridge and Valley physiographic region as the ice extended, left small populations behind when the ice began

receding and the species returned to their home ranges (Delcourt and Delcourt 1987). Little work has been done to analyze the vegetation and ecology of cliff systems in the southern Appalachians, despite the probable high biodiversity of cliff systems in this region. Early work on cliff systems in the southern Appalachians indicated that genetic variation among and within disjunct populations of *T. occidentalis* was higher than that observed in the main range at higher latitudes. In the same study entire communities of boreal bog plants were found in association with the *T. occidentalis* stands as glacial relicts in the Ridge and Valley Physiographic Province (Walker 1987). As mentioned previously, researchers in the southern Appalachians found that lichen community species composition changes along a vertical gradient on the rock surface and that the face forms a community significantly different from the rock outcrops at the cliff edge (Smith 1998). In 2003, a project was conducted that compared the microarthropod communities of cliff faces to the cliff edge and base before and after fire disturbance. The study showed that although microarthropod densities changed significantly on the cliff edge and base, the density of cliff-face microarthropods did not change significantly (Pleszewski 2003). This suggests that cliff face habitats are buffered from natural disturbances such as fire, thus explaining how vegetation such as trees may attain such ancient ages on cliff faces. Most recently a study was conducted for the National Park Service to determine the effect of rock climbing on the species diversity and percent cover of vegetation in the Obed Wild and Scenic River Gorge in Tennessee. Six separate cliff-system climbing areas were surveyed, comparing climbed and unclimbed faces, including the cliff edge, cliff face and talus of each (Walker and Parrisher 2005). This study demonstrated that, while climbing only impacted lichen communities in a significant way on faces, the talus was heavily impacted as climbers used approaches at the base of cliff systems. The study also indicated that a no topping-off policy established for cliff systems in the Obed was working to preserve fragile communities and rare species found on the cliff edges (Walker and Parisher 2005). In 2006, the CERG published a study which addressed small-scale spatial relations on cliff faces. This study focused on the effect small scale physical features, or microfeatures (such as ledges, pockets and cracks) have on the cliff-face vegetative community composition. Kuntz and Larson (2006) found that greater surface heterogeneity increased the abundance and diversity of the vegetative community, and that the presence of particular vegetative forms strongly corresponds with the soil volume of these microfeatures.

Including microfeature analysis in cliff-system studies allows the scientific community to more accurately assess the effect of surface heterogeneity on the structure and composition of cliff-system vegetation. This approach takes in to consideration the heterogeneity of the rock surface, and the difference in environmental and biotic conditions between the sheer rock surface and the many microfeatures on the cliff. It is also possible to determine the preference of specific vegetative forms for particular types of microfeatures. My study of the White Rocks cliff system is one of the first cliff system studies to incorporate this type of analysis. It is important to include a characterization of cliff-system microfeatures as they are extremely important to cliff-system vegetation. These small scale physical features allow for the accumulation of soil, water, and nutrients, enabling species to persist in otherwise uninhabitable environments. Microfeatures retain water more readily than the sheer cliff face due to the physical properties of water, and the increased surface area for adhesion provided by the heterogeneity of the feature. Without microfeatures, soil development and accumulation would be severely limited on cliff systems, occurring only on

areas with very low slopes. Nutrient availability on cliff systems with little or no heterogeneity is extremely limiting. However, studies have shown that nutrient concentrations in microfeatures are much higher, and support slow growing vegetation (Larson et al. 2000). Species which grow very quickly in traditional horizontal environments are capable of persisting in microfeatures on cliff systems, although the growth rates of the species are significantly reduced under these conditions.

The present study identifies microfeatures in one of three categories, including cracks, pockets and ledges. Ledges can be defined as features extending outwards horizontally from the cliff face, while pockets are defined as circular or ovoid features extending into the rock face. Cracks or crevices are defined as long, narrow features extending into the rock face. This study incorporates microfeature analyses to test the hypotheses that the vegetative community composition of the White Rocks cliff system changes both vertically and horizontally, as has been observed in previous cliff-system surveys in the southern Appalachians. Additionally, multivariate analyses were used to determine how surface heterogeneity impacts cliff-system vegetation.

Site Description

Cumberland Gap National Historical Park (CUGA) is located in the Cumberland Plateau physiographic region, and the White Rocks Cliff system is the eastern-most cliff structure of the Cumberland Plateau. As such, the White Rocks Cliff system forms the escarpment for the Ridge and Valley physiographic province to the east. The White Rocks Cliff system comprises a portion of the state border between Kentucky to the north and Virginia to the south. The cliff system is located on the southern slope of Cumberland

Mountain at the far eastern end of CUGA. The cliff system is composed of Pennsylvanian sandstone conglomerate of the Lee formation. The sandstone is approximately 90% quartz, but can be conglomerated with quartz pebbles up to 75% (Hinkle 1975). The cliff also is composed of significant amounts of iron, which are exposed as erosion-resistant horizontal bands, or as a patina on the surface of the sandstone. Soils of the scarp slope of Cumberland Mountain have been described as Muskingum and Stony colluvium, which are sandy and acidic (Hinkle 1975).

CUGA receives an average of 50.92 inches of rain per year, receiving more than half of this total from April to September (Hinkle 1975). Several streams originate within the Park boundaries, but there are not any streams in the immediate vicinity of the cliff system. Precipitation drains to both sides of the Cumberland Mountain ridge line, and thus down the cliff face in some areas. There are several seeps at the base of the cliff which support lush pockets of bryophyte and vascular plant communities, including populations of *Saxifraga michauxii* (Michaux's saxifrage).

The climate of CUGA is classified as humid and second mesothermal (Thornwaite 1948). The warmest month is July and the coldest is January. Temperatures around the White Rocks cliff systems are typically 5 to 10 degrees cooler due to the greater elevation (Hinkle 1975).

Previous Investigations and Species of Special Concern

Several previous vegetation studies have been conducted within the Cumberland Gap National Historical Park. Hinkle (1975) was the first comprehensive survey and was followed by Pounds et al. (1989). Although both studies surveyed the areas above and below

the White Rocks cliff system, neither surveyed the face itself. The inclusion of cliff-face surveys are important due to several sensitive and listed (KY and VA) cliff face and rock outcrop species. *Minuartia glabra* is listed by the state of Kentucky as threatened. It has been previously reported in the rocky outcrop areas of the cliff top (Hinkle 1975; Pounds et al. 1989). *Maianthemum canadense* is listed by the state of Kentucky as threatened. It has previously been reported in areas in the vicinity of the White Rocks cliff system. *Paronychia argyrocoma* is listed by the state of Kentucky as an endangered species. It has previously been reported in the rocky outcrop areas of the cliff top. *Vaccinium erythrocarpum* is also listed as endangered in Kentucky. It was listed as a single occurrence in the vicinity the White Rocks cliff top (Pounds et al. 1989). Additionally, the perpetually wet seeps at the base of the cliff support populations of *Saxifraga michauxii*. These represent the previously described significant species that would likely be impacted by rock climbing activity at White Rocks.

The present study represents the first instance that a pristine cliff system has been examined systematically within the Cumberland Plateau physiographic region. While there was some evidence of illegal climbing at the site (presence of fixed anchors at one location) the system has had minimal human influence on the face. The cliff top and edge have been severely damaged by human traffic.

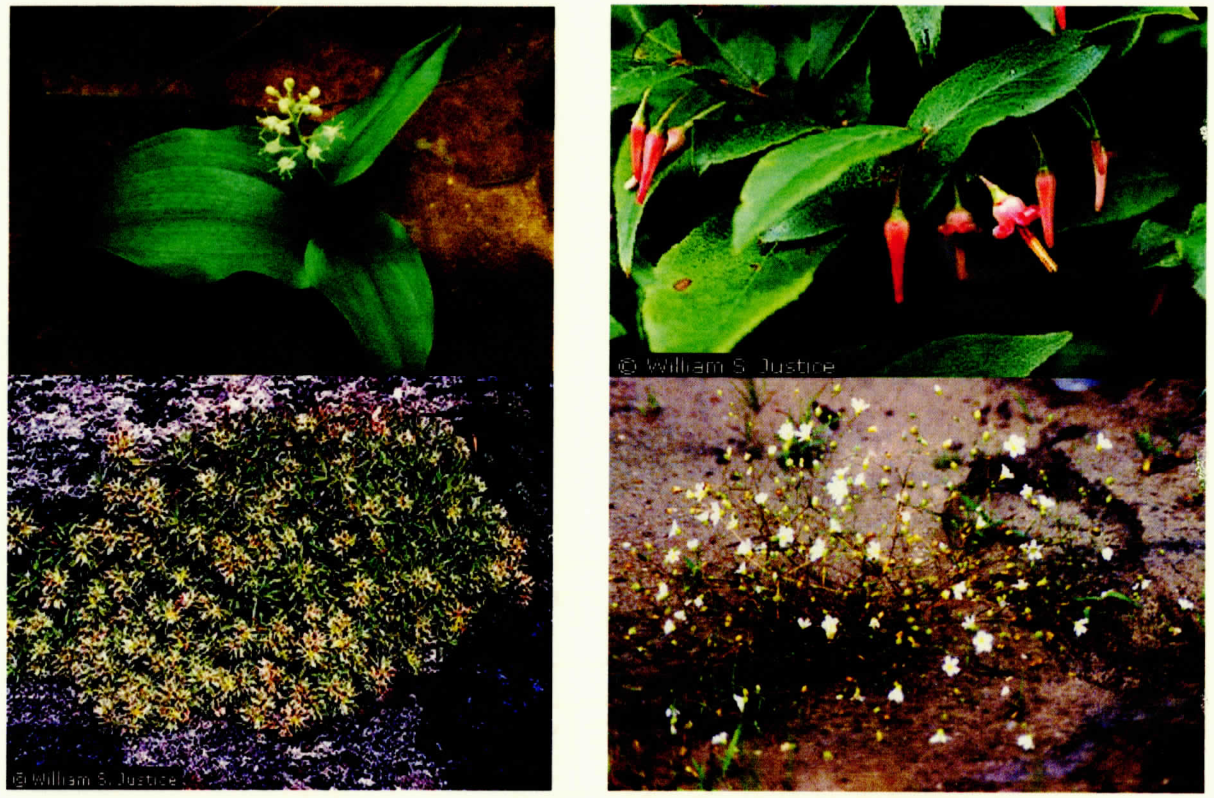

Fig. 2 Vascular species of special concern at White Rocks. Clockwise from top left: *Maianthemum canadense* (USDA-NRCS PLANTS Database), *Vaccinium erythrocarpum* (William S. Justice @ USDA-NRCS PLANTS Database), *Paronychia argyrocoma* (William S. Justice @ USDA-NRCS PLANTS Database), *Minuartia glabra* (USDA-NRCS PLANTS Database).

Table 1 State of Kentucky, State of Virginia, and global conservation status for vascular species of special concern at White Rocks.

Species	Kentucky State Rank	Virginia State Rank	Global Rank
Maianthemum canadense	S2	SNR	G5
Vaccinium erythrocarpum	S1	S4	G5
Paronychia argyrocoma	S1	S4	G4
Minuartia glabra	S1S2	SNR	G4

The goal of the White Rocks cliff system study was to analyze the impact of biotic and abiotic environmental variables, as well as to determine the impact of both large and small scale physical characteristics on the species composition and spatial distribution of the vegetative community. It was hypothesized that vascular species will most frequently occur in large microfeatures with significant soil accumulation and low slopes, while bryophyte and lichen species will be restricted to smaller features, with less soil accumulation and higher slopes. It was hypothesized that the vegetative community would exhibit both vertical horizontal changes in species composition as observed in other studies in the southern Appalachians. Finally, it was hypothesized that vegetative community composition changes in relation to substrate composition.

MATERIALS AND METHODS

The White Rocks cliff system is located at the far eastern end of the CUGA. The cliffs range from 61 meters to 91.5 meters in height and are composed of Pennsylvanian conglomeratic sandstone of the Lee Formation. White Rocks can be approached from the west via the Ridge Trail, or from the south via the Thomas Walker Civic Park and the Ewing Trail, in Ewing, Virginia. The area closest to the cliff edge supports a vegetative community consisting of low shrubs interspersed with hardwood tree species including *Hamammelis virginiana, Rhododendron catawbiense* and *Quercus* species. This forest type was first described as the Chestnut Oak association but more recently is designated as Appalachian Oak Forest type (Stephenson 1993). Most recently, the forest community in the immediate vicinity of the White Rocks cliff system in close proximity to the cliff edge has been described as Southern Appalachian Mountain Laurel Bald (White 2006).

Transect and Quadrat Construction

Locations for twelve vertical transects were determined using a random number table. These transect locations were measured along the cliff top from a permanent location, and recorded with a GPS unit. To create quadrats for use in the survey, PVC piping was cut to length and joined together using 1.27cm diameter 90° elbows to create the quadrat frame with an area of 1 m^2. The quadrats were further divided in to 25 sub-plots of 400 cm^2 by drilling evenly spaced holes in the pipes every 20 cm and running utility string through the

holes to create a grid. These quadrats were used to estimate percent coverage of vegetation and features (Figure 3).

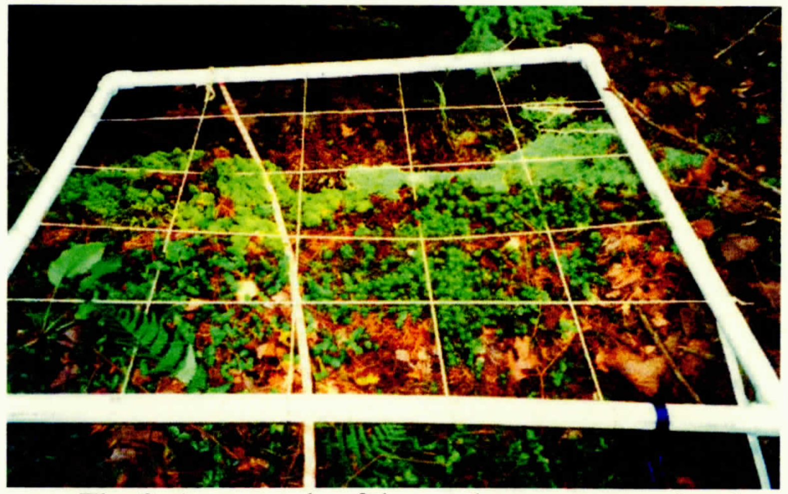

Fig. 3 An example of the quadrats constructed and employed during the study.

Climbing Equipment

The cliff face was accessed using technical rock climbing equipment. Static ropes were used in order to reduce rope elongation and bouncing associated with typical dynamic climbing ropes. Reduced bouncing resulted in less rope abrasion and increased overall safety. Rappel anchors were constructed on the cliff top using load-bearing webbing rated to 4,000 lbs or 17kn. Technical rock climbing equipment was used to safely access the cliff face.

Sampling Technique

Transect surveys of the White Rocks cliff face were conducted from June to August of 2005 and May of 2006. Transect locations and the locations of populations of listed plant species and seeps were recorded with a GPS unit. Climbing anchors were constructed on the cliff top using stout canopy or sub canopy trees as anchor points. Transects, which extended from the cliff edge to the cliff base and included any areas of bare rock on the cliff edge and talus, were surveyed from top to bottom. Along each transect, plots were surveyed every three meters, beginning one meter away from the cliff edge, and extending one meter beyond the cliff base or as necessary to include continuous areas of bare rock (Fig. 4). A field tape was attached to the anchors, and the tape pulled down the cliff by the researcher. Plot locations were communicated to the researcher by the belayer via two way radio for recording.

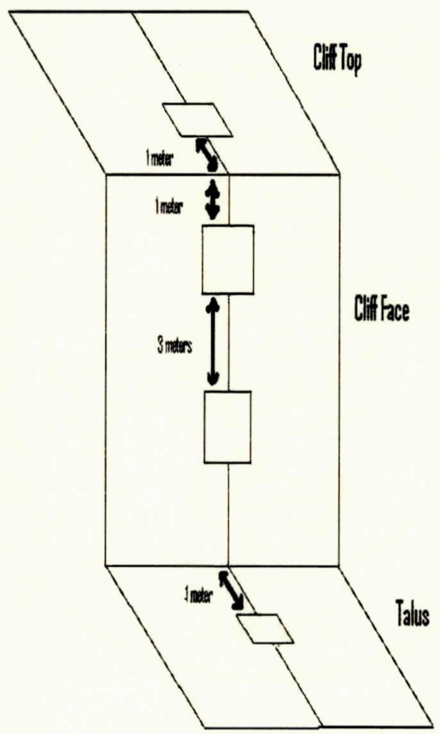

Fig. 4 Diagram of the employed sampling design.

For each plot of all transects, the slope and aspect of the plot was recorded. The slope was measured using a Suunto inclinometer. For plots in which the rock surface was uneven, the slope was measured using the frame of the quadrat. Plot aspect was recorded using a

magnetic compass, unadjusted for declination. As with slope, aspect was measured using the quadrat frame when the rock surface was uneven. As aspect is radial data, readings of 358° and 2°, while numerically dissimilar, are in reality very close in aspect values. However readings in this format may alter the results of the analysis. Thus the recorded aspect was converted to two readings, relative northness and relative eastness (cosine and sine of the data respectively) to provide a truer indication of the effect of aspect on the vegetation by preventing statistical misinterpretation.

In each plot the type and number of microfeatures was recorded, types of which included cracks, pockets, and ledges. The area (ledges) and volume (cracks and pockets) of each microfeature was calculated by measuring the length, width and depth of the feature to nearest 0.5 cm. If a feature extended beyond the quadrat boundary, only the portion of the feature within the quadrat was measured. For instances such as the occurrence of a crack in a ledge, both features were measured independently.

Soil volume is important as it is required for significant vascular species development. As such, it is an important variable to measure as it may influence species composition and structure. For each microfeature, soil depth was calculated as the average of five separate soil depth measurements. This average was then multiplied by the microfeature area to determine an estimated soil volume for the microfeature. Total plot soil volume was then calculated as the sum of the microfeature soil volumes per plot. Surface heterogeneity also may be a significant factor in the development of vegetative communities, as increased surface heterogeneity may provide more habitat and rooting space for vascular plant species. Thus the surface heterogeneity of each plot was calculated as the sum of the area of all microfeatures within the plot.

Biological characterizations were made by visual estimations using the previously described quadrats. For vegetation two measurements were taken for each group - vascular plants, bryophytes and lichens. These measurements were total percent cover by the group and total percent cover by each species within the group. For example, total percent vascular plant cover was determined as the percentage of the total quadrat area occupied by vascular plants. Additionally, total percent cover was determined for each individual species of vascular plant. Any species covering less than one percent of the total plot area was recorded as such. Percent cover included vegetation not originating with the quadrat, but within the quadrat boundary. Presence or absence of each vascular species also was recorded for each microfeature within the plot.

Total bryophyte percent cover also was determined as the percentage of the total quadrat occupied by bryophyte species, and included bryophyte vegetation originating outside of the quadrat area, but within the quadrat boundary. Species identification of bryophyte samples in the field was not possible, and thus species differentiation was based upon obvious observable differences (morphotype descriptions). Each species percent cover was recorded as the percent of the quadrat area occupied by a bryophyte species. The presence or absence of each bryophyte species was also recorded for each microfeature in the plot area.

Total lichen percent cover also was determined as the percentage of the total quadrat area occupied by lichens. As with bryophytes, lichen identification in the field was not possible and species differentiation was based on obvious observable differences. Species percent cover again was measured as the percent of the total quadrat area occupied by the lichen species. Lichen morphotype percent cover (fruticose, foliose and crustose) was

determined after identification as the sum of the species percent covers of each lichen morphotype. As observed for vascular and bryophyte specimens, the presence or absence of each lichen species was recorded for each microfeature in the plot area.

Sample Processing

Vascular plant samples were taken at each plot where possible. Vascular plants were temporarily placed in paper bags 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 the plant presses were placed in a dryer for at least one week. Samples were identified by Derrick Poindexter, ASU herbarium, using the nomenclature of Weakley (Weakley 2006).

Bryophyte samples were collected and placed in paper bags, each labeled with transect and plot number. Bryophyte samples were transported to the Appalachian State University herbarium where they were dried for at least one week. These samples were then sent out for analysis by Keith Bowman, bryologist, SUNY Syracuse, and identified using the nomenclature of Stotler and Crandall-Stotler (Stotler and Crandall-Stotler 1977).

Lichen samples were taken where possible. When sampling crustose lichens, it was often necessary to remove a small portion of the rock. This was done in a manner which minimized impact and scarring. Lichens samples also were placed in paper bags labeled with transect and plot numbers. The samples were returned to Appalachian State University and tentatively identified. Lichen samples were then sent out for identification by Dr. Coleman McCleneghan, a mycological consultant, using the nomenclature of Lichens of North America (Brodo et al. 2001).

Rock samples characteristic of the plot also were taken where possible. These samples were placed in paper bags and labeled with transect and plot number, and analyzed by Anthony Love of the ASU Department of Geology for basic rock type and mineral composition.

Statistical Analysis

All recorded data was entered into a Microsoft Excel spreadsheet. The data was analyzed by Dr. Uta Matthes, Research Associate of the University of Guelph Cliff Face Ecology Research Group. The data was analyzed with multivariate ordination analysis techniques including Detrended Correspondence analysis (DCA) and Canonical Correspondence analysis (CCA) using Canodraw software. When using univariate analyses (such as regression), it is often difficult to determine how different variables interact to control community structure. Using multivariate analyses, it becomes possible to analyze the effect of multiple environmental variables at once, saving time and allowing for more accurate analyses, as ordination allows researchers to determine the relative importance of each environmental variable measured.

Ordination analysis is the arrangement of samples along a gradient, while multivariate analysis is the same but with multiple gradients. Detrended Correspondence Analysis analyzes only the vegetative data and arranges the data based on only the occurrences of the species. This analysis shows any large scale trends in the data, and can be overlaid on the measured environmental variables to identify any rough effect.

Canonical Correspondence Analysis incorporates both the vegetative (presence-absence and percent cover) data and the environmental variable data (slope, aspect, surface

heterogeneity). This analysis detects patterns of variation in the species scores that is best explained by the measured environmental variables. CCA also shows which of the environmental variables most significantly impacts the vegetation and thus community structure. The first CCA axis is determined as the hyper-dimension which accounts for the greatest degree of variation in data, and further axes are constrained to account for the remaining variation that is orthogonal to the first axis.

GIS Database

A GIS model was developed using the Environmental Systems Research Institute's (ESRI) latest version of ArcGIS Desktop software (i.e. ArcMap 9.1). Data for the model were collected using global positioning systems (GPS) equipment. Specifically, a Trimble GeoXT hand-held unit with ArcPAD software installed was used. Pathfinder Office software was used for post-processing the GPS data that was collected in the field. In addition to ancillary data acquired from the Park Service, other ancillary data were collected as well, including ortho-imagery from the National Agriculture Imagery and Mapping Program and the United States Geological Survey.

RESULTS

Species Numbers

Fourteen vascular plant species were identified on the cliff system (cliff top, cliff face, and talus) including *Paronychia argyrocoma*, which is listed in Kentucky as an endangered species. Nine bryophyte species were identified, the most abundant of which was *Campylopus tallulensis*. Forty-eight lichen species were found on the cliff face, the most abundant of which were umbilicate lichens of the genus *Lasallia* (Appendix A). Table two compares the number of vascular, bryophyte and lichen species identified on the White Rocks cliff system to six cliff systems surveyed at the Obed Wild and Scenic River National Park (OBRI) (Walker and Parrisher 2005). The diversity of lichen taxa was higher at White rocks, even when all systems surveyed at OBRI were totaled. The bryophyte diversity at White Rocks was much lower, as only 9 bryophyte species were identified on the White Rocks cliff system.

Table 2 Comparison of bryophyte and lichen diversity between White Rocks and the Obed Wild and Scenic River Cliff systems.

	Lilly Bluffs	Lilly Boulders	North Clear Creek	South Clear Creek	Obed Wall	Y-12Wall	ObedTotal	WhiteRocks
Lichen species	15	6	31	15	26	9	47	48
Bryophyte species	38	25	19	7	6	3	65	9

Lichen Species of Interest

The White Rocks cliff system survey identified several lichen species occurring on or around the cliff face that are biogeographically rare, relict, disjunct or represent new habitat occurrences for their taxons. Possibly the most significant of these is the foliose lichen *Umbilicaria torrefacta* (Fig. 5). This umbilicate lichen occurs in Northern Canada and Alaska, with subdistributions in the Cascade Range and Rocky Mountains of the continental United States. The White Rocks cliff system population is the first report of this species in the southeastern United States, making it a possible candidate for listing for protection. *Xanthoparmelia wyomingica*, a foliose lichen found on the White Rocks cliff system also is a disjunct species (Fig. 5). It typically occurs in the American and Canadian Rockies on rocky and mossy soil in that region. *Arctoparmelia centrifuga* and the closely related *Arctoparmelia incurva*, both foliose lichens, have arctic and boreal distributions as well, occurring from the northeastern United States through Canada (Fig. 5). Other disjunct lichen species included *Lecanora rupicola,* a crustose lichen and *Cladonia pocillum*, a foliose lichen species. *Lecanora rupicola* typically occurs from the American Rockies west, while *Cladonia pocillum* is reported ranging from the northeastern to northcentral US and throughout the American Rockies (Fig. 5). *Hypotrachyna croceopustulata,* a narrow southern Appalachian endemic lichen species typically occurs on the bark of conifers and hardwood deciduous tree species. This lichen species was identified on the rock face of the White Rocks cliff system, a habitat not previously reported for this species. In the United States it has been reported only in North Carolina, Kentucky, Tennessee, West Virginia and Virginia. It typically occurs on conifers at high elevation and on deciduous species at lower elevations. *Dirinaria aegialita* and *Canoparmelia texana*, with southeastern distributions from Maryland, to Louisiana and Missouri, also typically occur on the bark of hardwood tree species, not typically on rock as found at White Rocks (Fig.5).

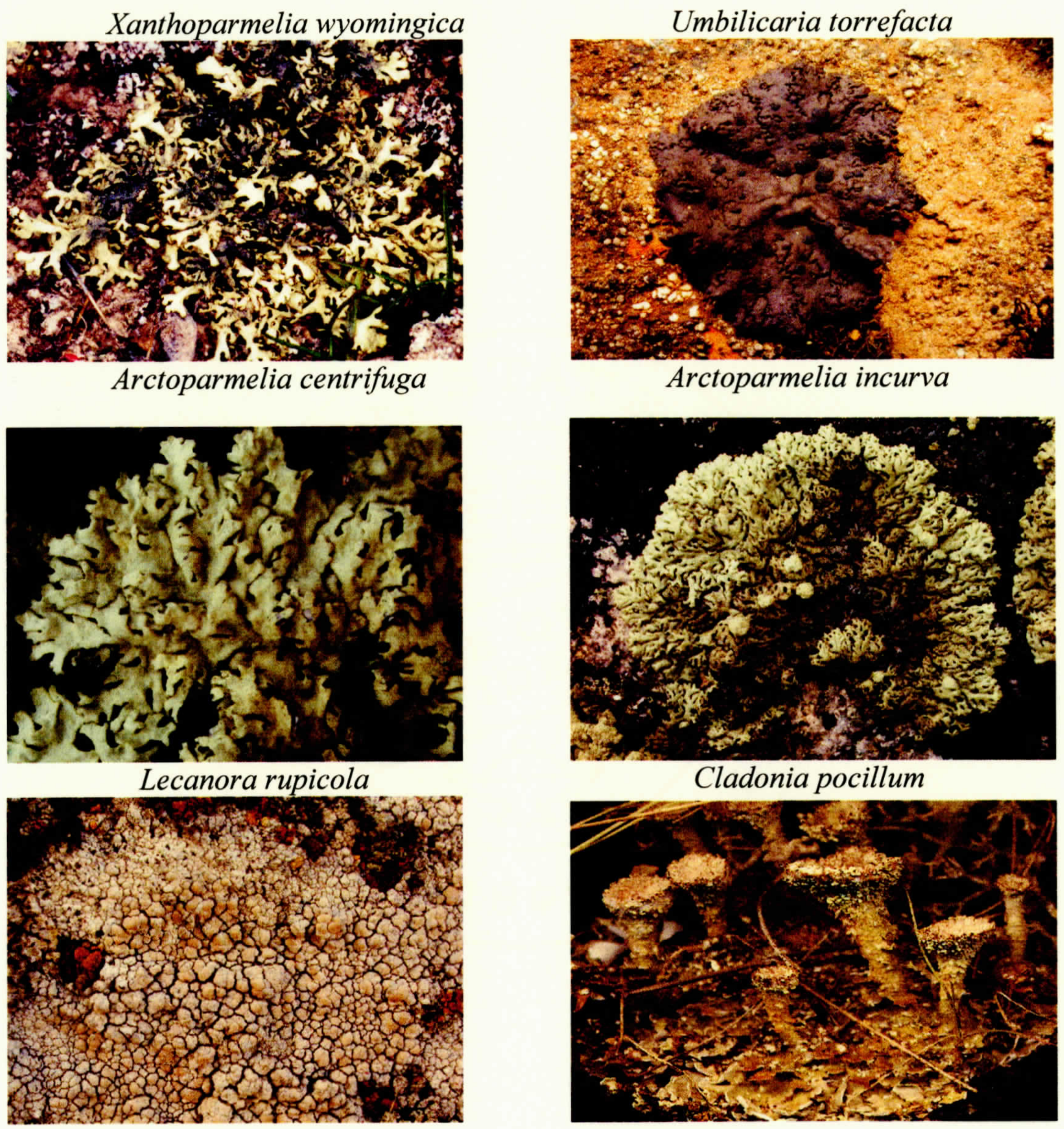

Fig. 5 Arctic and boreal disjunct lichens species identified during the White Rocks survey.

Statistical Analyses

Statistical analyses were conducted for a set of data detailing the percent cover, or abundance, of each species per plot, as well as for a set of data indicating frequency. This was done to identify any variation within the data. It was found that the percent cover data yielded more information than the occurrence data, thus only these results are reported. Analyses were run on the full data set which included all vegetative forms, as well as separately for vascular species only and lichen species only.

DCA Percent Cover of All Vegetation

The eigenvalues for the first three axes of the DCA analysis run for all vegetative data were relatively high, indicating significant patterns in the data (Table 3). The analyses indicated that vascular species separated out from non-vascular species (Fig. 6). Additionally, the analyses indicated that plots in which the vegetation is primarily vascular were distinct from plots in which the vegetation was primarily non-vascular (Fig. 7).

Table 3 DCA eigenvalues for axes 1, 2, and 3 for all vegetative classes, vascular species only, and lichen species only.

Class	*Axis*	*Eigenvalue*
All Vegetation	1	0.804
	2	0.636
	3	0.587
Vascular Species	1	0.793
	2	0.494
	3	0.318
Lichen Species	1	0.7631
	2	0.7056
	3	0.5133

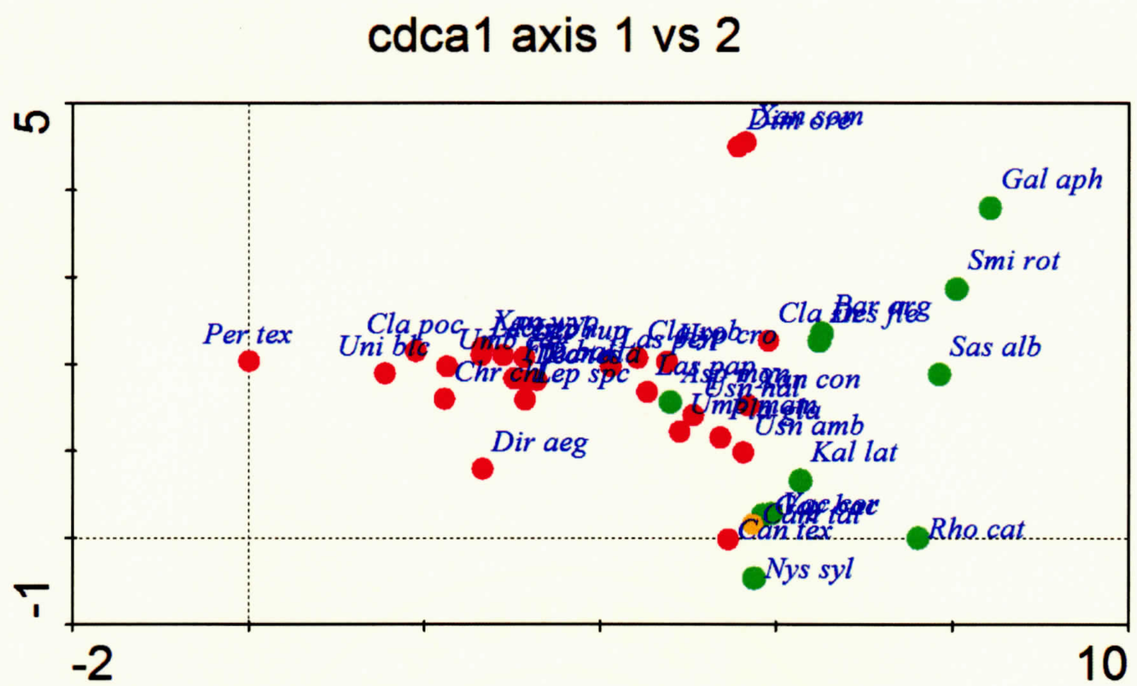

Fig. 6 Percent cover DCA ordination of all species. Axis 1 vs. axis 2. Vascular species (green) separate out from non-vascular species (red) along axis 1.

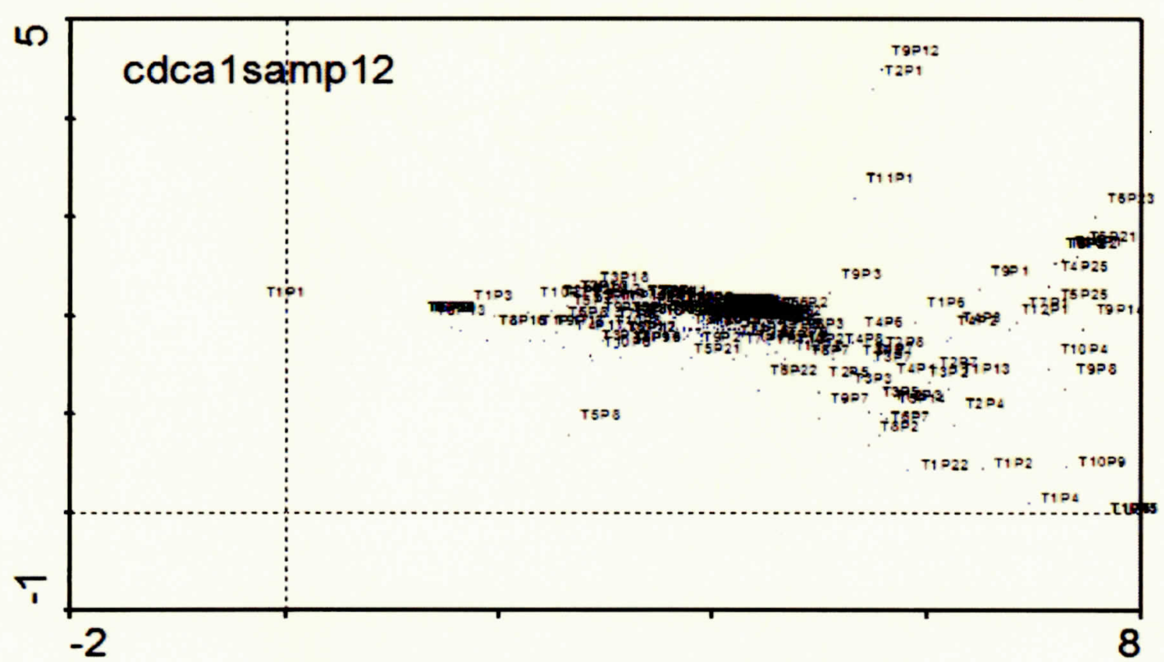

Fig. 7 Percent cover DCA ordination of all samples. Axis 1 vs. axis 2. Sample with predominantly vascular species separate from sample with predominantly non-vascular species along axis 1.

When the environmental variables (which did not affect this DCA analysis) are overlaid it can be seen that slope corresponds with the distribution of vascular and nonvascular species, as nonvascular species correspond with a steeper slope and vascular species with a lower slope (less steep) (Fig. 8). Abbreviations for environmental variables are listed in Appendix D.

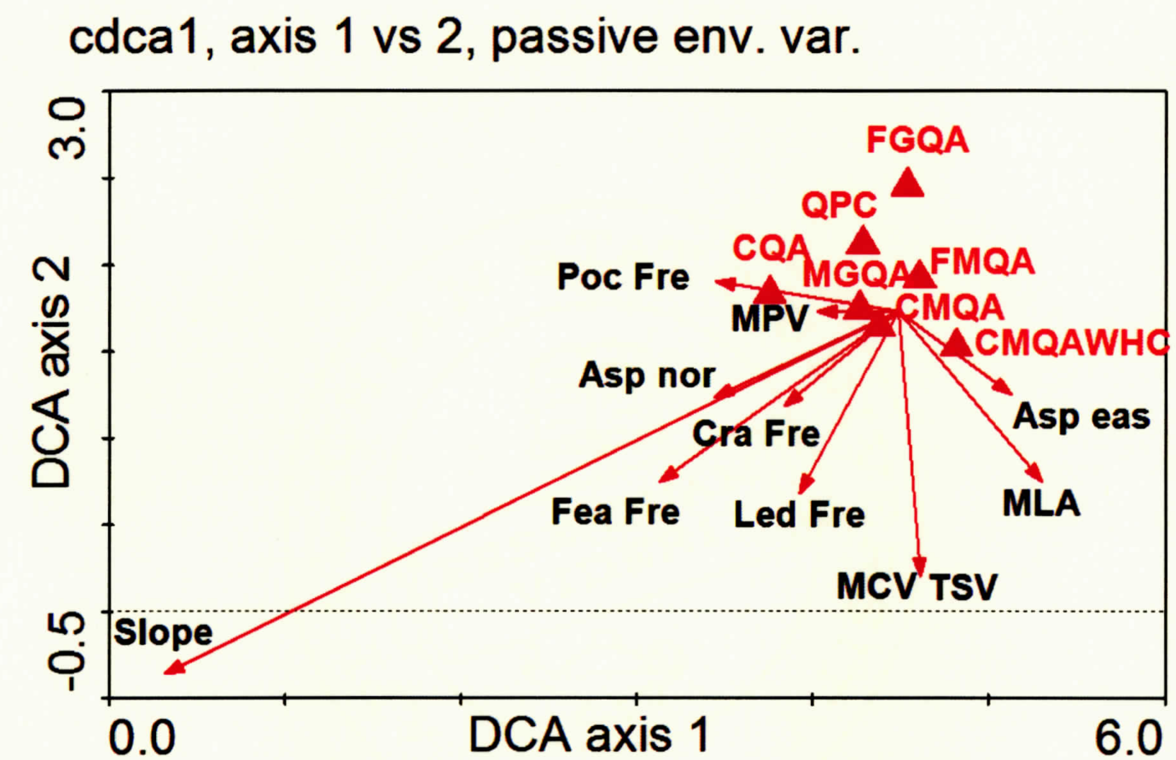

Fig. 8 Percent cover DCA overlay of environmental variables. Axis 1 vs. axis 2. Slope is primarily responsible for the separation of vascular and non-vascular species.

Slope does not account for all of the variation, as the eigenvector is not parallel to the first axis (Fig. 7). The DCA analysis did not indicate which measured environmental variables were associated with the second and third composite axes created. This analysis also showed that rock type does not significantly impact the vegetative species composition of the White Rocks cliff system.

CCA Percent Cover of All Vegetation

The CCA analysis of all vegetation produced eignevalues lower than the DCA analysis of all vegetation (Table 4). As predicted by the percent cover DCA, slope is the most significant measured environmental variable affecting the vegetative community (Table 5), and again the vascular species separate from the non-vascular species along the slope gradient (Fig. 9, Fig. 10).

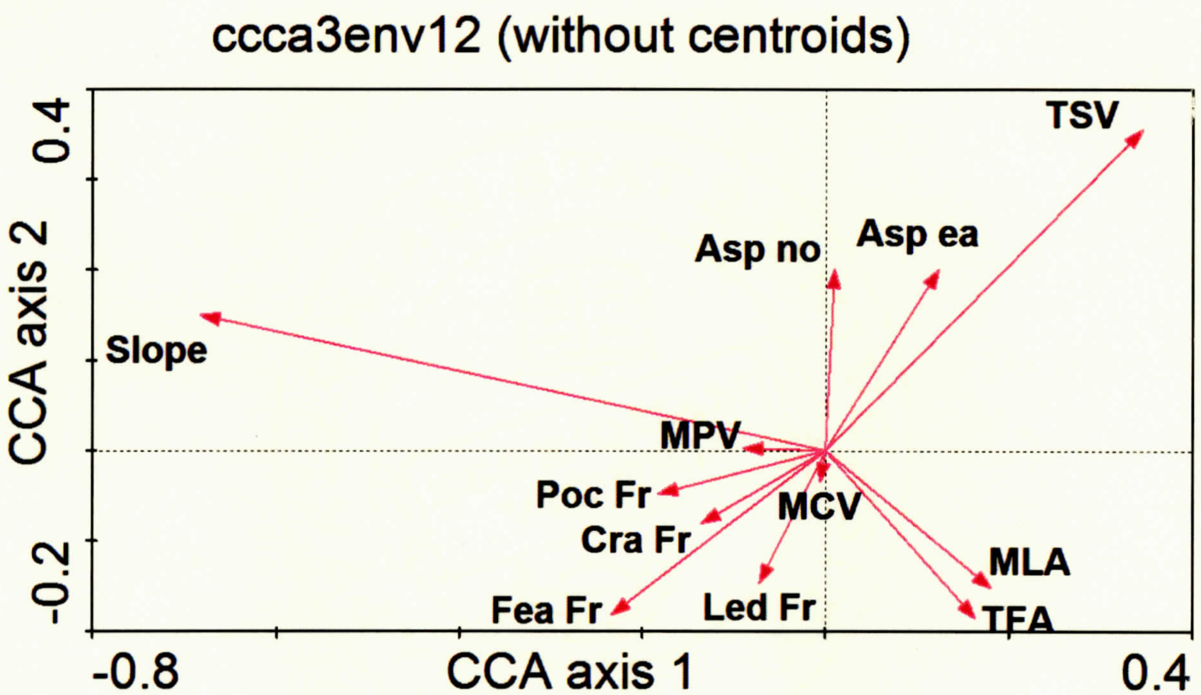

Fig. 9 Percent cover CCA of all species without centroids. Axis 1 vs. axis 2. Slope is the most significant variable affecting the vegetative community.

Table 4 CCA eigenvalues for axes 1, 2, and 3 for all vegetative classes, vascular species only, and lichen species only.

Class	*Axis*	*Eigenvalue*
All Vegetation	1	0.468
	2	0.187
	3	0.154
Vascular Species	1	0.448
	2	0.334
	3	0.247
Lichen Species	1	0.2094
	2	0.1445
	3	0.1013

Table 5 Environmental variables which significantly impact the vegetative community as indicated by the CCA analysis and Monte Carlo Permutations of the percent cover data of all vegetation, vascular species only, and lichen species only.

Class	*Variable*	*P*	*F*
All Vegetation	Slope	0.0040	8.6200
	Location - Face	0.0040	3.0500
	Total Soil Volume	0.0400	2.9600
Vascular Species	Talus	0.0060	4.2000
	Total Feature Area	0.0100	3.4300
	Feature Frequency	0.0220	2.8100
	Location - Top	0.0160	2.7300
	Aspect East	0.0240	2.6100
	Mean Crevice Volume	0.0360	2.4700
	Ledge Frequency	0.0360	2.0400
Lichen Species	Slope	0.0020	3.5600

Number of Monte Carlo permutations = 499.0

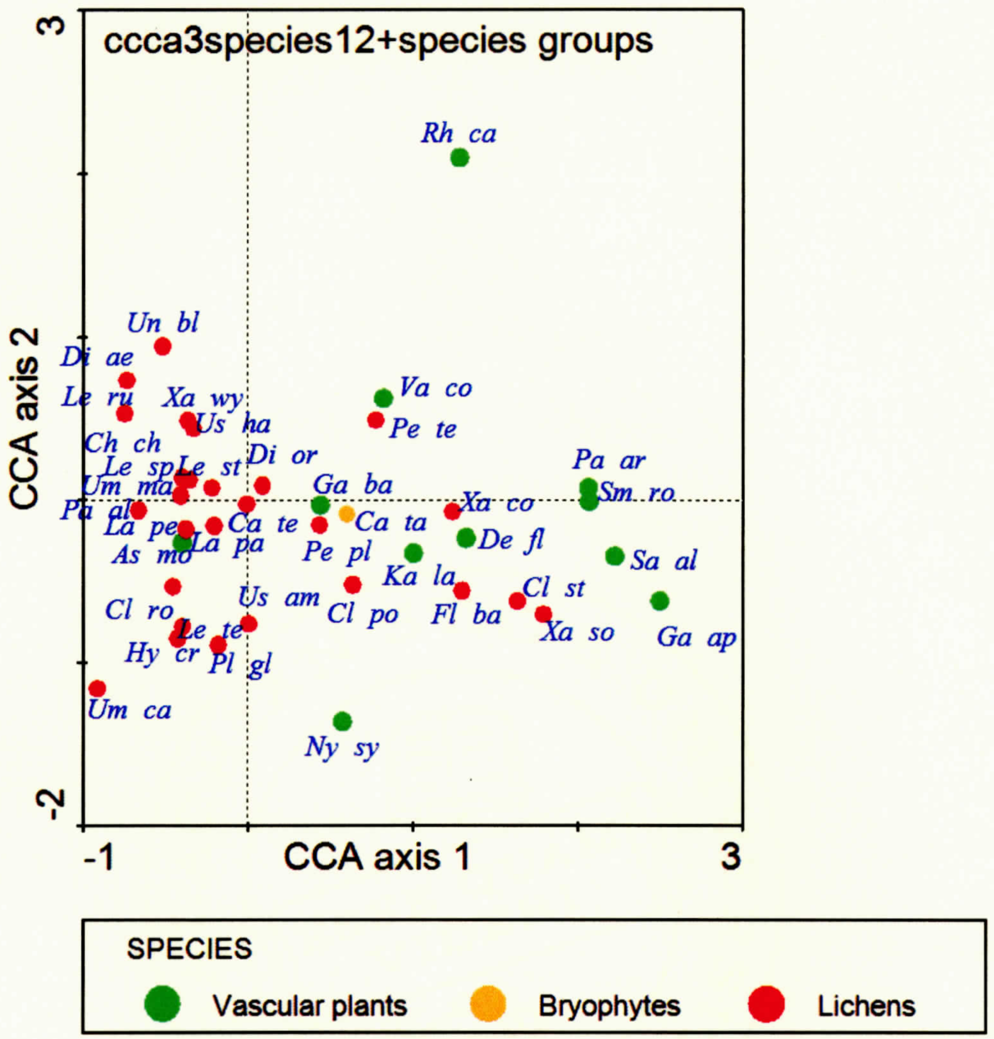

Fig. 10 Percent cover CCA of all species. Axis 1 vs. axis 2. Vascular species (green) separate from non-vascular species (yellow=bryophytes, red=lichens) along the slope gradient.

The vegetative cover CCA also showed that the location of the quadrat on the cliff face itself was not as important as the environmental characteristics associated with those locations, as the plots do not separate from each other entirely based on location. (Fig. 11, Fig. 12). This is because plots in the respective locations of cliff top, cliff face and talus do not separate out entirely and thus some face plots share characteristics with the top and talus plots.

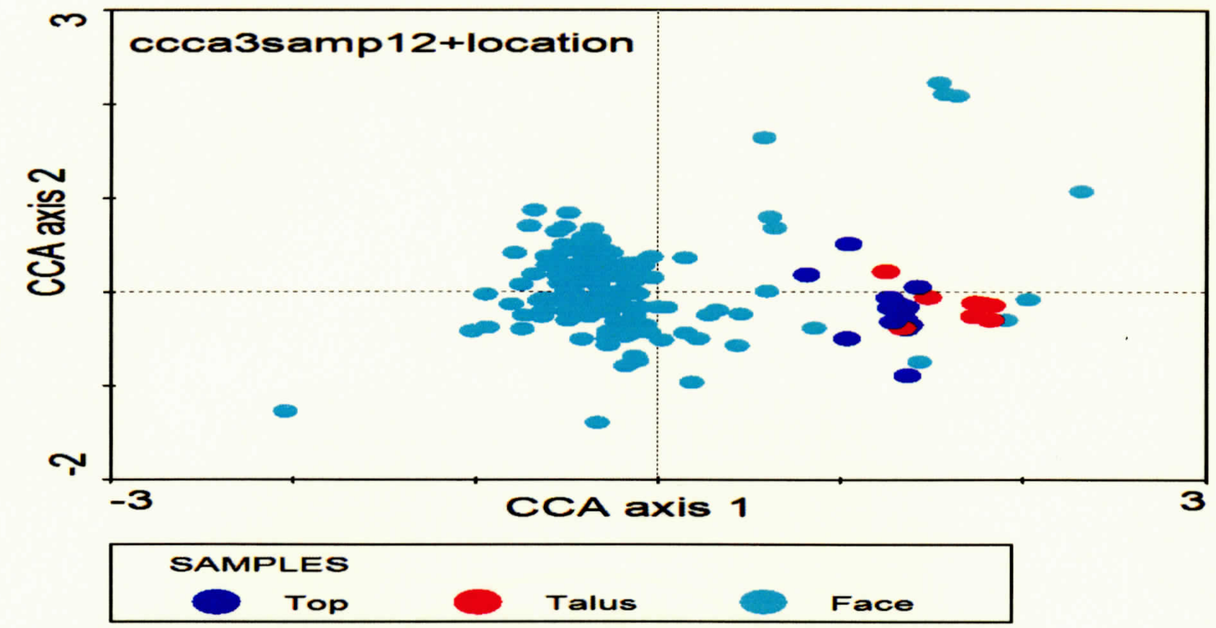

Fig. 11 Percent cover CCA of sample locations. Axis 1 vs. axis 2. The samples on the cliff top and talus separate from the samples on the cliff face, indicating that sample location impacts species composition.

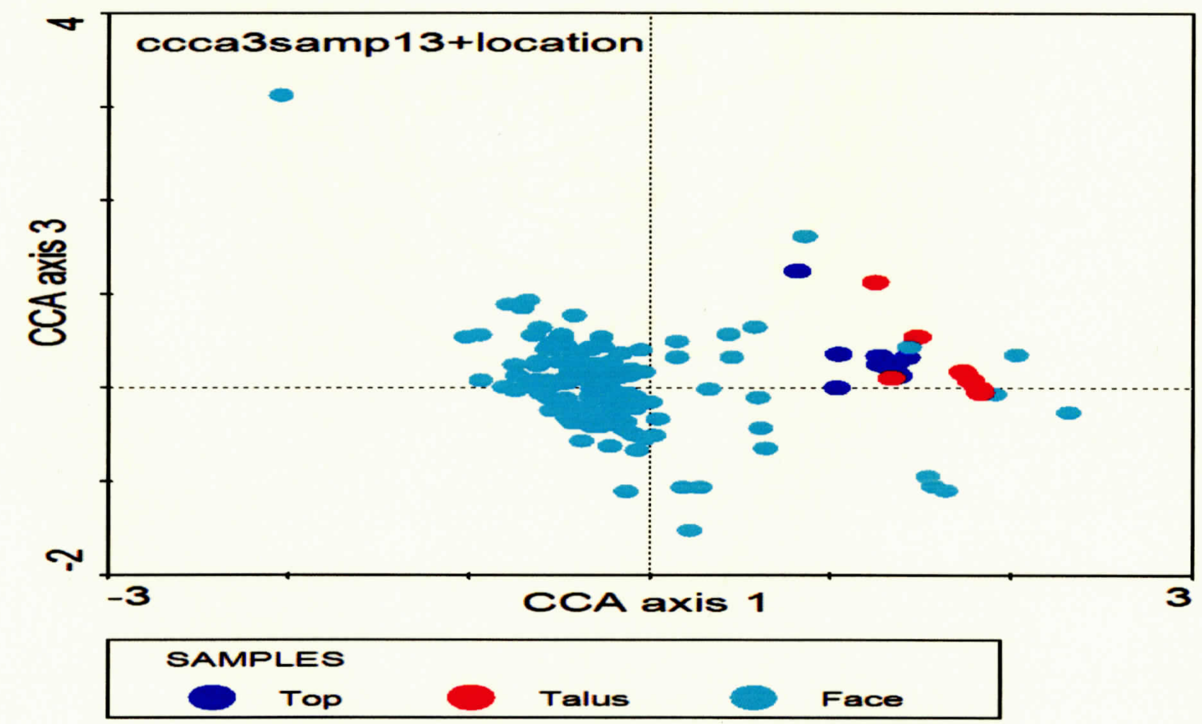

Fig. 12 Percent cover CCA of sample locations. Axis 1 vs. axis 3. The samples location on the cliff system again impacts species composition of the vegetative community.

The percent cover CCA also shows that the second axis is highly correlated with both the northness and eastness aspect components, as well as total soil volume, as shown by Figure 14. Monte Carlo permutations indicated that of the environmental variables measured, three are significant, including slope, plot location and total plot soil volume (Table 5). Slope, again, is highly correlated with the first axis, but does not account for all of the variation. The second most significant environmental variable is location on the cliff system; specifically, quadrats located on the cliff face have a moderately different species composition than do those on the cliff top and talus (Fig. 11, Fig. 12.) The third significant environmental variable measured was total plot soil volume.

Finally, the percent cover CCA shows that slope and quadrat location together significantly impact the vegetative communities, as the correlation between these variables is 0.724 (r^2). Interestingly, total plot soil volume is not as strongly correlated with slope as expected (r^2 = -0.1848), but is more strongly correlated with plots located on the cliff face (r^2 = 0.081).

To insure that the interaction between cliff top, cliff face and talus plots were not obscuring fine-scale effects caused by the measured environmental variables, a partial CCA was conducted using the data from the cliff-face plots only. Although the three significant variables were different in the cliff face only CCA (Table 6), the arrangement of the samples in the ordination plots is very similar. This indicated that the interaction between the cliff top, cliff face and talus plots did not obscure fine-scale environmental effects.

Table 6 Partial CCA of percent cover data of cliff face samples only. Environmental variables which significantly impact the vegetative community of the cliff face samples only.

Class	*Variable*	*P*	*F*
All Vegetation	Total Soil Volume	0.0200	6.7800
	Mean Ledge Area	0.0140	4.0000
	Slope	0.0160	3.3100

Number of Monte Carlo permutations = 499.0

Vascular Species Only DCA

The DCA analysis for the vascular species only indicated that the most significant variable accounting for vegetative community composition was not one of the environmental variables surveyed. The slope and aspect variables are still marginally correlated with the first axis, indicating that the unknown variable responsible for the majority of the variation is also correlated with slope and aspect (Fig. 13). The variables accounting for the second greatest degree of variation, associated with the second axis, are plot mean crack volume, and plot mean ledge area, both of which are indicators of surface heterogeneity. Additionally the DCA analysis revealed that the location of the plot on the cliff system does not significantly affect vascular species composition (Fig. 14, Fig. 15), as cliff-face plots (blue) and cliff-top and talus plots (red) do not separate out from each other.

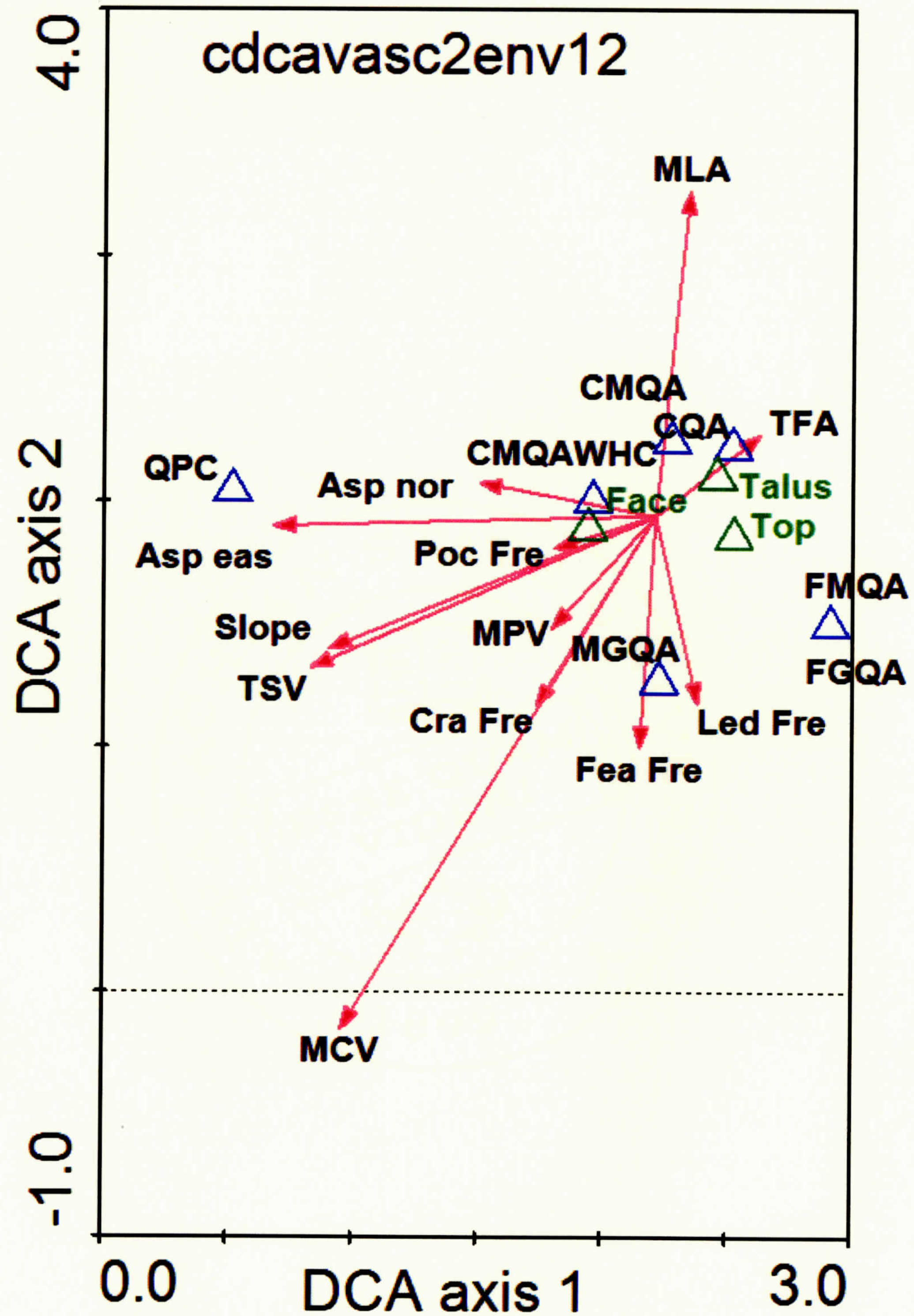

Fig. 13 Vascular species only DCA. Axis 1 vs. axis 2. Mean ledge area (MLA) and mean crevice volume (MCV) primarily impact the vascular species composition.

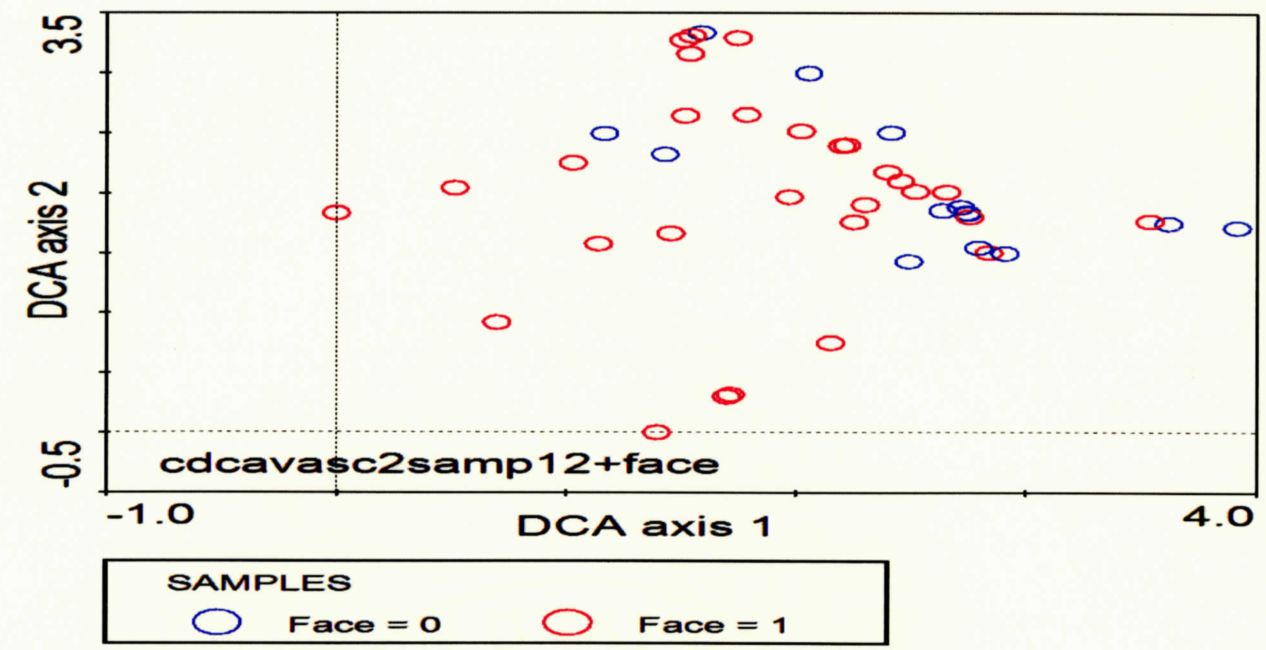

Fig. 14 Vascular species only DCA. Axis 1 vs. axis 2. Plot location on the cliff system does not significantly impact vascular species composition.

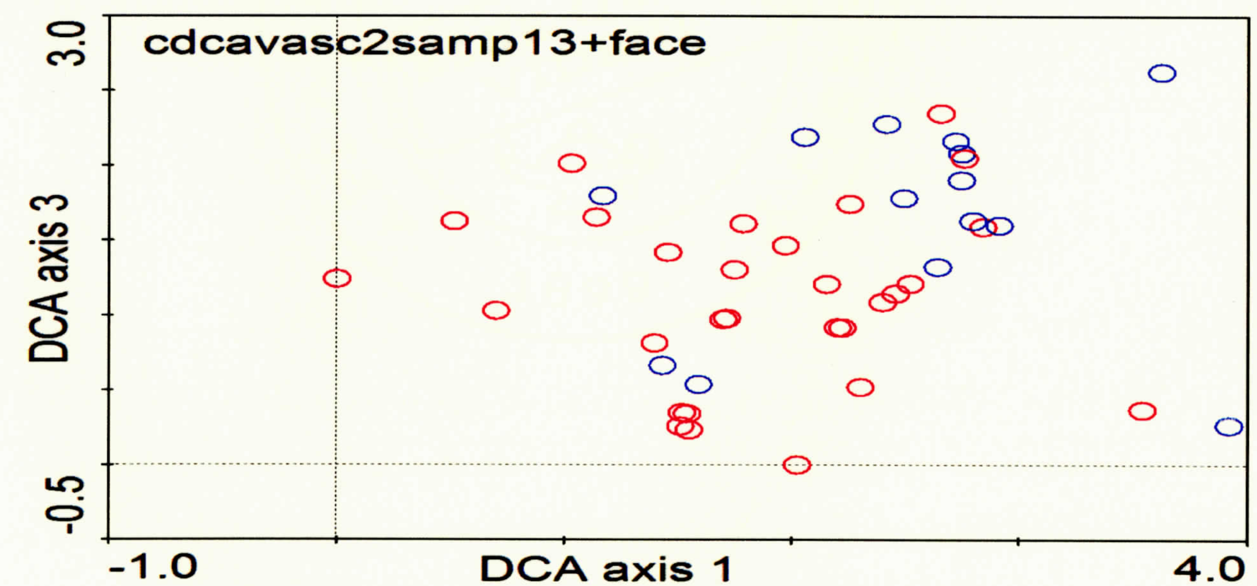

Fig. 15 Vascular species only DCA. Axis 1 vs. axis 3. Plot location on the cliff system does not significantly impact vascular species composition.

Vascular Species Only CCA

The CCA analysis of the vascular species did not conclusively indicate which variables impact species composition. The three highest CCA eigenvalues are significantly lower than those of the vascular species only DCA, indicating that the correlations between the data and the axes are much weaker. The CCA analysis of the vascular species indicated that these species do not separate from each other based on which transect they are located, indicating that vegetation is somewhat homogeneous across the cliff system. Additionally, this analysis indicated that the measured environmental variables do not account for all the variation in community composition. As seen in Figure 16, the first axis is most closely associated with total feature area, mean ledge area, total plot soil volume, slope, and the eastness component of aspect (Fig. 16). Based on the calculated eigenvalues, axis one is most strongly correlated with the location on the cliff face. This means that the location on the cliff face accounts for the greatest degree of variation and thus plots on the cliff face do have a significantly different community composition than do those on the cliff top and talus. This variable has an eigenvalue of 0.3974, while the second most significant variable associated with the first axis is total plot soil volume, with an eigenvalue of 0.3209 (Appendix C). This shows that the species composition of the White Rocks vegetative community changes vertically on the cliff system. The analysis showed that the second axis is most significantly correlated with feature frequency, with an eigenvalue of 0.5510.

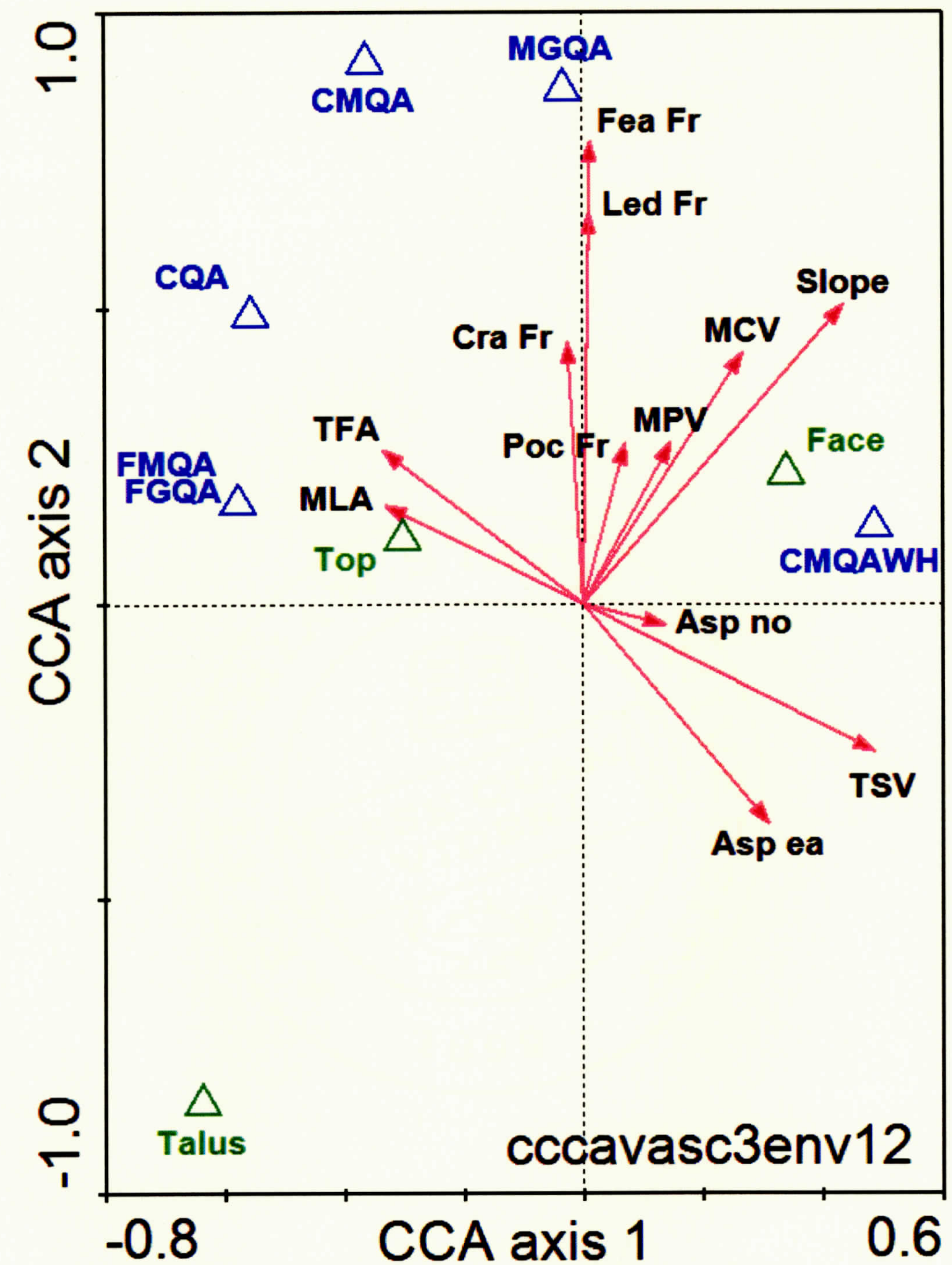

Fig. 16 Vascular species only CCA. Axis 1 vs. axis 2. The length of the eigenvectors indicate that feature area, slope, and soil volume most strongly impact vascular species composition.

The vascular-species only CCA also indicated that the plots on the cliff face, and cliff top and talus were more distinct than the DCA analysis, again indicating that location on the cliff face is an important variable explaining the differences in community composition (Fig. 17). Monte Carlo permutations indicated that the most significant measured environmental variables influencing vascular community structure were location on the cliff face, feature frequency, and feature area (Table 5).

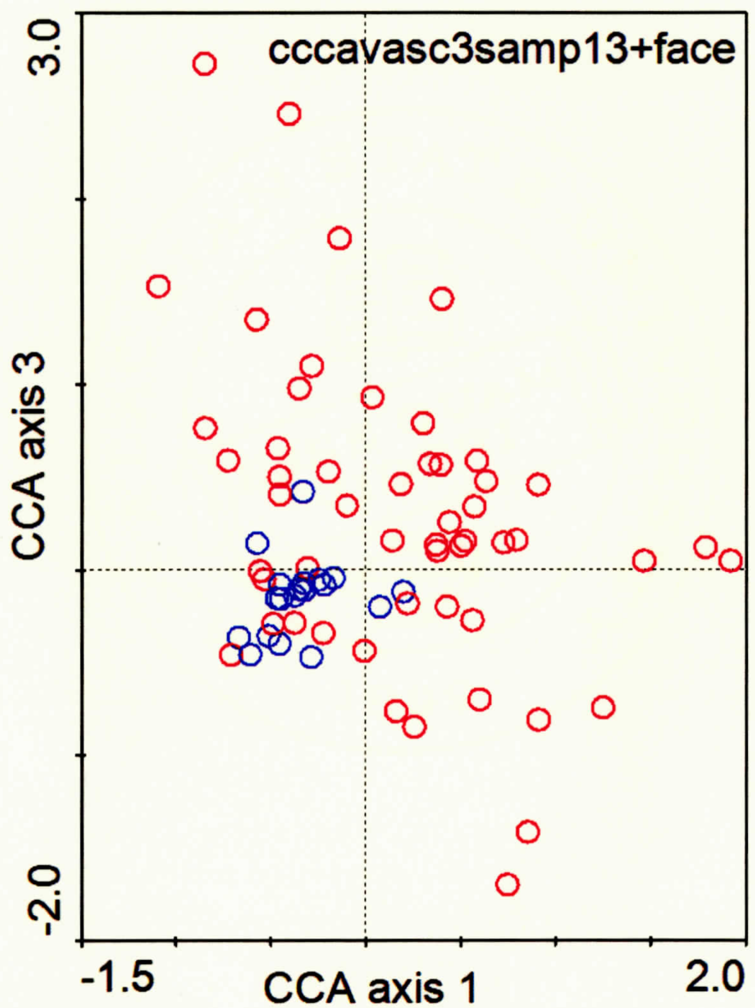

Fig. 17 Vascular species only CCA. Axis 1 vs. axis 3. Sample location on the cliff system does impact vascular species composition, as shown by the limited separation of cliff-face plots (red), and cliff-top and talus plots (blue).

Lichen Species only DCA

The lichen species only DCA revealed that lichen composition on the cliff face was very distinct from lichen composition on the cliff top and talus (Fig. 18), and that there is no clear connection between transect and lichen community meaning that the lichen communities differ among plots on the top, face and talus, but are relatively similar across the cliff system within those general locations. In other words, the lichen community on the cliff top is homogenous along the length of the cliff system, but is distinct from the community on the cliff face, which itself is homogenous along the cliff system (Fig. 19). This indicates vertical change in the lichen community on the White Rocks cliff system.

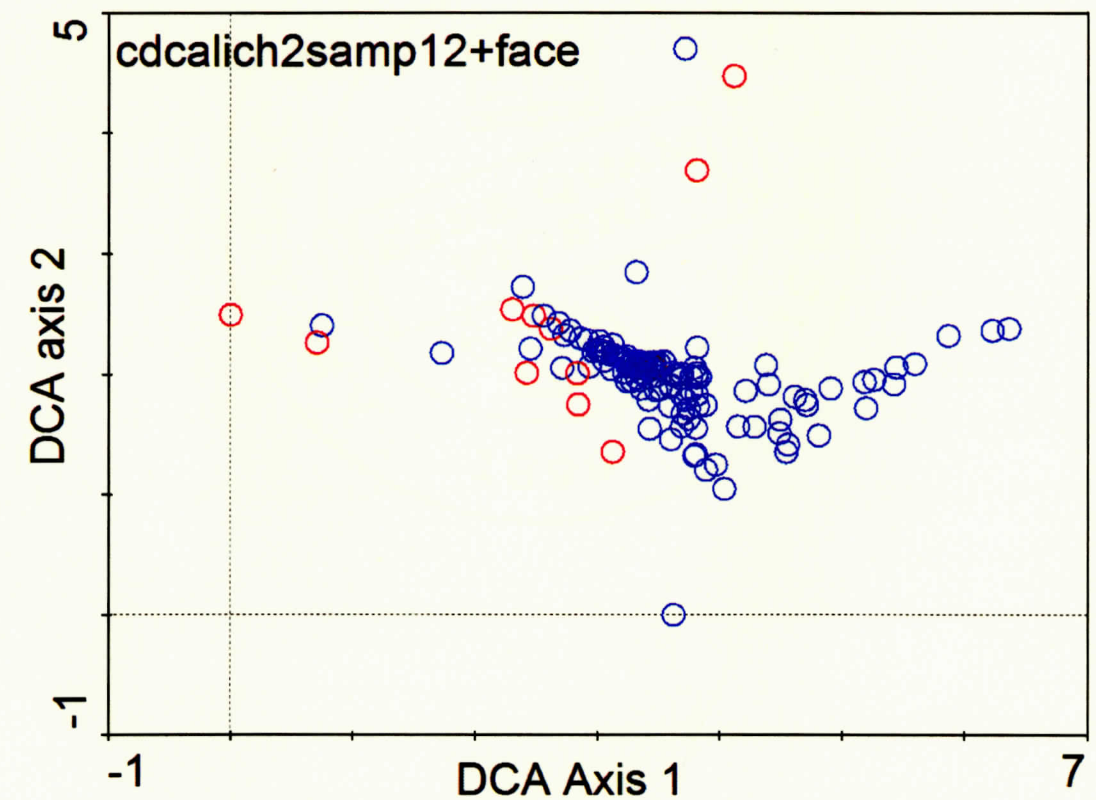

Fig. 18 Lichen species only DCA. Axis 1 vs. axis 3. Sample location on the cliff system does impact lichen species composition, as shown by the separation of cliff-face (blue) and cliff-top and talus plots (red).

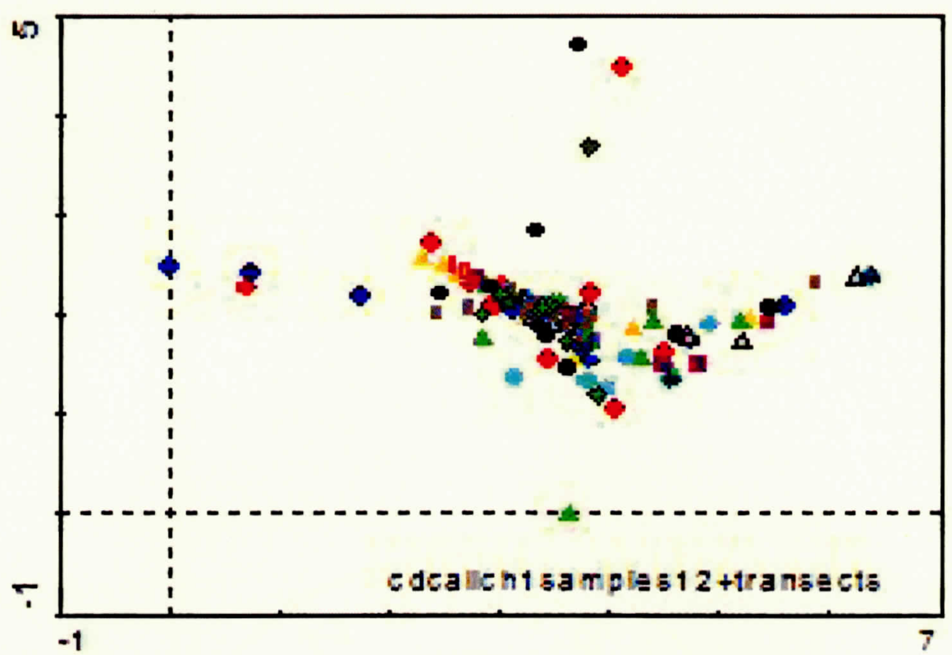

Fig. 19 Lichen species only DCA. Axis 1 vs. axis 2. Lichen species composition is similar within plots on the cliff top, cliff face, and talus.

The DCA also indicated that all three lichen morphotypes (crustose, foliose and fruiticose) occur equally on the cliff system, without any significant pattern in their distribution (Fig. 20). The measured environmental variables most significantly affecting the lichen community are slope, aspect and plot total soil volume (Fig 21).

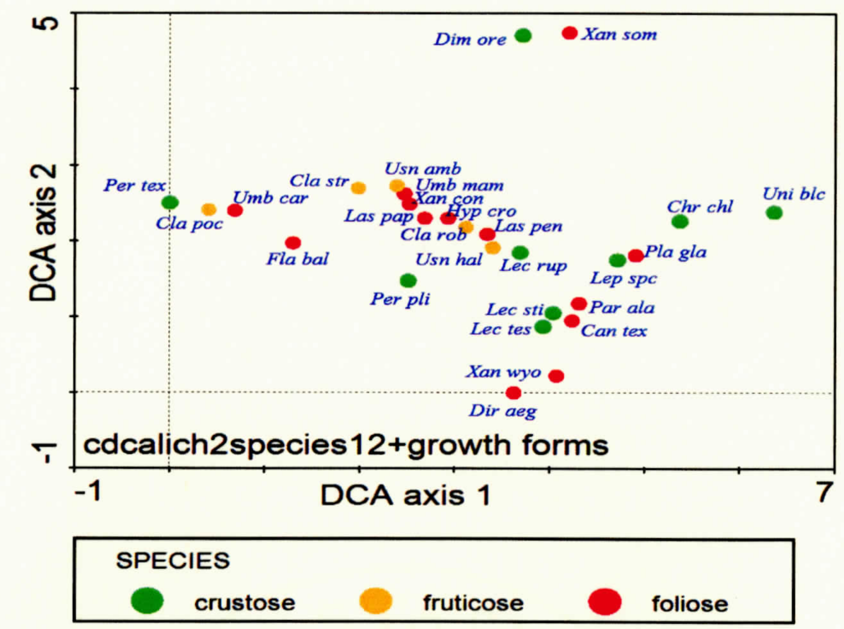

Fig. 20 Lichen species only DCA. Axis 1 vs. axis 2. Lichen morphotypes occur relatively equally on the cliff face.

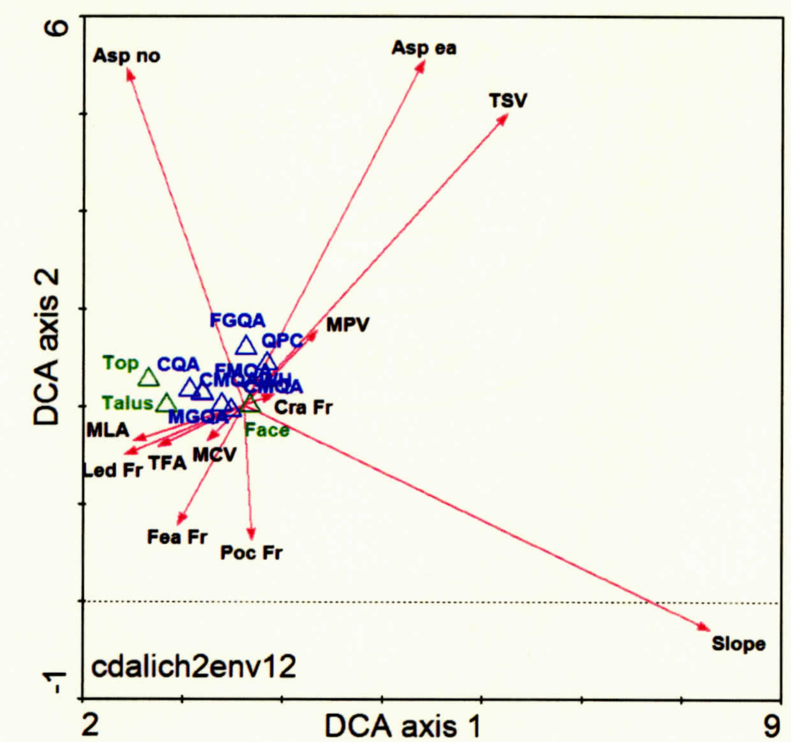

Fig. 21 Lichen species only DCA overlay of environmental variables. Axis 1 vs. axis 2. Lichen species composition is affected by slope, total soil volume, aspect and feature frequency.

Lichen Species CCA

The eigenvalues for the lichen species only CCA were significantly lower than those for the DCA, again indicating that the variation in lichen species was not entirely accounted for by the environmental variables measured. This also indicates that the measured environmental variables more accurately explain the variation of the vascular community than in the lichen community. The only significant variable affecting lichens was slope, with plot locations on the cliff top being nearly significant (Table 5). Figure 22 shows that the lichens on the cliff face (blue) and the lichens on the cliff top and talus (red) are very distinct, which can be explained by the location of the quadrat on the cliff system, which also corresponds to the significant change in slope (Table 5).

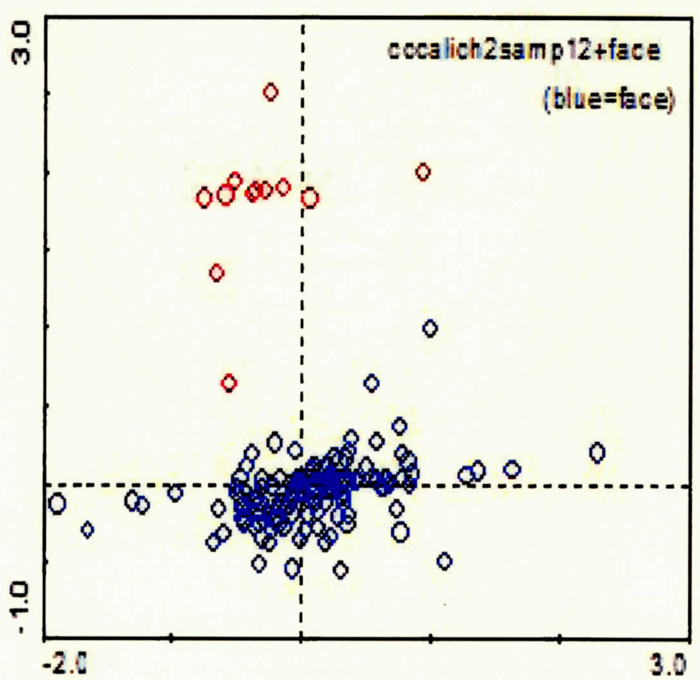

Fig. 22 Lichen species only CCA. Axis 1 vs. axis 2. Sample location on the cliff system significantly impacts lichen species composition, as shown by the separation of cliff-face plots (blue) and cliff-top and talus plots (red).

The lichen species only CCA analysis also indicated that slope and location on the cliff face are most closely associated with the second CCA axis, while differences in species composition on axis one can be explained by aspect, soil volume, and feature frequency (Fig 23).

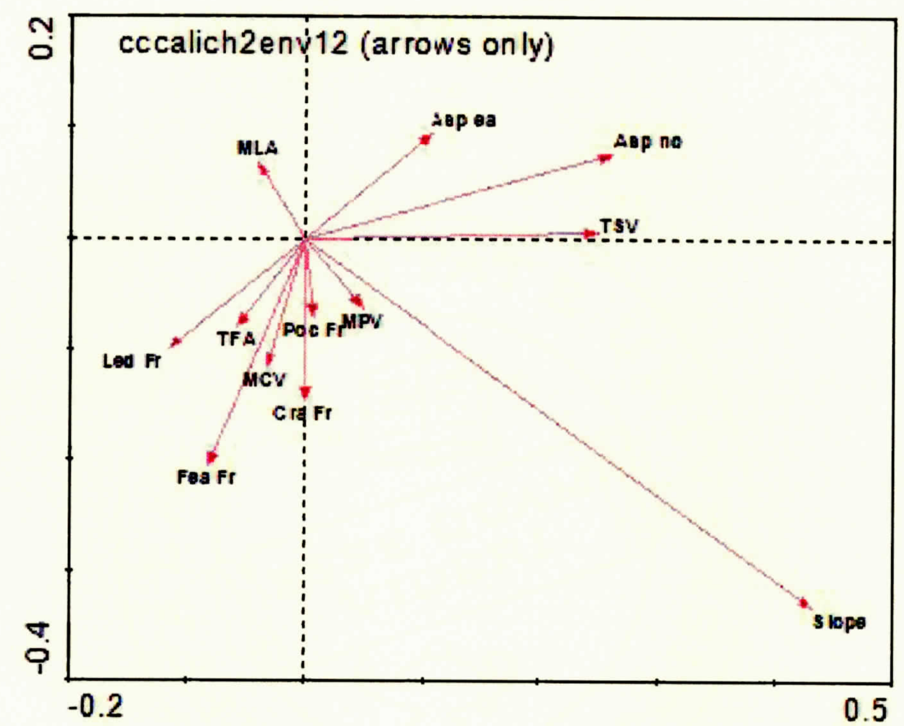

Fig. 23 Lichen species only CCA. Axis 1 vs. axis 2. Lichen species composition is impacted by aspect, soil volume, and feature frequency (axis 1), and by slope and sample location (axis 2).

Microfeature DCA

The microfeature DCA analysis indicated that vascular plants and non-vascular plants separate out from each other very cleanly (Fig. 24, Fig. 25). When the species distribution is compared to a diagram of the environmental variables, it can be seen that the first axis is very highly correlated with slope, and that vascular species separate from non-vascular species along this gradient (Fig. 26). Additionally, total plot soil volume and total feature area (surface heterogeneity) also are highly correlated with the first axis, indicating that these variables significantly affect the vegetation occurring on microfeatures of the White Rocks cliff system. The second axis of the microfeature DCA is most closely correlated with height of the microfeature and plot aspect. The vectors of these variables are perpendicular to the vectors for slope, depth, soil volume and total feature area, indicating that they are orthogonal to one another and not related. All of the above characteristics are negatively correlated with slope, indicating that as slope increases, the area, soil volume and other physical characteristics supporting vascular vegetation decrease (Fig. 26).

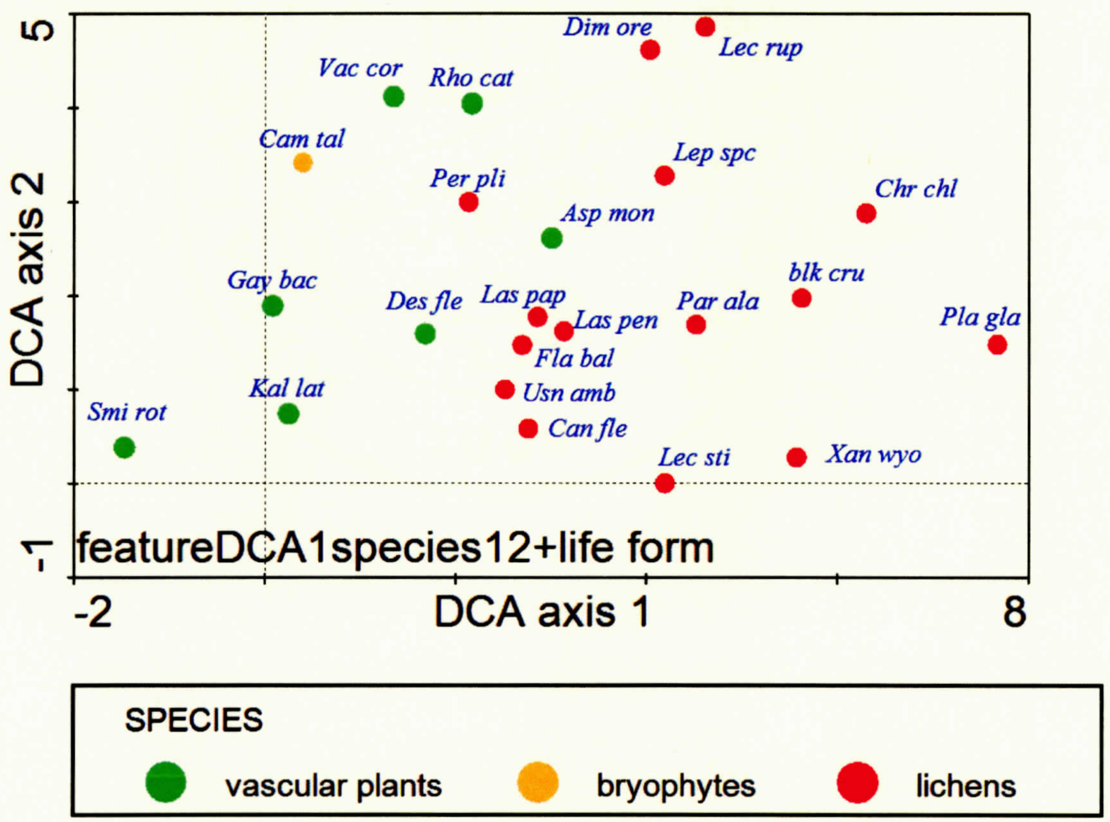

Fig. 24 Microfeature DCA. Axis 1 vs. axis 2. Vascular species (green) separate from non-vascular species (yellow=bryophytes, red=lichens).

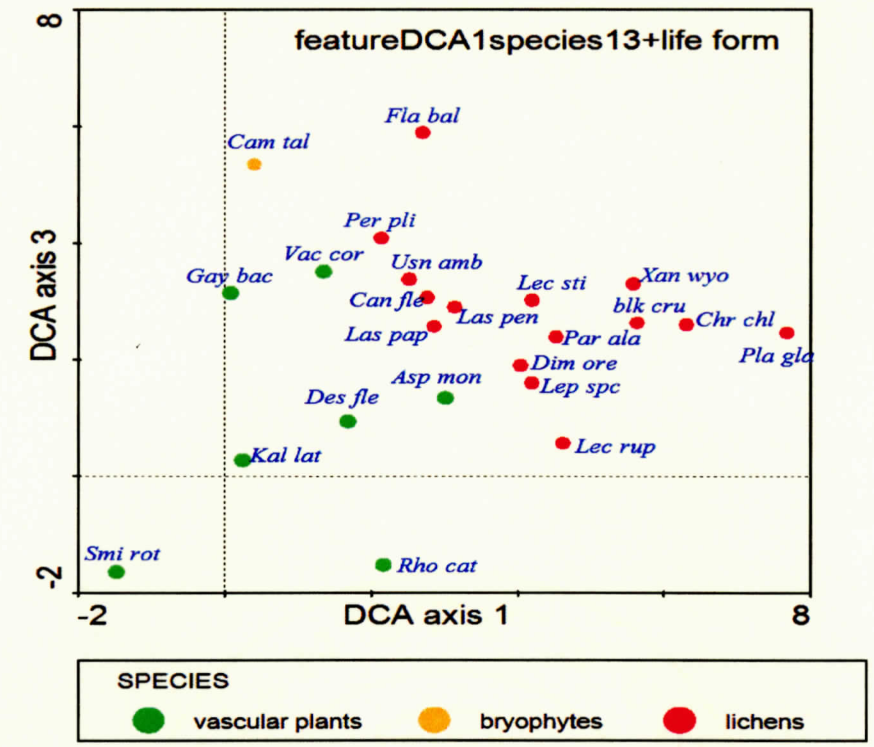

Fig. 25 Microfeature DCA. Axis 1 vs. axis 3. Vascular species (green) separate from non-vascular species (yellow=bryophytes, red=lichens).

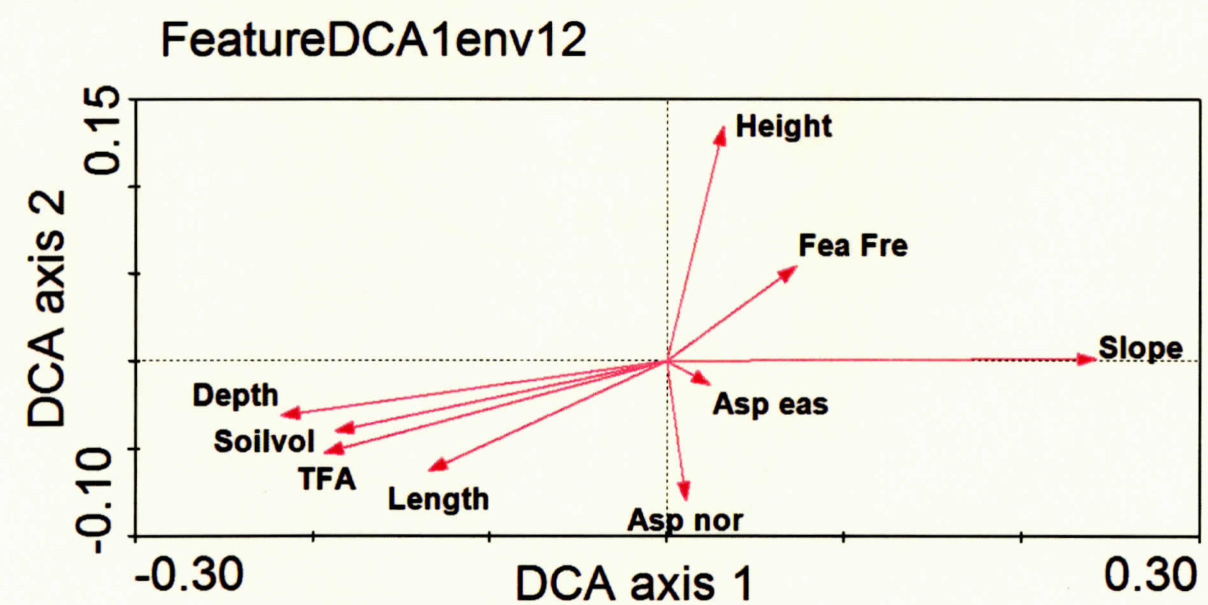

Fig. 26 Microfeature DCA overlay of environmental variables. Axis 1 vs. axis 2. Slope and soil volume are likely responsible for the separation of vascular and non-vascular species.

The microfeature DCA also indicated that vegetative forms are not correlated with a specific type of microfeature (Fig. 27), as can be seen by the lack of separation of the microfeature types, and the lack of any pattern corresponding with the distribution of species. The distribution is however impacted by the size of the microfeature and the associated characteristics (soil volume, surface area and associated variables such as light, water, and nutrient availability) (Fig. 25, Fig. 26).

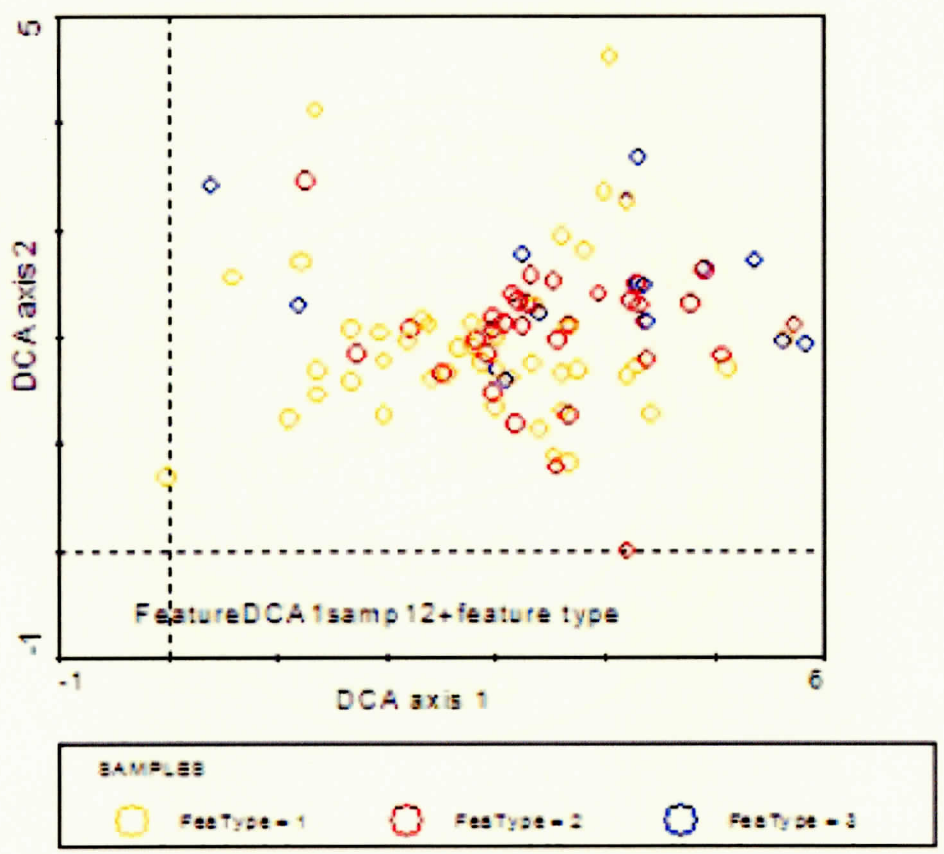

Fig. 27 Microfeature DCA. Axis 1 vs. axis 2. Microfeature type does not impact species composition on the microfeatures, as shown by the lack of separation of ledges (yellow), cracks (red), and pockets (blue).

Microfeature CCA

The eigenvalues of the three most significant variables in the CCA were 0.369, 0.170, and 0.087. These values were significantly lower than the values of the DCA, indicating again, that the measured variables account for little of the variation in the species composition and community structure. The microfeature CCA did again indicate that vascular species separated from non-vascular species (Fig. 28), and that this separation is likely due to the gradient associated with microfeature soil volume (Fig. 29).

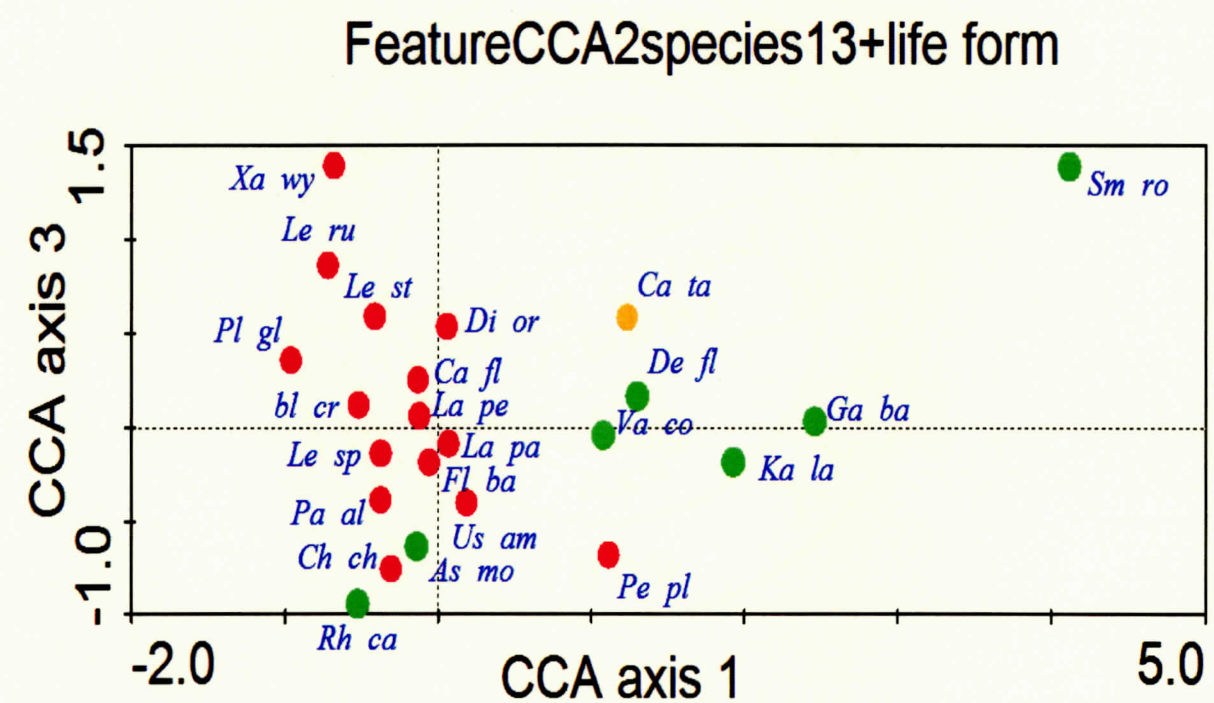

Fig. 28 Microfeature CCA. Axis 1 vs. axis 3. Vascular species (green) separate from non-vascular species (yellow=bryophyte, red=lichens).

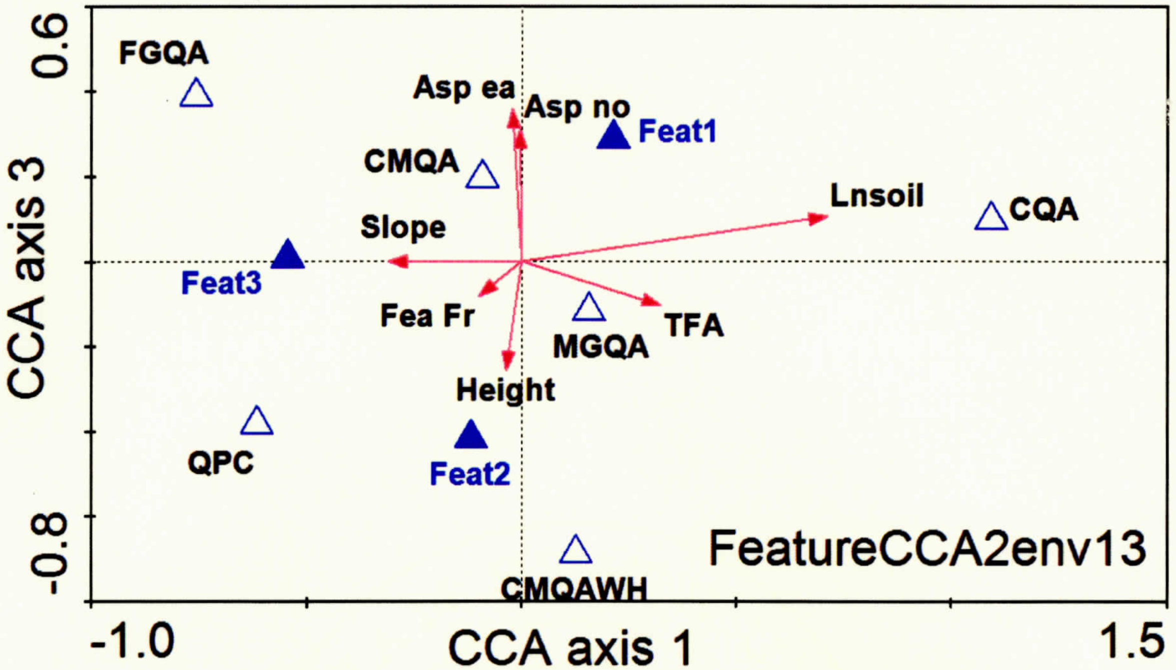

Fig. 29 Microfeature CCA. Axis 1 vs. axis 3. Vegetative species composition on microfeatures is impacted significantly by soil volume only.

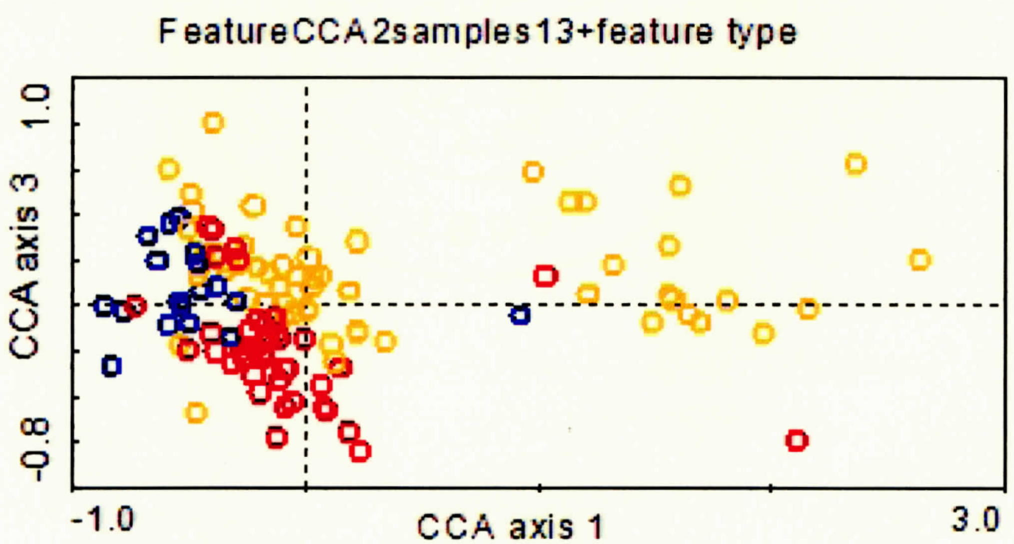

Fig. 30 Microfeature CCA. Axis 1 vs. axis 3. Vascular species occur primarily on ledges, while non-vascular species occur on all microfeature types (yellow=ledges, red-cracks, blue=pockets).

The CCA indicated that vascular plants occur primarily on ledges, as ledges have soil while cracks and pockets of the White Rocks systems typically do not. The CCA analysis also indicated that non-vascular species occur on all feature types (Fig. 28, Fig. 30), and that vascular plants occur on features with higher soil volume (Fig. 31).

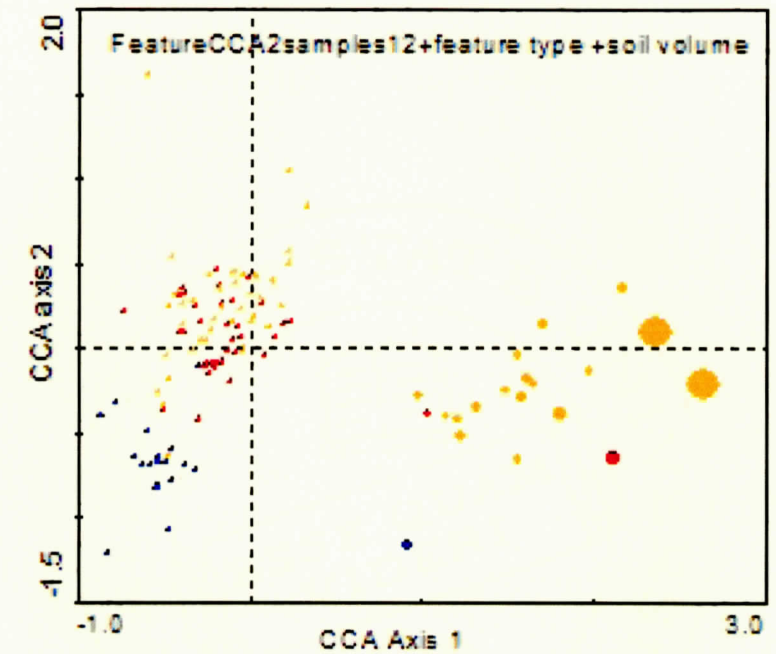

Fig. 31 Microfeature CCA. Axis 1 vs. axis 2. Larger circles have greater soil volumes. Vascular species occur primarily on features with greater soil volumes (yellow=ledges, red=cracks, blue=pockets).

Finally, the microfeature CCA analysis indicated that species richness does not correspond with higher soil volume. It was seen that features with higher soil volumes generally had lower species richness than do features with average soil volumes, but more than features with very low soil volumes (Fig. 32). The microfeature CCA analysis also indicated that there was no sampling bias during the cliff survey, as indicated by Figure 33, which displays microfeatures by type with their respective transects.

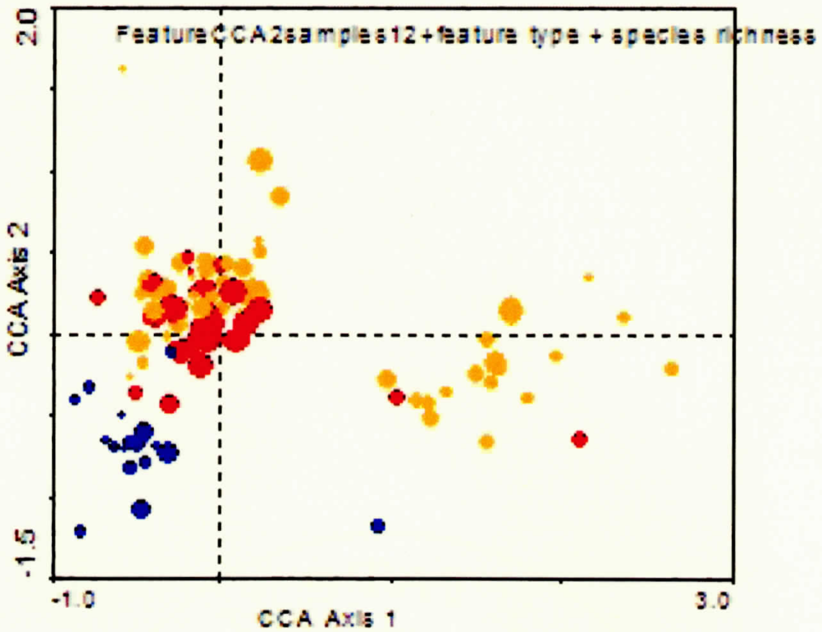

Fig. 32 Microfeature CCA. Axis 1 vs. axis 2. Larger circles indicate greater species richness. When analyzed with Figure 31, it is seen that greater soil volume does not increase species richness.

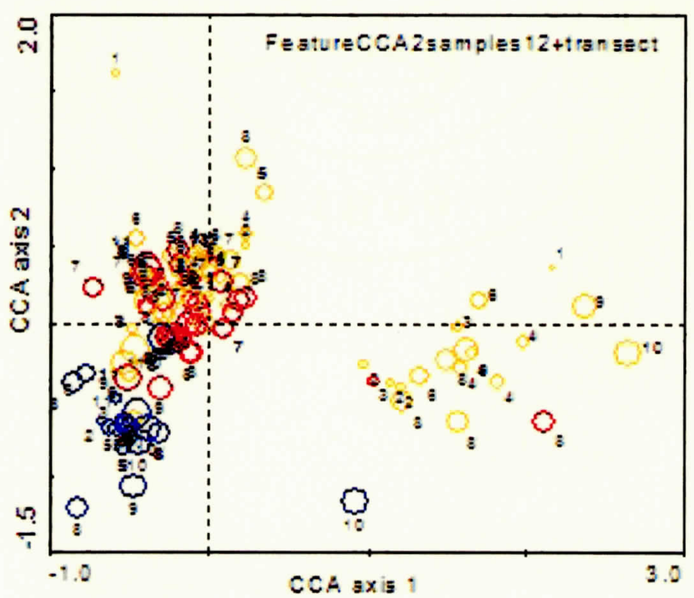

Fig. 33 Microfeature CCA. Axis 1 vs. axis 2. Lack of separation between samples of each transect indicate that there was no sampling bias during the survey.

Microfeature Partial CCA

A partial CCA analysis was run on the microfeature data only to determine whether or not microfeature characteristics including feature type, soil volume and height had more or less influence than large scale environmental characteristics of the cliff systems, including slope, aspect, and total feature area. The analysis indicated that each set of characteristics contributed approximately the same to the variation of the vegetative community, as the large scale and microfeature characteristics contributed 11% and 10% of the total variation respectively.

GIS Database

Using data obtained during the survey of the White Rocks cliff system, a GIS map and database of the cliff top was constructed and shows the locations of the 12 transects, as well as the location of the vernal pool from which they were measured. Additionally, the map indicates the location of populations of *Paronychia argyrocoma*, *Maianthemum canadense*, and *Minuartia glabra*. Finally the map indicates the location of several large rock outcrops on the cliff top, and the location of one perennial seep (with an associated population of *Saxifraga michauxii*) at the cliff base. The database includes a vegetational layer that lists vascular plant, moss and lichen species by quadrat. In addition, a digital elevation model obtained for the area was converted into a 3-D image upon which the shape files were overlain to indicate the trails approaching the White Rocks Cliff system (Appendix B).

DISCUSSION

Throughout history cliff systems have been very important to humanity as they have provided shelter and hiding places for our species (Larson et al. 2000). More recently cliffs have been employed during times of war for their strategic advantage. During the last several decades however, the use of cliffs has changed dramatically as recreational activity has increased with the growing popularity of hiking, backpacking, and especially rock climbing. Biologically cliff systems are very important as well. Cliff systems remain very important to local and global biodiversity, as they serve as a habitat that allows normally poor competitors to escape competition from species better adapted to horizontal environments. Cliff faces also protect biodiversity in that they protect species from disturbance, both natural and anthropogenic. Cliff faces have been shown to protect species from fire disturbance, and the topographic nature of the landscape prevents significant human impact, including logging and development (Plesewszki 2003). As a result, certain species are found only on cliff faces and rock outcrops due to this decreased disturbance. Many of these species are rare and threatened, a condition exacerbated by the increasing scarcity of pristine cliff face habitats.

Cliff-ecosystem communities are controlled by several physical factors that do not constrain communities in other environments to the same degree. At the same time, cliff systems are buffered from extremes of some physical factors including temperature because of the indirect angle of midday light. They also provide protection from natural and

anthropogenic disturbances for the biota associated with them. To a large degree, the physical factors that limit growth on cliff faces are related to gravity and mass. Most plants rely on the formation of soils from which they acquire nutrients, water, and rooting space. These factors often limit the size and mass of cliff-face plant species, as the larger the individual, the less likely the small ledges and volumes of soil found on these vertical habitats are able to accommodate them. Additionally, soil accumulation on cliff faces is restricted to features on the rock. The slope or steepness of these features further limits the possibility of soil and moisture accumulation. As a result most vascular plant vegetation and even mosses are limited to relatively large features on which soil develops, or to small features with low slope on which soil may accumulate. On small features with low soil volumes, rooting space and nutrient availability limit vegetative growth. These physical factors provide slow growing species an advantage over fast growing species, resulting in the domination of the cliff face community by slower growing species such as *Thuja occidentalis*.

Cliff-face ecology is a fairly young field, and there are still several environmental variables which control community assemblage on cliff faces which are not entirely understood. The results of the White Rocks survey indicated that the measured environmental variables accounted for much of the variation in the vascular species community composition, but for very little of the variation in lichen species composition. Two characteristics that are typically the most difficult to measure in the field are light quality and moisture, and may likely account for the remaining variation observed in the species composition on White Rocks and other cliff systems. While both of these characteristics are important requirements for plant survival and reproduction, due to the logistical limitations imposed by the nature of cliff-face research, there has yet to be developed an accurate way to measure these variables. However, some of the impact of these variables on community structure in cliff systems may be inferred from other physical variables which are more easily measured.

As seen in the results of this study, slope impacts community structure and composition in all analyses. Vascular species, which are typically larger and have higher moisture requirements, are restricted to large features with greater soil volume or to extensive cracks and fissures. This is in contrast to the lichen community, which seems to increase in abundance and diversity with features characterized by higher (steeper) slopes with fewer features present and less soil accumulation. As seen in the results of the vascular species only CCA, plants of the White Rocks cliff system are controlled predominantly by surface heterogeneity and slope. These characteristics correspond with greater soil accumulation and thus greater water and nutrient availability. Areas with lower slope also receive more direct light than do areas with steeper slope. Alternatively, areas with steep slope and lower surface heterogeneity are predominantly occupied by non-vascular species, as there is little or no soil development, less available water, and less direct sunlight.

Feature size, soil accumulation, and surface heterogeneity also impact water retention on cliff faces. Water on bare, steep sections of cliff faces evaporates rapidly, imposing water stress on plant species. However, features on the cliff face with soil or deep cracks and crevices prevent water from evaporating as quickly, making it available for uptake by vegetation, as increased surface heterogeneity allows for water to pool in fissures and pockets, and prevents it from evaporating. Likewise, the surface tension of water on a

smooth rock surface in a crack or fissure makes water more easily absorbed by plant roots than the hydroscopic films around soil particles with stronger adhesion properties.

Nutrient availability also is a limiting factor on cliff systems, because without essential nutrients, vegetative survival is not possible. The White Rocks cliff system has a geologic structure such that it includes horizontal bands of precipitated iron. It has been observed in other cliff systems (Walker 1987) that when a permeable rock formation, such as the sandstone conglomerate at White Rocks, interfaces with a relatively impermeable layer such as the precipitated iron deposits, the water seeping through such systems flows out horizontally onto the face. Due to the character of the cliff, the bands of erosion-resistant iron often form ledges, on which soil accumulates. This, in conjunction with the water which seeps out on to the cliff face in these locations, may create a more hospitable environment for vegetative establishment and survival. The results of the microfeature analysis indicate that this is likely the case, as it is not microfeature type that impacts species composition, but the associated environmental characteristics including slope, soil volume, and surface heterogeneity.

Despite the presence of microfeatures with some conditions favorable for vascular plant establishment, the south-facing aspect of the White Rocks cliff system introduces significant pressure on vascular and bryophyte species. The increased temperature and reduction in water retention associated with this aspect imposes restrictions on vascular and bryophyte plant development compared to lichens. This limitation on vascular and bryophyte species establishment likely reduces competitive pressure on lichens for light and space, possibly explaining the more diverse and abundant lichen assemblage on the White

Rocks cliff systems as opposed to the relatively depauperate vascular and bryophyte assemblages.

Some results of this study are in contrast to observations made in other recent cliff-system studies. For example, Kuntz and Larson (2006) found that the vegetative communities surveyed on the Niagara Escarpment did respond to microfeature type, whereas the present study indicated that it was not microfeature type, but the associated characteristics including slope, soil volume and microfeature size, which impacted species composition. Furthermore this study, as with other studies conducted in the southern Appalachians, demonstrated that the lichen community composition does change vertically. The studies conducted along the Niagara Escarpment have not yet identified any vertical differentiation in the lichen community. This may be due to the significantly greater height of the cliff systems surveyed in the southern Appalachians, as taller cliffs may be more likely to develop a stratified vegetative community in response to environmental variables such as moisture and light availability. This study does support observations by the CERG as there was no horizontal differentiation in the vegetative community of the White Rocks cliff system. An important result of the White Rocks survey was the identification of several novel arctic and boreal disjunct lichen species. Several other studies conducted in the southern Appalachians have found arctic and boreal disjunct species as well.

The southern Appalachians have historically represented an area of high biodiversity, and this is reflected by the abundance of arctic and boreal disjunct lichens species identified during the survey of the White Rocks cliff system. These were likely established during the most recent glacial period, the Wisconsin, as species migrated southward ahead of the glacial ice sheet and associated climate changes. As the glaciers reached their maximum extent,

populations of arctic and boreal vascular, bryophyte and lichen species were likely established in the area. Delcourt and Delcourt (1987) have proposed that the Ridge and Valley physiographic province acted as an important migration corridor for vegetation during glacial advances and retreats. The Cumberland Plateau physiographic region, and in this study the White Rocks cliff system, may have acted as a natural boundary to further westward migration, resulting in the establishment of many of the arctic and boreal disjunct species identified on the White Rocks cliff system. This hypothesis is further supported by the lack of arctic and boreal disjunct species on the cliff systems surveyed during the Obed River study, which is located in the western region of the Cumberland Plateau.

Cliff faces offer a refuge for species that are poor competitors in the face of climate change and with the arrival of species better adapted to those changes. Considering this, it is not unlikely that many boreal and arctic species were able to establish populations on the White Rocks cliff system at glacial maximum that have become relicts during the interglacial periods. Other arctic and boreal relict populations have been observed on cliff systems in the Ridge and Valley physiographic region as well (Clebsch and Walker 1988). Walker (1987) found that genetic variation within and among disjunct populations of *T. occidentalis* was higher, with unique genetic assemblages compared to those populations observed in the main range at higher latitudes, indicating that they have persisted on cliff faces during interglacial periods, perhaps through several glacial advances and retreats. It is not unreasonable to assume that some of the glacial relicts on White Rocks may likewise hold unique genetic assemblages given their likely ancient establishment and subsequent isolation.

Glacial relict species such as *T. occidentalis* and *Umbilicaria torrefacta* are also able to persist in these refugia due to decreased environmental stress associated with the current environmental conditions. Cliff faces ameliorate physical factors such as temperature, with increased light availability for species with low tolerance for light competition. Cliff faces also protect species from anthropogenic and natural disturbance. These factors likely explain the establishment and persistence of arctic and boreal lichen species found on the White Rocks cliff system. Introductions of human disturbances at this point may have an adverse effect on these ancient assemblages.

Due to the increase in rock climbing popularity, non-impacted, pristine cliff systems are becoming increasingly rare. The presence of several threatened and endangered plant species, and the unique occurrence of novel arctic and boreal disjunct lichen species on the White Rocks cliff system, present a rare opportunity to protect cliff-face biodiversity in the southern Appalachians. At present, large areas of the cliff top have been extensively damaged by trampling caused by recreation, most likely having removed populations of *Minuartia glabra* and *Paronychia argyrocoma*. Lichen and bryophyte species occurring on the cliff top also have been negatively impacted.

Summary

The White Rocks survey identified three state threatened or endangered species. *Paronychia argyrocoma*, listed in the state of Kentucky, was identified on the cliff face in one quadrat, and observed outside of the survey area in multiple other locations. On the cliff top, which has seen significant damage due to trampling from recreational use, limited numbers of individual *Minuartia glabra* specimens were identified in several places, but not on the cliff face. *Maianthemum canadense* was observed in one large area near the cliff edge.

The statistical analysis of the survey data revealed that, of the many environmental variables measured, slope, soil volume, surface heterogeneity, and in some cases aspect and the plot location on the cliff face significantly impacted the vegetative community of the White Rocks cliff system. It was found that the lichen community composition did not change significantly east to west across the cliff face, but that lichen species composition did vary according to vertical position on the cliff face. The microfeature analysis revealed that again, vascular species separated from non-vascular species not based upon microfeature type, but along natural gradients of associated characteristics. Additionally, several lichen species were identified growing on atypical substrates (vertical rock rather than vertical tree trunks), or occurred as arctic or boreal disjuncts, likely representing glacial relict populations. Furthermore, the lichen species diversity at this site far exceeds that of lichen communities that have been systematically surveyed in other cliff systems within the Cumberland Plateau physiographic region (Walker and Parrisher 2005). Finally, there were no arctic and boreal disjunct lichen species observed in the OBRI study (Walker and Parrisher 2005), further supporting the theory that these populations were established on the White Rocks cliff system at least as long ago as during the most recent ice age.

Management Implications

The White Rocks cliff system is an attractive destination for multiple user groups, including hikers and equestrians. However, while these user groups have significantly impacted some of the fragile habitats that house or likely once housed rare and restricted species on the cliff top, the face and talus areas of the cliff system remain relatively pristine. Climbing access would introduce substantially more disturbance to a greater area of the cliff system. Due to the height of the cliffs, climbing would most likely occur in a ground-up style, using either traditionally placed protection equipment or installed bolts. During the survey conducted for the present study, one piece of climbing gear was observed on the rock, indicating illegal climbing on the cliff system. Due to this ground-up climbing style, areas most susceptible to the greatest impact would be along the cliff base and cliff top. Results of previous cliff-face studies have also shown that climbing has a significant impact on the vegetation of the cliff-base talus area (Walker and Parisher 2005). Trampling by visitors may create additional ecological problems, including significant erosion and invasion by non-native species. Also, there are two perennial seeps along the cliff base that would likely be impacted by climbing approaches. These support rich communities of Michaux's Saxifrage (*Saxifraga michauxii*) and abundant bryophytes.

The physical nature of the rock itself is not conducive to climbing activity. The rock is extremely soft and can be rubbed away by hand in many places. This makes the placement of traditional protection (spring-loaded camming devices, stoppers, and hexes) particularly dangerous, as these devices rely on outward pressure placed on the rock to keep them secure. As a result, if this area was opened to climbing, it may be necessary to install bolts in the cliff face to provide safe climbing protection, further impacting the cliff face system. Routes created on the White Rocks cliff system would most likely be developed where there are natural lines of holds to follow, and thus would correspond with areas that are heavily vegetated, based on the results of the statistical analyses. Previous studies have found that the removal of vascular and bryophyte vegetation associated with climbing leads to changes in species composition, as both the abundance and diversity of lichen species increases. Climbing impacts the foliose and fruiticose morphotypes more heavily than crustose morphotype lichens. Crustose lichen diversity and abundance was observed to have actually

increased in climbed areas of the Linville Gorge Wilderness Area, likely as a result of reduced competition from more sensitive lichen morphotypes (Smith 1998). At the White Rocks cliff system the reduced presence of vascular plants and bryophytes resulting from the southern aspect of the cliff system, coupled with the porous nature of the rock itself is likely why there is a great abundance and diversity of lichen species, especially foliose and fruticose morphotypes. Introducing disturbance in the form of climbing to this system would undoubtedly significantly alter the lichen community composition.

Additionally, areas of the cliff top farther away from the well-used overlook area at the west end of the cliff face may be exposed to disturbance. To minimize impact on the sensitive vegetative communities on the cliff top, which contain *Minuartia glabra*, *Maianthemum canadense*, and *Paronychia argyrocoma*, access to the cliff top should be restricted to areas that do not support these rare and restricted species. In the case of the Obed Wild and Scenic River National Park, recovery of fragile moss and lichen communities that house listed species was observed ten years after the initiation of restricted access to the cliff edge. The use of boardwalks with deck overlooks and interpretive signs placed in relatively nonsensitive areas of cliff edge in that Park has effectively restricted access to fragile lichen and plant communities.

As shown in the GIS database compiled from the White Rocks survey, one *Paronychia argyrocoma* specimen was found within sampling transects on the cliff face. Additional individuals were observed outside of the survey area in close proximity, also on the cliff face. This strongly suggests that *Paronychia argyrocoma* may be relatively common on the cliff face, with many possible occurrences in areas which were not surveyed. Due to the endangered status of this species (S1 listing in the State of Kentucky) and its limited presence at this site, it may be important to restrict activity in this area of the cliff face, as well as areas with similar physical properties, since the statistical analyses have established that such vascular flora is associated with particular physical features.

The cliff-face habitat at White Rocks contains an assemblage of arctic and boreal lichen species that are likely glacial relicts from previous ice ages. There are also lichen taxa that are new occurrences for the Southern Appalachians and that are uncommon, even in their main range. Because of the rare, restricted, disjunct and relict plants and lichens at this site it was recommended that White Rocks be protected from the previously documented disturbance that comes from climbing on cliff faces and unrestricted hiking at the cliff edge. Likewise, other cliff systems and rock outcrops in the Cumberland Gap National Historic Park should likewise be protected from such visitor impacts until systematic vegetative surveys can be conducted in those areas as well. If only 12 transects at White Rocks revealed such a rich diversity of significant lichens and vascular plants then it can be predicted that other such systems in the park may house additional populations of these species and even more examples of rare, restricted and disjunct taxons.

In response to the technical report written for the National Park Service summarizing the results of this study, the agency has closed the White Rocks cliff system to rock climbing and rappelling activity.

Future Considerations

Cliff-face ecology is a constantly developing field. There were some aspects of cliff-face parameters and surveys that were not included in the present study such as detection of endolithic organisms. Physical variables including light and water have yet to be effectively incorporated in cliff-face studies due to the lack of a logistically feasible means of accurately

measuring these parameters. As cliff-face ecology becomes more refined, with the development of instrumentation to characterize light quality and moisture, it may be possible to develop a predictive model for individual species locations within cliff systems based upon their association with the abiotic features of such systems. In the future these aspects, in addition to further development of the GIS database with future surveys and observations the management of the White Rocks cliff system will continue to be enhanced.

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Appendix A
Species Lists

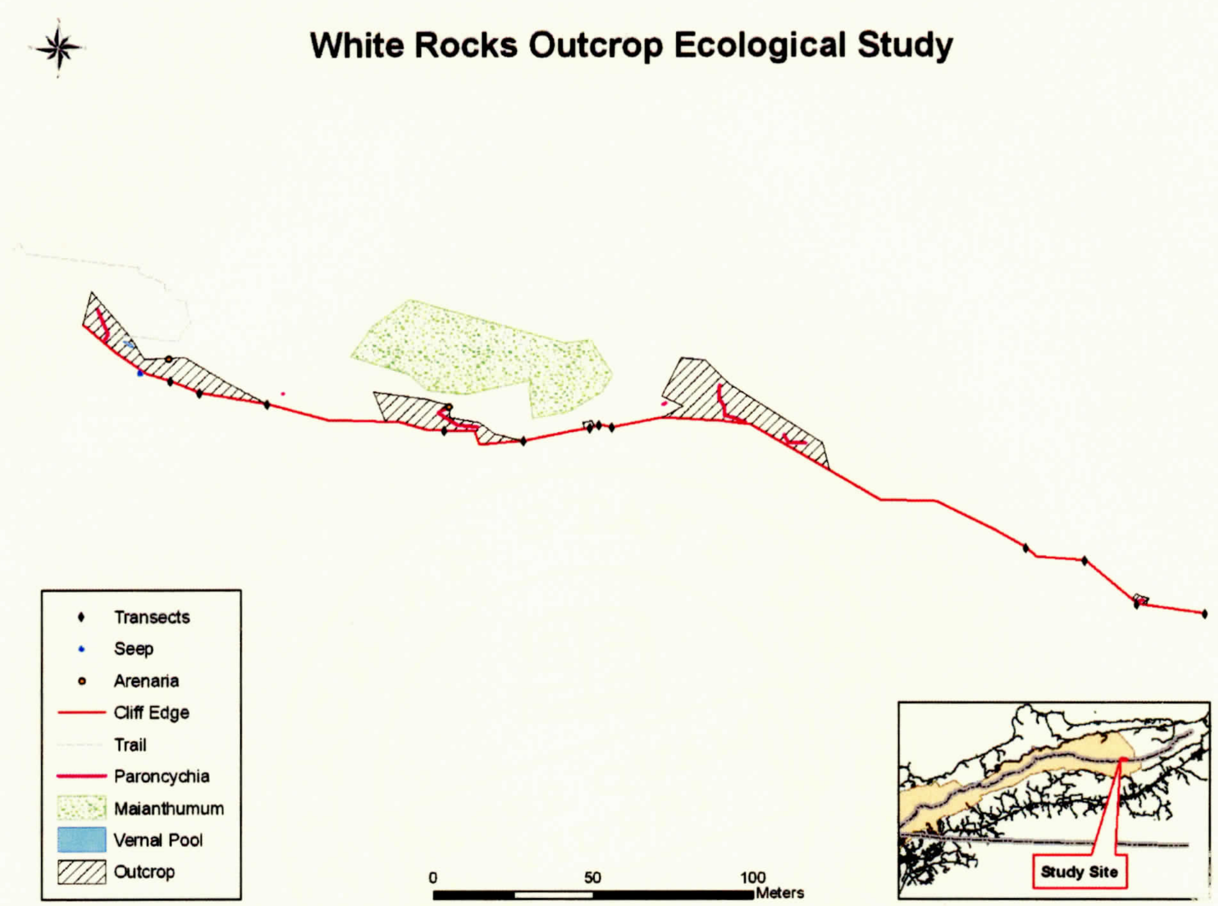
Appendix A – Species Lists with Statistical Analysis Abbreviations

	Vascular Species		Bryophyte Species		Lichen Species
	Aronia melanocarpa	Cam tal	Campylopus tallulensis		Arctoparmelia centrifuga
Asp mon	Asplenium montanum		Cephaloziella obtusilobula		Arctoparmelia incurva
Des fle	Deschampsia flexuosa		Dicranodontium denudatum	Can tex	Canoparmelia texana
Gal aph	Galax aphyla		Dicranum flagellare	Chr chl	Chrysothrix chlorina
Gay bac	Gaylusaccia bacatta		Dicranum scoparium		Cladina mitis
	Hamammelis virginiana		Dicranium spurium		Cladonia didyma
Kal lat	Kalmia latifolia		Entodon brevisitus		Cladonia macilenta
Nys syl	Nyssa sylvatica		Hedwigia ciliata	Cla str	Cladonia strepsilis
Par arg	Paronychia argyrocoma		Odontoschisma prostratum	Cla poc	Cladonia pocillum
Rho cat	Rhododendron catawbiense				Cladonia polydactyla
Sas alb	Sassafras albidum			Cla rob	Cladonia robbinsii
Smi rot	Smilax rotundifolia				Dibaeis baeomyces
Vac cor	Vaccinium corymbosum			Dim ore	Dimelaena oreina
	Vaccinium pallidum			Dir aeg	Dirinaria aegialita
				Fla bal	Flavoparmelia baltimorensis
					Flavoparmelia caperata
					Fuscidea recensa
				Hyp cro	Hypotrachyna croceopustulata
				Las pap	Lasallia papulosa
				Las pen	Lasallia pensylvanica
				Lec rup	Lecanora rupicola
					Lecidea tessellata
				Lec tes	Lecidea testulata
				Lec sti	Lecidella stigmatea
					Lepraria lobificans
					Lepraria neglecta
					Leproloma membranaceum
					Melanelia culbersonii
				Par ala	Paraparmelia alabamensis
					Parmelinopsis minarum
				Per pli	Pertusaria plittiana
				Per tex	Pertusaria texana
					Phaeophysica hispidula
					Phaeophysica insignis
					Phaeophysica pusilloides
					Physica halei
					Physica subtilis
				Pla gla	Platismatia glauca
					Pseudevernia consocians
					Punctelia subrudecta
				Umb car	Umbilicaria caroliniana
				Umb mam	Umbilicaria mammulata
					Umbilicaria torrefacta
				Usn amb	Usnea amblyoclada
				Usn hal	Usnea halei
				Xan cons	Xanthoparmelia conspersa
				Xan som	Xanthoparmelia somloensis
				Xan wyo	Xanthoparmelia wyomingica

Appendix B

White Rocks Outcrop Ecological Study

Appendix B



GIS Data for the White Rocks Study

Data Explanation and Simple Usage Instructions

The GIS data for the White Rocks ASU study are stored in a geodatabase named **White_Rocks_ASU_Study.mdb**. The file looks like a .mdb file in windows explorer, but when viewed in ArcGIS, it reads as a geodatabse, which is the latest data model for storing GIS data. Inside the geodatabase is a feature class (shapefile) and two feature datasets. Inside each dataset (Biological, Physical) are more feature classes. Think of a geodatabase as a filing cabinet, with the feature datasets being the drawers and the feature classes being the folders.

The main file inside the geodatabse is the *Transects* feature class. This feature class contains all information about each transect, including:
Transect number (TRANSECT)
Total number of plots for that transect (TLT_PLOTS)

A column for each of the 39 vegetation types sampled, and marked present or absent with a yes or no
Total number of vasculars for that transect (TLT_VSCLRS)
Total number of bryophytes for that transect (TLT_BRYPHY)
Total number of lichens for that transect (TLT_LCHNS)
Total vegetation for that transect (TLT_VEG)

The Biological feature dataset contains three feature classes:
Maianthemum_canadense
Paronychia_argyrocoma
Minuartia_glabra

The Physical feature dataset contains five feature classes:
Big_Outcropping
Cliff_Edge
Outcropping
Seep
Vernal_Pool

To view the GIS data in ArcMap (any version), follow the following steps:

Save the White_Rocks_ASU_Study.mdb to a local drive

Open a blank ArcMap document

Use the add data button to add in the data layers stored in the geodatabase (you may have to connect to the drive containing the .mdb file)
Browse to the folder containing the geodatabase and double click on it (it should look like a can)
The Transects feature class will appear just inside
You will have to double click again on the feature datasets to open up the feature classes stored inside of them

To access the data stored in the Transects feature class, use the identify tool. You can perform queries on this file. You can also view its attribute table by right-clicking on the file in the table of contents.

The data contained in this geodatabse were collected using a Trimble GeoXT unit with ArcPad software on May 24th, 2006. The data was post-processed using Trimble's Pathfinder Office software. All data were collected in WGS 1984 coordinates, then reprojected to NAD 1983 UTM Zone 17 to match data that was originally received from the NPS.

Appendix C

Vascular Species only CCA: Eigenvalues of Enivronmental Variables

Appendix C Vascular species only CCA eigenvalues of the measured environmental variables, axes 1, 2, and 3.

Variable	*Axis 1*	*Axis 2*	*Axis 3*
Top	-0.1915	0.0750	-0.0903
Face	0.3974	0.2778	0.1547
Talus	-0.2950	-0.4427	-0.0971
Asp nor	0.0849	-0.0165	-0.0636
Asp eas	0.2092	-0.2574	-0.0707
Slope	0.3025	0.3563	0.2341
Led Fre	-0.0008	0.4769	0.0563
Cra Fre	0.0031	0.2949	0.2998
Poc Fre	0.0648	0.1802	0.1869
Fea Fre	0.0125	0.5510	0.1983
MLA	-0.2220	0.1114	0.0680
MCV	0.1782	0.3088	0.0312
MPV	0.0847	0.2109	-0.1088
TSV	0.3209	-0.1622	-0.1003
TFA	-0.2225	0.1766	0.0794
CQA	-0.0587	0.0521	0.0461
MGQA	-0.0080	0.2809	0.0833
CMQAWHC	0.1038	0.0291	0.0542
CMQA	-0.1246	0.3284	0.1563
FGQA	-0.0474	0.0137	0.0009
FMQA	-0.0399	0.0115	0.0007
QPC	0.1668	-0.0144	0.3974

Appendix D
Abbreviations for Measured Environmental Variables

Appendix D Abbreviations for Measured Environmental Variables.

Environmental Variable	*Abbreviation*
Plot Location – Cliff Top	Top
Plot Location – Cliff Face	Face
Plot Location – Cliff Base	Talus
Aspect Northness	Asp Nor
Aspect Eastness	Asp Eas
Plot Slope	Slope
Plot Ledge Frequency	Led Fre
Plot Crack Frequent	Cra Fre
Plot Pocket Frequency	Poc Fre
Plot Total Feature Frequency	Fea Fre
Plot Mean Ledge Area	MLA
Plot Mean Crack Volume	MCV
Plot Mean Pocket Volume	MPV
Plot Total Soil Volume	TSV
Plot Total Feature Area	TFA
Conglomerated Quartz Arenite	CQA
Medium Grain Quartz Arenite	MGQA
Conglomerated Medium Grain Quartz Arenite with Hematite Concretions	CMQAWHC
Conglomerated Medium Grain Quartz Arenite	CMQA
Fine to Medium Grain Quartz Arenite	FMQA
Fine Grain Quartz Arenite	FGQA
Quartz Pebble Conglomerate	QPC

BIOGRAPHICAL SKETCH

David Ballinger earned his Bachelor of Science Degree in Biology from Salisbury University, located on Maryland's eastern shore. Upon graduating, David relocated to Boone, North Carolina and began work on a federally funded grant examining the vegetative community of the White Rocks cliff system. This work became his graduate research in the fall of 2005 when he started his graduate career at Appalachian State University, in Boone, North Carolina.