CHARACTERIZATION OF PLANT COMMUNITY STRUCTURE AND ABIOTIC CONDITIONS ON CLIMBED AND UNCLIMBED CLIFF FACES IN THE OBED RIVER GORGE

A Thesis

By

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ABSTRACT

CHARACTERIZATION OF PLANT COMMUNITY STRUCTURE

AND ABIOTIC CONDITIONS ON CLIMBED AND UNCLIMBED

CLIFF FACES IN THE OBED RIVER GORGE. (May 2009)

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The Obed River Gorge in Tennessee boasts one of the richest floras in the southeastern United States and is also a popular rock climbing destination. Many rare or endemic species have been found on cliff faces around the world, but the majority of the world's cliff ecosystems remain unexplored by biologists and little is known about ecosystem processes on cliffs. There is a growing concern that biodiversity on cliffs may be threatened by impacts from recreational rock climbing, and several recent studies have validated this concern. Vascular plants, bryophytes, and lichens were sampled on cliff faces, cliff edges and on talus slopes along 16 climbed and 16 unclimbed transects in six different cliff areas of the Obed River Gorge and its tributary, Clear Creek. Cliff-face flora was sampled from pairs of 1 m^2 plots located at three meter intervals along the transect. Unclimbed transects were paired with, and adjacent to, climbed transects. Abiotic factors including aspect, slope, surface heterogeneity, vertical position, and level

of disturbance were recorded for each pair of plots. Canonical Correspondence Analysis (CCA) was performed to determine the relative importance of each of these abiotic factors, as well as the impact of rock climbing, in shaping the cliff-face plant communities of the Obed River cliffs.

Habitat and site were the most important variables accounting for variation in the vegetation. Results indicate some impacts of foot traffic in the talus slopes of climbed areas on vascular and non-vascular species, and on cliff-face vegetation at the Y12 site. Analysis of Variance (ANOVA) was performed on all species to assess habitat preferences, and Duncan's Multiple Range Test was performed to determine if cover varied among habitat types for each species. Several species had significantly higher cover in certain habitats and were completely excluded from others. In addition, preliminary sectioning of a *Juniperus virginiana* snag in the talus slopes yielded 863 annual rings.

The vegetative composition, abiotic conditions, and influence of climbing disturbance were highly variable among the six sites sampled within the Obed River Gorge, which contrasts with previous studies of cliff vegetation and climbing impacts. Based on these results, it is suggested that the various sites be managed individually and that climbing management policies should be applied on a site by site basis.

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INTRODUCTION

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

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

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

Such relict plant populations may represent genetic reservoirs. Disjunct populations are typically thought to have less genetic variation than their main range counterparts, due to genetic bottleneck effect and inbreeding depression. However, some northern disjunct plant and animal populations in the southern Appalachians, including *Thuja occidentalis* and Northern Saw-whet Owls (*Aegolius acadicus*), were found to have far greater genetic variability than the populations sampled in the glaciated main range (Walker 1987; Tamishiro 1996). In the case of *T. occidentalis* in the southern Appalachians, long-lived, asexually reproducing populations may have preserved a diversity of alleles, while inbreeding in sexually reproducing populations that migrated north following glacial retreat resulted in a loss of diversity through founder effect. This is supported by the greater genetic diversity observed in southern Appalachian *T. occidentalis* populations compared to those of the Niagara Escarpment (Walker 1987). Southern Appalachian cliff-face populations may, therefore, be important reservoirs of genetic diversity for many northern plant species, which may allow these species to better adapt to future climate changes or exotic diseases (Davis and Shaw 2001; Jump and Penuelas 2005; Hammond-Kosack and Jones 1996).

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

It is important to recognize that a number of abiotic site factors are involved in organizing the vegetative communities on cliffs and any study of climbing impacts must also take these factors into account. Several studies have attempted to identify which physical factors influence the distribution of vegetation on cliff-faces in the southern Appalachians and on cliffs in general. The relative influence of such factors can be difficult to tease apart in field studies, because many are interrelated. Researchers have investigated the influences of light, moisture, temperature, bedrock composition, soil characteristics, surface heterogeneities of the face, vertical position on the face, aspect, slope, and latitude in attempts to understand which abiotic factors or combinations of factors account for the patterns observed in cliff-face vegetation (Yarranton and Green

1966; Larson et al. 1989; Coates and Kirkpatrick 1992; Wiser et al. 1996; Smith 1998; Larson et al. 2000b; Ballinger 2007). Several studies have demonstrated that physical factors vary greatly on a microsite scale on cliff faces and other rock outcrops, resulting in widely varying habitat conditions across short distances (Hora 1947; Wiser et al. 1996; Kuntz and Larson 2006).

Aspect

Aspect is thought to influence the distribution of mountain and cliff-face vegetation. Some studies have demonstrated that north-facing and south-facing cliffs have marked differences in species composition (Ursic et al. 1997; Walker 1987, Larson et al. 2000b) and in overall vegetative cover (Ashton and Webb 1977). These variations are probably related to differences in light, temperature, and moisture. North-facing cliffs receive about half the amount of direct radiation as south-facing cliffs annually (Larson et al. 2000). Species that prefer cool, moist conditions seem to have an affinity for north-facing cliffs. This is especially noticeable in the southern latitudes where north-facing slopes create microclimates more similar to those of higher latitude environments (Walker 1987). Studies of the Niagara Escarpment in Ontario, Canada found no relationship between cliff aspect and the distribution, age, or size of *Thuja occidentalis* (Larson et al. 2000b), whereas Walker (1987) found a significant difference in growth rate between *T. occidentalis* on north- and on south-facing cliffs in the southern Appalachian mountains. A similar pattern occurs for *Tilia cordata* P. Miller in France, where it is restricted to north-facing cliffs in the southern part of its range, but does not have an affinity for a particular aspect in the central and northern parts of its range (Pigott and Pigott 1993). *Tilia cordata* may be escaping the stress imposed by higher irradiance, lower moisture availability , and higher evapotranspiration rates in the south by colonizing north-facing cliffs .

Slope

While there is no critical angle that delineates cliff faces from other topographical features, climbers often describe a face as a surface with at least three points of contact required for humans to stabilize themselves. Slope angles of cliffs may range from the 180° surface of an overhang to a vertical 90° wall. Slopes less than 90° are usually not considered cliffs (Larson 2000), though some sport climbing routes occur on slopes slightly less than 90°. These routes are sometimes referred to as 'slab' routes. Cliffs with slopes greater than 90° are likely to be drier and shadier than vertical or less than vertical cliffs.

Soils

Due to the vertical nature of the cliff-face environment, soils are largely absent except where they accumulate in thin pockets in cracks, crevices, and on ledges. Several studies of cliffs and high-elevation rock outcrops have demonstrated correlations between soil depth or soil volume and vascular plant cover (Coates and Kirkpatrick 1992; Wiser et al. 1996; Kuntz and Larson 2006).

Surface Heterogeneity

The influence of soil availability suggests a significant relationship between the surface heterogeneities of the vertical cliff face (where soils accumulate) and the distribution of vegetation. Surface heterogeneities may result from differences in rock strength, differential rates of heating and cooling, sedimentation patterns, and mechanical shifting due to seismic activity (Larson et al. 2000b).

Ursic et al. (1997) demonstrated that the presence of ledges on the vertical walls of abandoned quarries significantly increased plant-species richness. A study of sandstone cliffs in Tasmania found cliff vegetation formed colonies in pockets and along joint crevices, but was absent from dry, smooth faces (Coates and Kirkpatrick 1992). Another study of steeply sloping granite outcrops at Wilson's Promontory in Victoria, Australia found that establishment of woody vegetation was strongly associated with rock joints (Ashton and Webb 1977).

Moisture

Moisture gradients have highly significant impacts on plant community composition and distribution in most habitats. Moisture availability on cliffs is determined by a number of other factors, including climate, the presence of perennial seeps, surface heterogeneities of the rock, and exposure and incident radiation, which in turn influence evaporative rates. A floristic study of the Fiery Gizzard Gorges on the Cumberland Plateau in Tennessee revealed that wet and dry sandstone bluffs have distinct species of plant assemblages that are significantly different from one another

(Clark 1966). It has been suggested that the increased surface temperature and windy conditions on exposed rocks increase evaporative rates, resulting in dry conditions and a strong selection for desiccation-tolerant species (Phillips 1982). Other researchers have suggested that cliff habitats actually buffer plants from drought because they retain moisture in deep cracks in the rock (Kelly et al. 1994); however, that moisture may only be available for woody species.

Vertical Zonation

The lower portions of vertical cliff faces, particularly those in narrow river gorges, are less exposed, and are therefore likely to experience different wind, temperature, and moisture regimes than cliff-face habitats near the top edge. A study of cliff-face plant and lichen communities in Linville Gorge Wilderness Area found a significant difference in species composition between the upper and lower reaches of the cliff faces, with shifts in community composition along a vertical gradient (Smith 1998). Light levels, in combination with other physical gradients, may also account for the vertical zonation of vegetation observed in some cliff systems (Smith 1998; Yarranton and Green 1966). On cliff faces and abandoned quarry walls surrounded by forest, the canopy beyond the talus shades the lower cliff-face, resulting in a community shift to shade-tolerant plants near the base (Ursic et al. 1997).

Light

A few studies have investigated light as a driving factor influencing the distribution of vegetation on cliffs. Many plant species thrive in shady habitats, whereas others are adapted to and require full sun. Across the mostly forested landscapes of the southern Appalachian Mountains, cliffs and other rock outcrops may be some of the few pristine habitats with high light levels. Baskin and Baskin (1988) found that among edaphic, genetic, and light factors, a requirement for high light levels was the most important characteristic common to endemic rock outcrop species in the eastern United States. Light levels on vertical cliffs are influenced by a number of factors, including aspect, slope, time of day, time of year, and exposure, and may vary widely among microsites in close proximity. Variation in light levels among microsites on cliff-faces has been shown to correlate with the presence or absence of certain plant species (Coates and Kirkpatrick 1992).

Previous Studies of Rock-Climbing Impacts on Vegetation

Until recently cliff faces have been relatively undisturbed by humans other than for mining operations. But in the past few decades rock climbing has become a popular sport throughout the western world. Several studies of the impacts of rock climbing on cliff-face vegetation have been conducted in the last decade (McMillan and Larson 2002, Smith 1998, Camp and Knight 1998, Larson and Kelly 1997, Nuzzo 1995). In each study climbing has been described as having a detrimental effect on cliff-face vegetation to varying extents. The types of impacts observed have included a reduction of vegetative cover, shifts in lichen community composition, the local extirpation of species sensitive to disturbance, and skewed size and age distributions of some vascular plants. Few of these studies have considered the impact of the physical environment on species composition. For example, Nuzzo (1995) was criticized for not considering the impact of overhangs on cliff-face vegetation with regard to rock-climbing disturbance (Larson 2000b).

In this study, I attempted to characterize the vegetative communities and the abiotic conditions affecting their distribution among the cliff habitats of the Obed National Wild and Scenic River Park, and to assess the impacts of recreational rock climbing there.

Park Description and Rock Climbing History

Recognized for its free-flowing condition, rugged terrain, and pristine waters, the Obed River was included in the Wild and Scenic Rivers System in 1976 and established as a unit of the National Park Service. The Obed is one of only nine Wild and Scenic Rivers authorized in the Southeastern United States. It flows over 45 miles through some of the most rugged and undeveloped terrain in eastern Tennessee. It offers a vast array of both cultural and natural resources. A complex network of streams drain the Park and adjacent lands supporting diverse flora and fauna, as well as providing numerous recreational opportunities including hiking, backpacking, fishing, white-water paddling, and rock climbing.

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

Geomorphology of the Cumberland Plateau

The Obed River flows across the Cumberland Plateau in east Tennessee. The Cumberland Plateau is a physiographic province of the southern Appalachian region that lies east of the eastern Highland Rim and west of the Ridge and Valley physiographic provinces. It is a broad upland that extends northeast from its Tennessee portion across Kentucky and into West Virginia and Pennsylvania where it is known as the Allegheny Plateau, and to the southwest into Alabama. The Cumberland Plateau of Tennessee is the southern extension of the Appalachian Plateaus Province (Fenneman 1938). In Tennessee it is recognized as a true tableland, with gently sloping uplands throughout most of its extent. It its Tennessee portion it averages 55 to 65 km in breadth with upland elevations from 460 m above mean sea level near Kentucky to nearly 610 m above mean sea level in the south. The two large river systems of the Plateau are the Clear Fork-Big South Fork drainages of the Cumberland River basin and the Obed-Emory, which exhibit similar morphologies. Unlike many stream channels these systems flow in shallow gorges in their upper reaches and are increasingly entrenched downstream. The lower reaches of these rivers have cut down 90 to 120 m below the surface of the Plateau. Much of this vertical depth is accounted for by bluffs, which comprise up to 30 m of the basin depth. While the larger tributaries join the stream at grade, the smaller ones often enter as waterfalls and seeps (Mayfield 1984). The bluffs of these two river systems are attractive as rock-climbing destinations, particularly in the Obed-Emory basin.

Geology of the Emory Basin

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

Hydrology of the Obed Basin

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

Soils of the Obed-Emory Basin

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

Climate of the Obed-Emory Basin

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

Previous Floristic Studies

The areas within the southern extent of the Cumberland Plateau of Tennessee have been the subject of several floristic studies including Fall Creek Falls State Park (Caplenor 1955, Bowman 2003, Fleming and Wofford 2004), Fiery Gizzard Gorge (Clark 1966), Savage Gulf Natural Area (Wofford et al, 1979), Frozen Head State Natural Area (Holtzclaw 1977), and several areas in the Upper Cumberland River Basin (Patrick 1979). The vegetation of Cumberland Plateau sandstone outcrops has been studied in detail by Perkins (1981).

Limited studies of the vegetational communities in the Obed have been completed (Schmalzer and DeSelm 1982, Schmalzer et al. 1985, Schmalzer 1989). Within the Obed River gorge Schmalzer et al. (1985) reported 734 vascular plant taxa within 393 genera and 122 families. Asteraceae was the most highly represented family, with 102 taxa, followed by Poaceae with 82 taxa. They also reported 59 introduced taxa that comprised eight percent of the total species list. Sixteen taxa reported from that study were on the Tennessee list of rare plants (Tennessee Natural Heritage Program 1982) or have been proposed for Federal listing (U.S. Dept. of the Interior 1980). One species of grass collected, *Sporobolus junceus* (Palisot de Beauvois) Kunth, was a state record for Tennessee (Patrick et al. 1983). Among those species listed as of special concern or threatened in the Schmalzer study are *Adlumia fungosa* (Aiton) Greene ex Britton, Sterns, & Poggenburg and *Polymnia laevigata* Beadle, each from single populations found in boulder fields along the Obed River, and *Phemeranthus teretifolius* (Pursh) Rafinesque, from a sandstone outcrop above Clear Creek. The relevance of the presence of these species for the present study is that they are in areas that could potentially be subject to impacts by rock-climbing activities. Although they included descriptions of some of the boulder field, cliff edge, and talus vegetation, these studies did not systematically sample the cliff-face vegetation of the Obed Gorge.

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

Obed Natural Communities

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

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

Semple, *Bromus pubescens* Muhlenberg ex Willdenow, and *Agrostis perennans* (Walter) Tuckerman.

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

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

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

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

Old-Growth Cliff-Dwelling Trees at the Obed

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

Purpose of Study

The purpose of the current study was: 1) to characterize the vegetative communities of the cliff-edge, cliff-face, and talus habitats of the six distinct climbing areas within the Obed National Wild and Scenic River Park; 2) to determine which physical factors are influencing the distribution of the vegetation in and among the cliff habitats of the Park; 3) to assess whether and to what extent recreational rock climbing is having a detrimental impact on cliff vegetation there; and 4) to provide resource managers with the information necessary to make sound decisions regarding rock-climbing management.

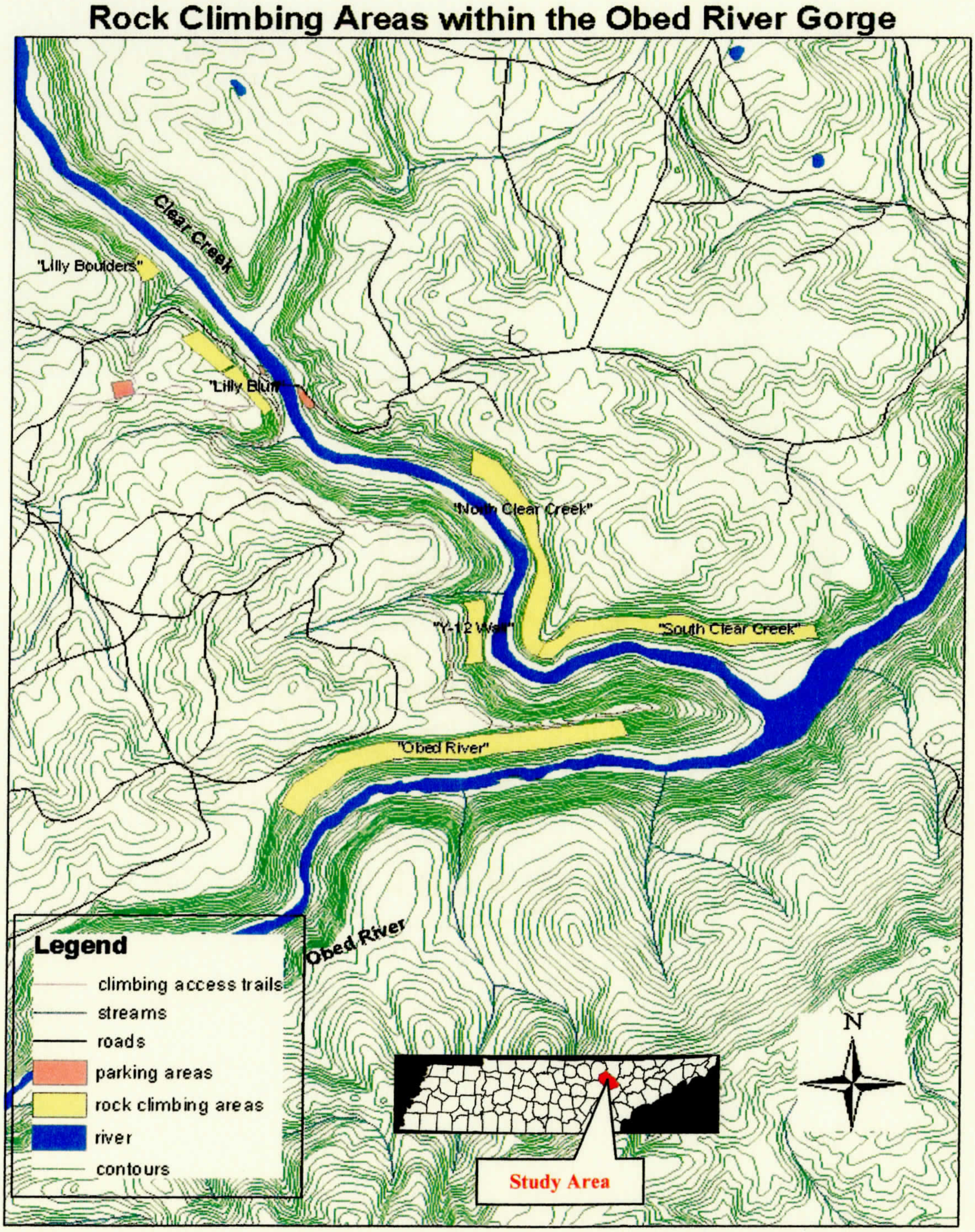


Figure 1. Map of the study area, including the six climbing sites sampled in the Obed National Wild and Scenic River Park, Morgan County, Tennessee

The North and South Clear Creek climbing areas are located on the north-east side of Clear Creek, which is accessed via a privately-owned parking area and trailhead off Doc Howard Road. The portion of the cliff band that is designated North Clear Creek lies north of a prominent oxbow in the creek, and the portion below the oxbow is designated South Clear Creek. These cliffs are south or south-west facing and are an average of 30m high. The surrounding forest may be described as xeric upland oak forest or oak-pine forest, including *Q. alba*, *Q. coccinea,* and *P. virginiana* (Schmalzer et al. 1985).

The Y12 Wall is located on the south-west side of Clear Creek, directly across the creek from the point between the North and South Clear Creek climbing areas. The Y12 area is accessed from the Lilly Bluff overlook parking area via the Point Trail and rope ladders leading from the plateau down to the talus. This steep, north-facing section of cliff band is perennially shady and moist. This area is characterized by mesic deciduous forest and hemlock forest.

The Obed Wall climbing area is located in the Obed River Gorge on the north side of the river, just above the confluence of the Obed River and Clear Creek. It is the most remote of all the areas in the study. This south-facing cliff line, which is approximately 20 to 30 m tall, is surrounded by xeric oak and oak-pine forests.

A climbing guidebook (Watford 1999) was used to assign numbers to all the routes in each of the six climbing areas described above, and a random number table was used to choose three climbing routes from each site. For each climbed transect chosen, an unclimbed transect was designated directly adjacent to it and marked with biodegradable lawn paint, for a total of 36 transects among all the areas. Due to time constraints at the end of the growing season, the North and South Clear Creek sites were combined and only four transects were sampled (two climbed, two unclimbed at North Clear Creek and one climbed and one unclimbed at South Clear Creek). In addition, only four transects were sampled at the Y12 Wall (two climbed and two unclimbed).

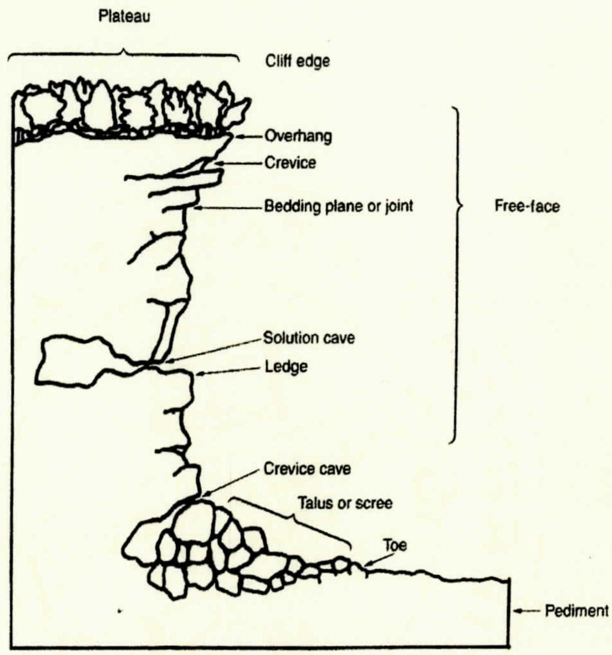


Figure 2. Diagram of a cliff system (Larson et al. 2000)

Using the rappel rope as the center line, a 1 m² quadrat was sampled on each side of the rope (one plot to the left of the rope and one to the right of the rope, labeled A and B, respectively), at three meter intervals along the face of the cliff, as well as in the talus and on the top edge (plateau) (Figure 2). The number of face plots (those located along the vertical portion of each transect) sampled varied with the height of the cliffs. The quadrat was constructed of 1.25 cm PVC pipe and nylon twine. The nylon twine was threaded through holes drilled in the pipe so that it formed a five-by-five grid of 20 cm subplots within the quadrat, each of which represented four percent of the area of the quadrat. The talus was always sampled using two pairs of plots; one pair was located directly adjacent to the cliff face at the base of the cliff and the second pair was located between 4m and 5m away from the cliff base. The cliff edge (plateau) was sampled in a similar manner, with a pair of plots located on the edge of the plateau, directly adjacent to the top of the cliff face, and another pair between four and five meters straight back from the edge. Each of these were labeled A (left of transect) and B (right of transect).

Sixty meter rock climbing ropes were used in conjunction with climbing harnesses, grigris, webbing, carabiners, quickdraws, 'frogs', and helmets to access the cliff faces. In some cases the system was secured to an anchor on the plateau, such as a large tree, and the cliff face was accessed by rappelling down from the top. In areas where access to the plateau was difficult, the system was set up from the talus area. In these instances an experienced climber climbed the cliff face and either placed the rope along the climbing route using quickdraws, which were clipped to the bolts in the rock, or, in the case of an unclimbed transect, placed traditional climbing protection pieces called cams, along with quickdraws, as they ascended the cliff. A grigri was used as a braking system when rappelling down from the tops of the cliffs, and an ascender (also called a Jumar) was used to move up the rope from the bases of the cliffs. 'Frogs', a relatively new type of protection used in traditional climbing, were attached to a 2m pole and used in areas where the cliff face was overhung in order to pull the researcher closer in to the face. In addition, an extra rope was secured to an anchor and attached to the researcher as a safety line. All sampling equipment was attached to the researcher's climbing harness with carabiners.

In each plot, each species present was described and the percent of the plot that it covered was recorded. Species that covered less than one percent of the plot were recorded as less than one percent. In addition, environmental data including aspect, slope, surface heterogeneity of the rock face, presence or absence of temporary or perennial seeps, presence or absence of overhanging roofs, categorical estimate of visibly evident disturbance (chalk, trampling, soil compaction, etc.), and cliff habitat type (edge, face, or talus) were recorded for each plot.

Aspect was determined for each plot by taking a compass bearing, recorded in degrees between 0 and 359, facing away from the cliff face. Aspect was then converted to a northness component and an eastness component using the following equations: northness = cosine((aspect° * Π)/180); eastness = sine ((aspect° * Π)/180).

Slope was visually assessed for each plot and classified as one of three categories; slopes that appeared to be approximately 90° were recorded as 'vertical', slopes that were less than 90° were recorded as 'less than vertical', and slopes that were greater than 90° were recorded as 'more than vertical'.

The surface heterogeneity of each plot was visually rated on a scale of 1 to 5. The value of 1 was assigned to a plot whose surface was virtually smooth. Plots whose surface consisted of cracks or crevices over 1 to 25 percent of their extent were given a value of 2. Plots whose surface consisted of cracks or crevices over 25 to 50 percent of their extent were given a value of 3. Those with cracks or crevices composing 50 to 75 percent of their extent were assigned a value of 4, and any plots with a substantial ledge taking up the majority of their area were given a value of 5. Seeps and overhanging roofs were included in the sampling by simply noting their presence or absence in each plot.

The level of anthropogenic disturbance was recorded for each plot by visual estimation, based on the presence and relative extent of trampled vegetation, compact soils, chalk, and campfire scars. Each plot was assigned one of four disturbance categories: none, low, moderate, or high.

Each plot was labeled as climbed or unclimbed, depending on whether it fell within an established climbing route. Some top edge plots occurring along a climbed transect were designated as unclimbed since they were above the top anchor of the route, where sport climbers typically complete a climb and rappel back down.

The vertical positions of face plots were recorded by numbering them from the base of the cliff face to the top of the face, with the first set of plots at the base always numbered 1a and 1b. In other words, the higher the plot number for each transect, the higher its vertical position on the face was.

Samples of each vascular plant, bryophyte, and lichen species that occurred in a plot were collected in the field and placed in a plant press (vascular plants) or a paper bag (bryophytes and lichens). All specimens were dried in a drying cabinet for one week. Vascular plants were identified using the nomenclature of Weakley (2007) and by consulting specimens in the vascular plant herbarium at Appalachian State University. Moss and liverwort identification was performed by Keith Bowman according to the nomenclature of Stotler and Crandall-Stotler (1977) and Anderson et al. (1990). Lichen specimens were identified by Karen Ritchie according to the nomenclature of Kirk et al. (2003).

All data were entered into an Excel spreadsheet. Detrended Correspondence Analysis (DCA) was performed, followed by Canonical Correspondence Analysis

(CCA), by Dr. Uta Matthes, using CANOCO™ version 4.5 software (Microcomputer Power, Ithaca, NY). Analyses were performed on the entire data set as a whole (referred to as the large data set) on each of the face, edge, and talus data sets alone, and on each of the six sites separately. Subsequently, Analysis of Variance (ANOVA) was performed using SAS© statistical software to assess species' habitat preferences (SAS Institute, Cary, NC). ANOVA was performed on all species to determine whether there were significant differences in percent cover between areas with and without an overhanging roof, and whether there were significant differences in percent cover between habitat types (edge, face, talus). Duncan's Multiple Range Test was then performed to determine whether there were significant differences in percent cover among habitat types for each species. Significance was assumed for all p-values <0.05.

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

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

RESULTS

CCA of Large Data Set

Habitat was the most important variable accounting for variation in the vegetation, with the edge habitat having the most unique community assemblage (Table 1). Site was the next most important variable included in the analysis, followed by the presence of a roof. Disturbance and climbing were marginally significant. The presence of a seep was insignificant.

Table 1. P Values and F Values for Site, Habitat, and Environmental Variables and for Climbing for the CCA of the Large Data Set

Variable	*p*	*F*
Edge	0.002	7.81
SCC	0.002	5.08
OBE	0.002	5.01
Roof	0.002	4.94
Face	0.002	3.80
LBO	0.002	3.19
LBL	0.002	3.57
NCC	0.002	2.67
Disturbance	0.002	1.95
Seep	0.130	1.40
Climbing	0.030	1.31

CCA of Face Data Set

Site, the presence of a roof, vertical position, and the north-south component of aspect were all statistically significant variables organizing the cliff-face vegetation (Table 2).Of the six sites that were sampled, the South Clear Creek site had the most unique community assemblage. Climbing, disturbance, the east-west component of aspect, the presence of a seep, slope, and surface heterogeneity were all insignificant for the cliff faces.

Because site differences were the most important factor accounting for variation in the vegetation on the cliff faces, a second run of the CCA was performed on the face data set, in which sites were defined as covariables. This allowed us to answer the question, 'Once differences among sites are accounted for, how much of the remaining variation in the vegetation can be determined for by the variables measured?' For the

Table 2. P Values and F Values for Site, Habitat, and Environmental Variables for the CCA of the Cliff-face Data Set, Run 1 (Run 1)

Variable	*P*	*F*
SCC	0.002	7.99
Roof	0.002	6.29
OBE	0.002	5.71
Y12	0.002	4.39
Position	0.002	4.39
Northness	0.002	3.45
LBL	0.002	3.45
LBO	0.002	2.95

Table 3. P Values and F Values for Habitat and Environmental Variables for Climbing for the CCA of the Face Data Set, Run 2 (with site defined as a covariable)

Variable	*P*	*F*
Northness	0.002	5.62
Position	0.002	3.50
Roof	0.008	3.53
Eastness	0.002	3.48
Seep	0.150	1.56
Slope	0.022	1.48
Climbing	0.326	0.96
Disturbance	0.462	0.93
Surface het.	0.602	0.80

second run, the north-south component of aspect, vertical position, the presence of a roof, the east-west component of aspect, and slope were all significant (Table 3). Climbing, disturbance, the presence of a seep, and surface heterogeneity were all insignificant. However, it is important to note that the eigenvalues (Table 4) were much lower for the second run, meaning that once variation among sites is removed from the analysis, the remaining variables have relatively less influence on the distribution of vegetation.

Table 4. Eigenvalues for the four axes of each DCA and CCA Analysis

		Eigenvalues			
Group	*Analysis Type*	*axis 1*	*axis 2*	*axis 3*	*axis 4*
Large data set	DCA	0.881	0.754	0.646	0.531
	CCA	0.841	0.685	0.525	0.422
Face data set	DCA	0.956	0.791	0.617	0.594
	CCA	0.812	0.563	0.506	*
	CCA, site as covariable	0.452	0.422	0.228	0.214
Face vascular plants	CCA	0.918	0.894	0.741	0.576
Face bryophytes	CCA	0.923	0.870	0.787	0.681
Face lichens	CCA	0.810	0.535	0.492	0.378
Edge data set	DCA	0.858	0.743	0.564	0.451
	CCA	0.636	0.517	0.430	0.390
	CCA, site as covariable	0.321	0.203	0.163	0.937
Talus data set	DCA	0.971	0.887	0.807	0.704
	CCA	0.957	0.895	0.884	0.840
	CCA, site as covariable	0.659	0.529	0.470	0.000
Lilly Bluffs	DCA	0.908	0.562	0.245	0.142
	CCA	0.289	0.197	0.143	0.091
Lilly Boulders	DCA	0.387	0.146	0.074	0.042
	CCA	0.152	0.123	0.076	0.034
North Clear Creek	DCA	0.980	0.833	0.136	0.068
	CCA	0.818	0.533	0.099	0.039
South Clear Creek	DCA	0.844	0.704	0.182	0.150
	CCA	0.576	0.522	0.244	0.186
Obed Wall	DCA	0.925	0.742	0.565	0.236
	CCA	0.626	0.459	0.390	0.115
Y12	DCA	0.922	0.633	0.312	0.126
	CCA	0.657	0.359	0.162	0.087

*missing data point

CCA of Face Data Set – Vascular Plants Only

Climbing and disturbance were insignificant variables for cliff-face vascular plants. The north-south and east-west components of aspect were the most important variables influencing the distribution of vascular plants on the cliff faces, followed by site differences (Table 5). Several variables were omitted due to negligible variance. These include roof, the Lilly Boulders site (LBO), and the North Clear Creek site (NCC). This is because there were no vascular plants on the cliff faces beneath roofs or on the cliff faces sampled at Lilly Boulders and North Clear Creek.

Table 5. P Values and F Values for Site, Habitat, and Environmental Variables and for Climbing for the CCA of the Face Vascular Plant Data

Variable	*P*	*F*
Northness	0.002	2.84
Eastness	0.002	2.29
Slope	0.076	2.07
SCC	0.028	1.85
OBE	0.008	1.87
LBL	0.092	1.86
Disturbance	0.070	1.78
Position	0.132	1.42
Climbing	0.366	1.07
Seep	0.446	1.03
Surface het.	0.442	1.06

CCA of Face Data Set – Bryophytes Only

Climbing was not a significant influence on bryophyte distribution on the cliff faces. Site, both the north-south component and the east-west component of aspect, disturbance, slope, surface heterogeneity, the presence of a seep, and vertical position on the face were all statistically significant variables organizing the bryophyte communities on the cliff faces (Table 6). The Y12 site had the most unique assemblage of bryophyte species, followed by the Lilly Boulders site.

Table 6. P Values and F Values for Site, Habitat, and Environmental Variables and for Climbing for the CCA of the Face Bryophyte Data Set

Variable	*P*	*F*
Y12	0.002	6.1
Northness	0.002	5.6
LBO	0.002	5.77
Disturbance	0.004	3.48
OBE	0.018	2.56
Slope	0.008	2.12
Surface het.	0.016	1.96
LBL	0.044	1.9
Eastness	0.004	2.86
Seep	0.002	3.32
Position	0.016	1.95
Climbing	0.358	1.06
NCC	0.974	0.26

Table 7. P Values and F Values for Site, Habitat, Environmental Variables and for Climbing for the CCA of Face Lichen Data Set

Variable	*P*	*F*
SCC	0.002	15.53
Roof	0.002	12.65
OBE	0.002	10.36
Position	0.002	9.69
Y12	0.002	8.27
Northness	0.002	5.72
LBL	0.002	5.53
LBO	0.002	4.27
Slope	0.042	2.11

CCA of Face Data Set – Lichens Only

Climbing had a statistically significant influence on cliff-face lichen cover (Table 7). Disturbance, however, was insignificant. Site, the presence of a roof, vertical position on the face, and the north-south component of aspect were all significant variables influencing lichen distribution on the cliff faces. Slope was marginally significant. The presence of a seep, the east-west component of aspect, and surface heterogeneity were all insignificant for cliff-face lichens.

CCA of Edge Data Set

Climbing was statistically insignificant for the top edges of the cliffs sampled (Table 8). Disturbance, however, was a significant factor accounting for variation in edge vegetation distribution. Site was the most important variable accounting for differences in edge vegetation, with the Obed Wall site (OBE) having the most unique species composition. The presence of a seep was insignificant. Eigenvalues for this analysis were slightly lower than those for the other data sets, meaning that less of the variation in edge vegetation can be explained by the variables measured. A second run of the CCA of edge data was conducted, with sites defined as covariables. Once variation among sites was accounted for, disturbance and the presence of a seep were the most important variables (Table 9). However, since the eigenvalues for the second run of the CCA were very low, these variables actually have a minimal influence on the vegetation. Climbing remained insignificant.

Table 8. P Values and F Values for Site, Habitat, and Environmental Variables and for Climbing for the CCA of the Edge Data Set, Run 1

Variable	*P*	*F*
OBE	0.002	3.08
NCC	0.002	2.85
LBL	0.002	2.34
LBO	0.006	2.32
Disturbance	0.004	1.7

Table 9. P Values and F Values for Habitat and Environmental Variables and for Climbing for the CCA of the Edge Data Set, Run 2 (with site defined as a covariable)

Variable	*P*	*F*
Disturbance	0.018	1.7
Seep	0.014	1.31
Climbing	0.12	1.13

CCA of Talus Data Set

Disturbance was the second most important variable influencing talus vegetation (Table 10). Climbing was also significant for the talus, though it was the least important significant variable measured. Site was the most important significant variable for the talus. The presence of a seep was also significant. A second run of the CCA for the talus was conducted to account for site variation. Once sites were defined as covariables, the presence of a seep and disturbance were the most important variables accounting for variation in the talus vegetation (Table 11). Climbing appeared to have an insignificant influence on talus vegetation in the second run results.

Table 10. P Values and F Values for Site, Habitat, Environmental Variables and for Climbing for the CCA of the Talus Data Set, Run 1

Variable	*P*	*F*
LBO	0.016	1.98
Y12	0.006	1.97
Disturbance	0.002	1.95
OBE	0.002	1.94
Seep	0.002	1.91
LBL	0.002	1.87
Climbing	0.006	1.59

Table 11. P Values and F Values for Habitat and Environmental Variables and for Climbing for the CCA of the Talus Data Set, Run 2

Variable	*P*	*F*
Seep	0.002	1.67
Disturbance	0.010	1.38
Climbing	0.086	1.31

CCA of Individual Sites

Because the vegetation of the study area cliffs is fairly site specific, CCA analyses were performed on each of the six sites individually. These analyses were conducted on the cliff-face data for each site (edge and talus data were excluded). Both the north-south and east-west components of aspect, as well as the presence of seeps were excluded from individual site analyses because they have high variance inflation factors.

Lilly Bluffs

Climbing and disturbance were insignificant for the Lilly Bluffs face data set (Table 12). Slope, the only significant variable for Lilly Bluffs, was only marginally significant. Vertical position on the cliff face and surface heterogeneity were both insignificant.

Lilly Boulders

Climbing was statistically insignificant for the Lilly Boulders site (Table 13). Disturbance was the most important significant variable measured, although the eigenvalues for this analysis were very low. This is primarily due to low sample size, because there were only a total of 25 face samples for the Lilly Boulders site. Slope was marginally significant. Vertical position and surface heterogeneity were insignificant for the Lilly Boulders.

Table 12. P Values and F Values for Habitat and Environmental Variables and for Climbing for the CCA of the Lilly Bluffs Face Data Set

Variable	*P*	*F*
Slope	0.030	2.04
Position	0.144	1.34
Surface het.	0.730	0.66
Climbing	0.588	0.84
Disturbance	0.174	1.43

Table 13. P Values and F Values for Habitat and for Environmental Variables and for Climbing for the CCA the of Lilly Boulders Face Data Set

Variable	*P*	*F*
Disturbance	0.036	2.15
Slope	0.048	1.93
Position	0.506	0.91
Surface het.	0.694	0.70
Climbing	0.786	0.55

North Clear Creek

Both climbing and disturbance were statistically significant for the North Clear Creek site (Table 14). Although climbing is not included in the forward selection table for this analysis, it has a perfect correlation with disturbance, meaning these two variables are identical for this site. Slope is the most important variable accounting for variation in the vegetation on the cliff faces at North Clear Creek, followed by disturbance and climbing. The eigenvalues for the first two axes of the CCA are high enough for these results to be considered reliable. Vertical position on the face was also significant for North Clear Creek. Surface heterogeneity was insignificant.

Table 14. P Values and F Values for Habitat and Environmental Variables and for Climbing for the CCA of the North Clear Creek Face Data Set

Variable	*P*	*F*
Slope	0.002	4.40
Disturbance	0.004	4.31
Position	0.002	4.09
Surface het.	0.77	0.54

Table 15. P Values and F Values for Habitat and Environmental Variables and for Climbing for the CCA of the South Clear Creek Face Data Set

Variable	*P*	*F*
Surface het.	0.012	2.70
Disturbance	0.004	2.53
Slope	0.03	1.91
Postion	0.012	1.91
Climbing	0.23	1.33

South Clear Creek

Disturbance was the second most important significant variable affecting the cliff-face vegetation at South Clear Creek (Table 15). Although climbing was insignificant according to the forward selection results, it was highly correlated with disturbance. Surface heterogeneity was the most important significant variable for the South Clear Creek site, followed by disturbance, slope, and vertical position on the face. The first two axes of the CCA have acceptable eigenvalues.

Obed Wall

Climbing was significant for the Obed Wall site, and was the second most important variable influencing the distribution of cliff-face vegetation there (Table 16). Vertical position on the face was the most important variable. Disturbance was marginally significant. Surface heterogeneity and slope were both insignificant. The first axis eigenvalue is fairly high and the second axis eigenvalue still accounts for some of the variation in the data.

Table 16. P Values and F Values for Habitat and Environmnetal Variables and for Climbing for the CCA of the Obed Wall Face Data Set

Variable	*P*	*F*
Position	0.002	2.54
Climbing	0.008	2.33
Disturbance	0.048	2.03
Surface het.	0.788	0.66
Slope	0.746	0.52

Table 17. P Values and F Values for Habitat and Environmental Variables and for Climbing for the CCA of the Y12 Face Data Set

Variable	*P*	*F*
Disturbance	0.002	4.82
Climbing	0.002	4.43
Slope	0.044	1.88
Position	0.354	1.12
Surface het.	0.654	0.72

Y12

Disturbance and climbing were the two most important variables accounting for variation in the cliff-face vegetation at the Y12 site (Table 17). Slope was marginally significant. Vertical position on the face and surface heterogeneity were insignificant for the Y12 site. The first axis eigenvalue is fairly high but the other three are quite low.

Analysis of Variance (ANOVA)

Percent cover of all species was significantly higher ($p < 0.001$, df=1) in areas without an overhanging roof than in those with an overhanging roof. Only four species of lichens (*Dimelaena oreina*, *Lepraria incana*, *Lepraria lobificans*, *Chrysothrix candelaris*) and one vascular plant species (*Mitchella repens* Linnaeus) were present in both roofed and unroofed areas.

Several species had significantly higher percent cover in certain habitat types than others (Table 18). Three of these species had highly significant ($p < 0.0001$) differences in cover between habitat types: Greenbrier (*Smilax glauca* Walter) had greater cover in the talus than on the edge, and was absent from the face; *Usnea amblyoclada* had greater cover in the talus than on the face, and was absent from the edge; and *Xanthoparmelia plittii* had greater cover in the talus than on the edge, and was absent from the face. *Heuchera parviflora* Bartling, *Dicranum montanum*, and *Lejeunea laetevirens* all had significantly higher cover in the talus than on the face. *Schizachyrium scoparium* (Michaux) Nash *var. scoparium* cover was marginally higher in the talus than on the face. Poison ivy (*Toxicodendron radicans*) (Linnaeus) Kuntze *var. negundo* (Greene) Reveal and grape (*Vitis sp.* Linnaeus), both woody vines, had significantly higher cover on the cliff face than on the talus and edge, respectively. Poison ivy was absent from the edge and *Vitis spp.* were absent from the talus. *Lasallia papulosa*, an umbilicate lichen, had significantly higher cover on the edge than on the face but was completely absent from the talus.

Table 18: Pr > F Values for Species with Significantly Different Cover Across Habitat Types

Species	*Pr > F*
Chrysothrix candelaris	0.0385
Dicranum montanum	0.0106
Heuchera parviflora	0.0209
Lasallia papulosa	0.0098
Lejeunea laetevirens	0.0140
Schizachyrium scoparium	0.0532
Smilax glauca	<0.0001
Toxicodendron radicans	0.0214
Usnea amblyoclada	<0.0001
Vitis sp.	0.0193
Xanthoparmelia plittii	<0.0001

DISCUSSION

Habitat (edge, face, or talus) and site were by far the most important variables accounting for variation in the vegetation in the large data set, indicating that the vegetative communities in each habitat are distinct, and that the communities differ between the six sites. The variation in species composition between habitats is illustrated by the ordination attribute plots for habitat (Figure 3). The clustering of points within each habitat demonstrates the relative similarity of species composition within a particular habitat, as well as the dissimilarity between habitats. By comparing the habitat ordination diagrams it is evident that the plots separate out across the first axis based on habitat type, and that edge habitats are the most unique with respect to species composition, because the edge cluster is further away from the other two clusters (face and talus plots). This is also supported by the forward selection results, in which the edge habitat had the highest F-value (Table 1). The edge habitat also had the highest species richness, which can be seen by comparing diagrams (a) and (d) in Figure 3. In the species richness diagram (d), each point represents a sample plot and the size of the point corresponds to the number of species in that plot. Most of the plots with the highest species richness are clustered together in the lower right quadrant of the (d), which corresponds to the edge plots shown in (a). Cliff edge habitats are distinguished from the cliff face and talus by the unique combination of physical conditions that occur in them.

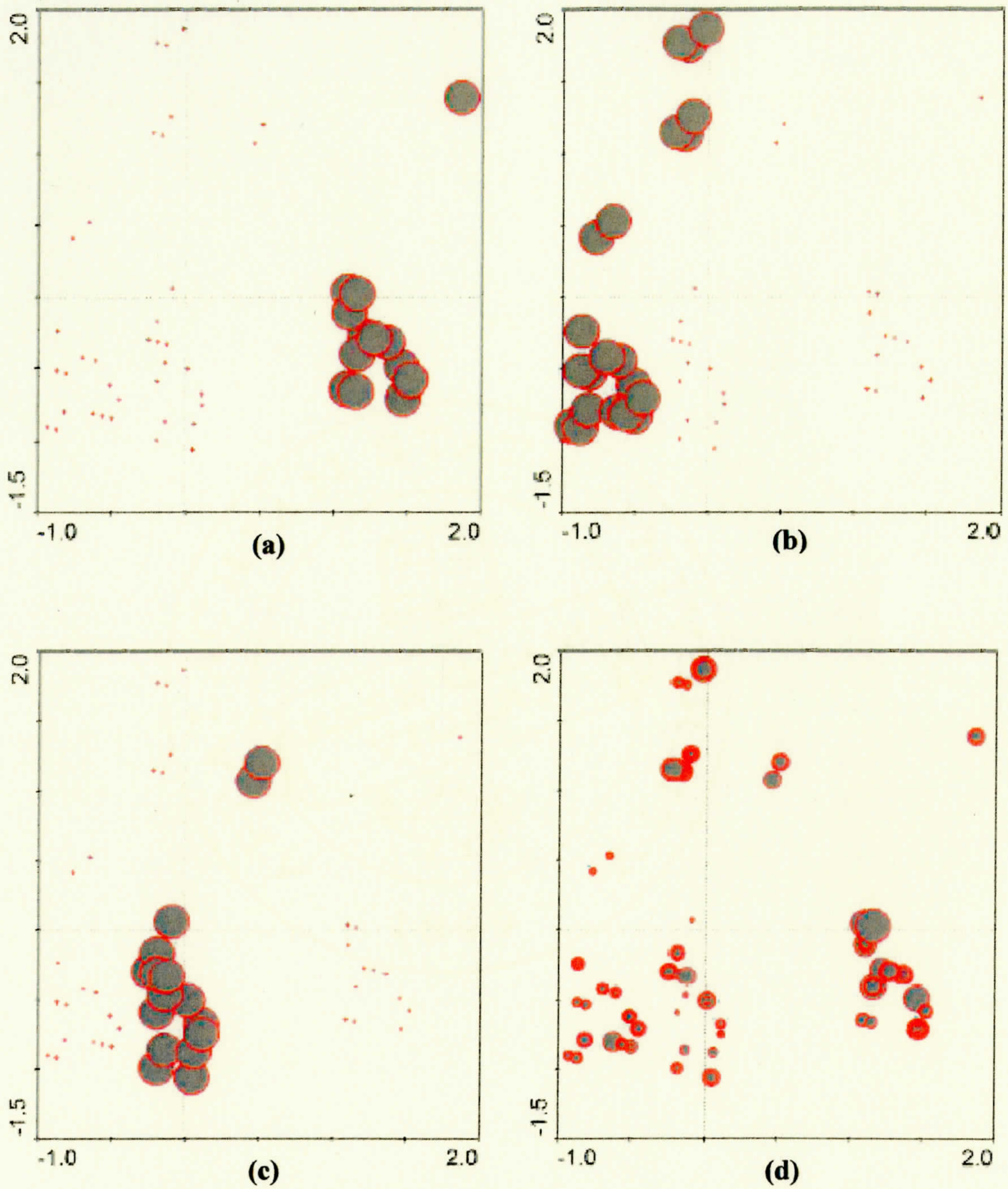


Figure 3. Variation in species composition and species richness between habitat types. Ordination attribute plots, axes 1 and 2, for (a) edge habitats; (b) face habitats; (c) talus habitats. In figure (d), the diameter of the points corresponds to species richness (the larger the diameter, the higher the species richness in that plot).

These horizontal rock outcrop habitats have thin mats of soil, but unlike soils on the cliff face, these mats are not subject to sloughing due to gravity. Edge habitats have little to no canopy cover, unlike the talus and lower cliff face. Because of this and their horizontal orientation, they are exposed to higher levels of direct insolation than the cliff face or talus. Furthermore, due to their exposed topographic position, they probably experience more extreme fluctuations in temperature and moisture than the face or talus habitats, though these variables were not measured in this study. They contain several species of rock outcrop endemics, including *Phemeranthus teretifolius* and *Minuartia glabra*. The unique and often harsh conditions in these habitats exclude many species adapted to the conditions of the adjacent plateau forest, except in pockets with the deepest soil accumulation (Sharitz and McCormick 1973; Bartlett et al. 1991).

Site was the second most important variable for the large data set, indicating that the Obed cliff vegetation is fairly site-specific. This trend can be seen in the attribute plots for the individual sites (Figure 4), in which the plots from each site seem to separate out on the second axis. Plots within each site are clustered closely together and away from the plots from other sites. The separation of plots from different habitats across axis 1 can also be seen in the site diagrams. It is possible that abiotic conditions account, at least partially, for the site-specific variation in the vegetation. For example, the Lilly Bluffs, Lilly Boulders, and Y12 plots, which are all on north-facing slopes, cluster relatively close together in the diagrams. This indicates that aspect, which influences light, temperature, and moisture availability, may account for some of the variation in vegetation between sites. Although climbing and disturbance were statistically significant in the large data set analysis, they were the least influential of the significant

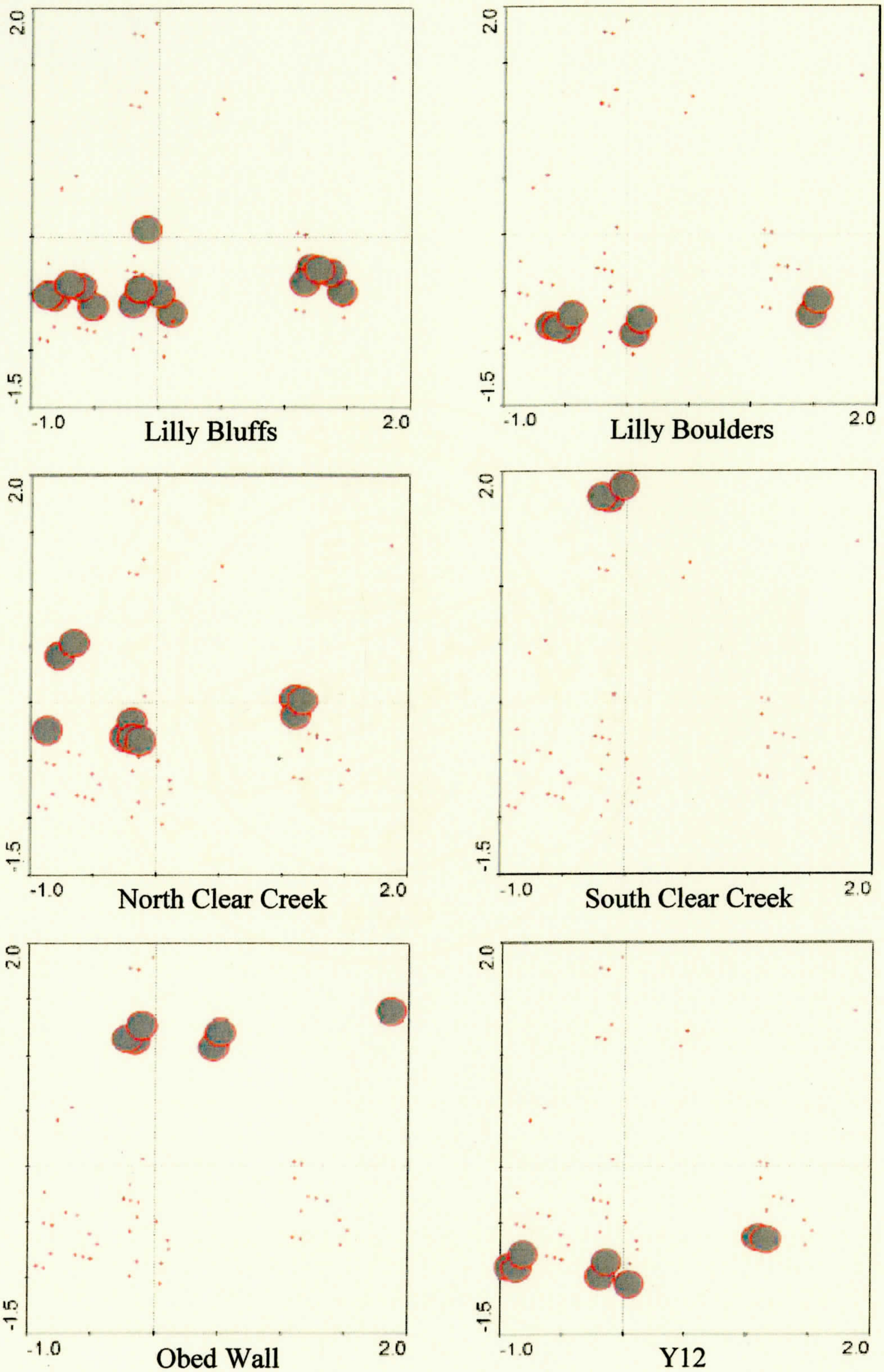
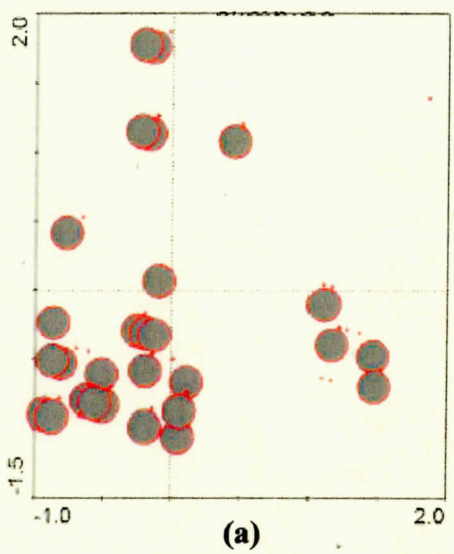


Figure 4. Ordination attribute plots for each site sampled, axes 1 and 2

variables, and examination of the ordination attribute plots for these variables reveals no clear pattern (Figure 5). This can be interpreted to mean that, for the large data set at least, variation in the vegetation among sample plots is not correlated with either climbing status (climbed or unclimbed) or the observed level of disturbance in those plots.



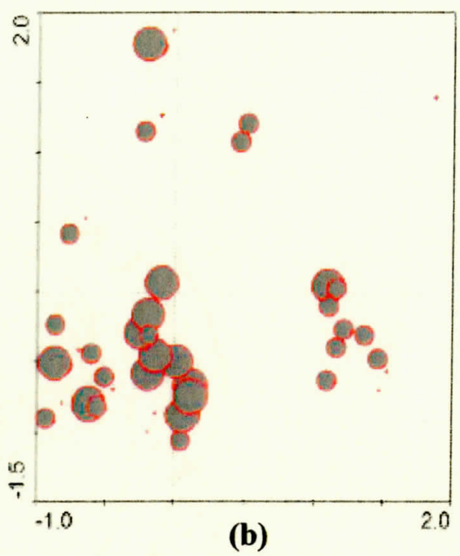


Figure 5. Ordination attribute plots for climbing (a) and disturbance (b), axes 1 and 2

Because habitat was the most important variable accounting for variation in the vegetation in the large data set, CCA analysis was conducted on each habitat type individually, beginning with the cliff-face plots only (face data set). Site was the most important significant variable for the face data set, meaning that most of the variation in cliff-face vegetation can be attributed to differences between the six sites (Table 2). The South Clear Creek (SCC) site had the most unique community assemblage, as indicated by its F-value relative to the other significant variables. The variability between sites is reiterated by the attribute plots for individual sites in the face data set (Figure 6), in which

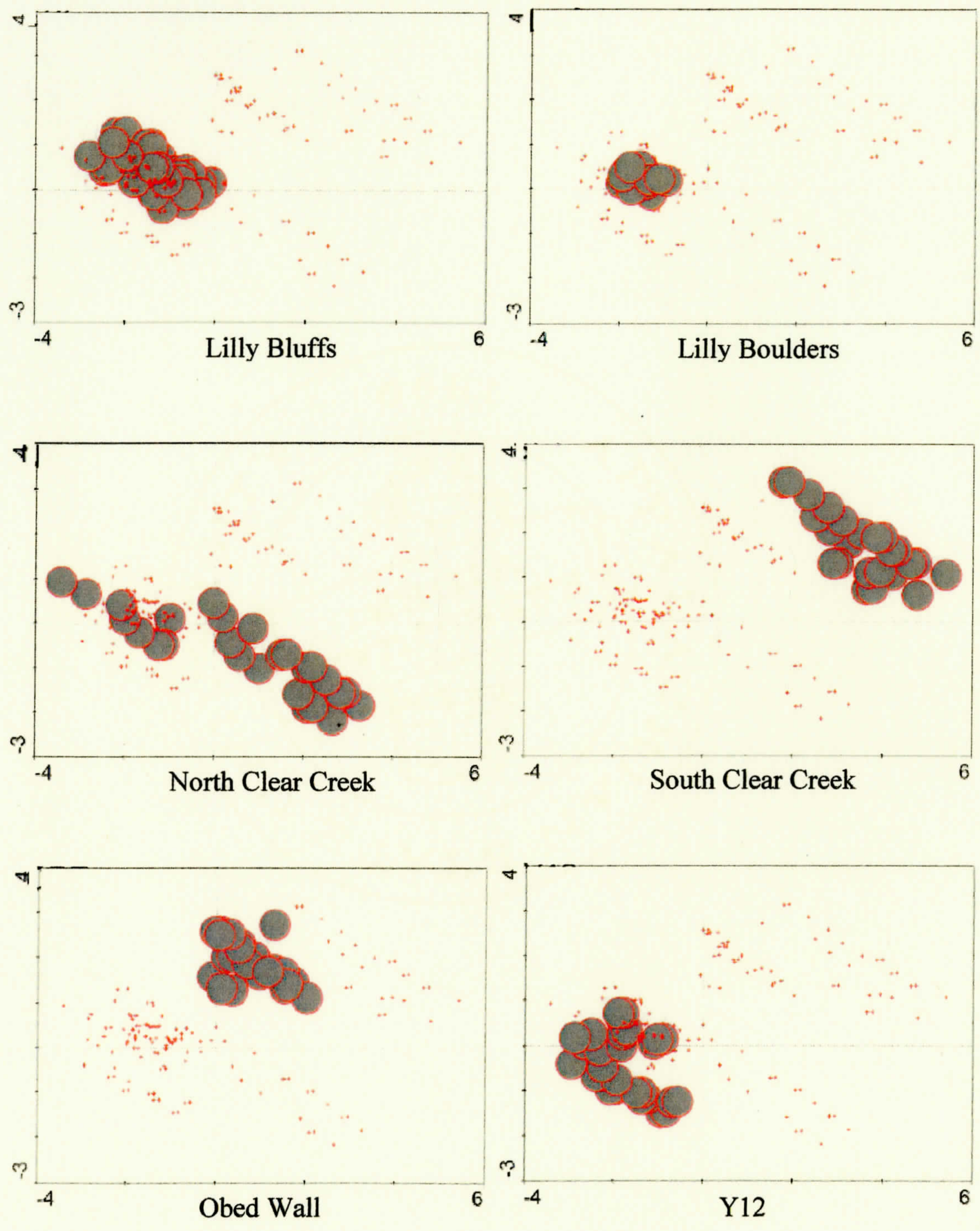


Figure 6. Ordination attribute plots for face habitats at each of the six sampling sites.

the plots within any particular site are tightly clustered together.

The presence of an overhang was the second most important significant variable accounting for variation in the cliff-face vegetation. By comparing the attribute plots for roofs and for species richness (Figure 7), it is clear that the plots occurring beneath an overhang have the lowest species richness. Cliff researchers in Tasmania observed that overhangs on cliff-faces in their region are heavily shaded and often bare (Coates and Kirkpatrick 1992). In the current study, none of the plots beneath an overhang contained any vascular plants. The paucity of vegetation beneath overhangs is probably due to greatly reduced moisture availability in these microsites relative to other cliff-face habitats (Larson et al. 2000b).

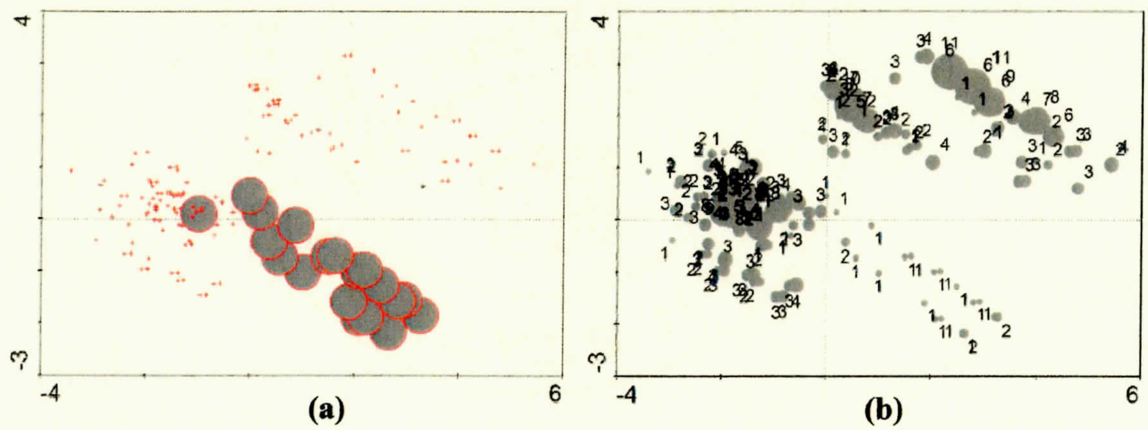


Figure 7. Ordination attribute plots for roofs (a) and for species richness (b), axes 1 and 2

The second run of the face data set CCA was an attempt to answer the question, 'once variation among sites is accounted for, how much of the remaining variation in the vegetation is due to the other variables measured?' Because the eigenvalues are notably lower for the second run, one may conclude that a large portion of the variation in the cliff-face vegetation is due to variation among sites. However, these eigenvalues are still considered significant by statisticians. The next two most important variables influencing the cliff-face vegetation are the north-south component of aspect (northness) and the vertical position on the face. This indicates that species composition differs between north- and south-facing cliffs and from the bottom to the top of the faces. This is further supported by the ordination diagram of environmental variables (Figure 8), in which northness seems to be correlated with axis 1 (the most important gradient) and vertical position with axis 2 (the second most important gradient). Ashton and Webb (1977) found a significant difference in overall vegetative cover between north-facing and south-facing granite outcrops in Victoria, Canada. This is consistent with the general observation that the north-facing Lilly Bluffs, Lilly Boulders, and Y12 cliffs are more vegetated, overall, than their south-facing counterparts at North Clear Creek, South Clear Creek, and the Obed Wall.

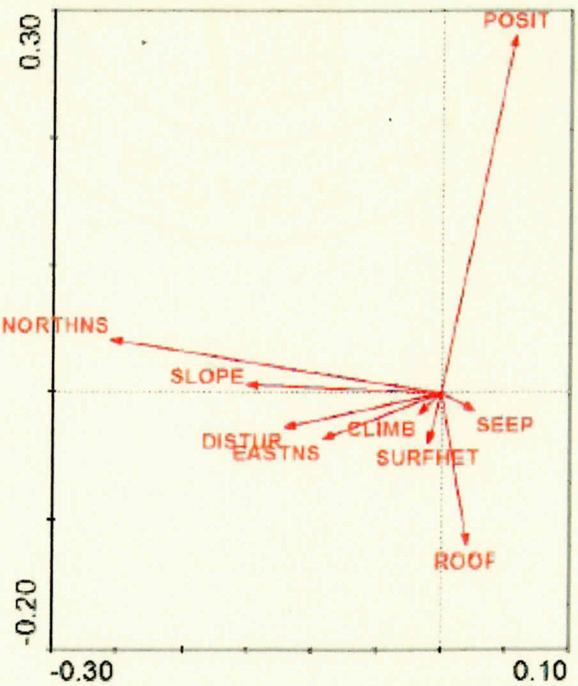


Figure 8. Ordination diagram for abiotic variables, axes 1 and 2

Based on the forward selection results and ordination diagrams for the face data set, it is evident that climbing and disturbance are among the least important factors influencing species composition in the vertical cliff-face habitat. The attribute plots for climbing and disturbance (Figure 9) on the cliff faces show no discernible pattern, indicating that changes in species composition are not correlated with climbing or disturbance. It is possible that the climbers who developed the routes in the Obed purposely chose areas with little vegetation on the face.

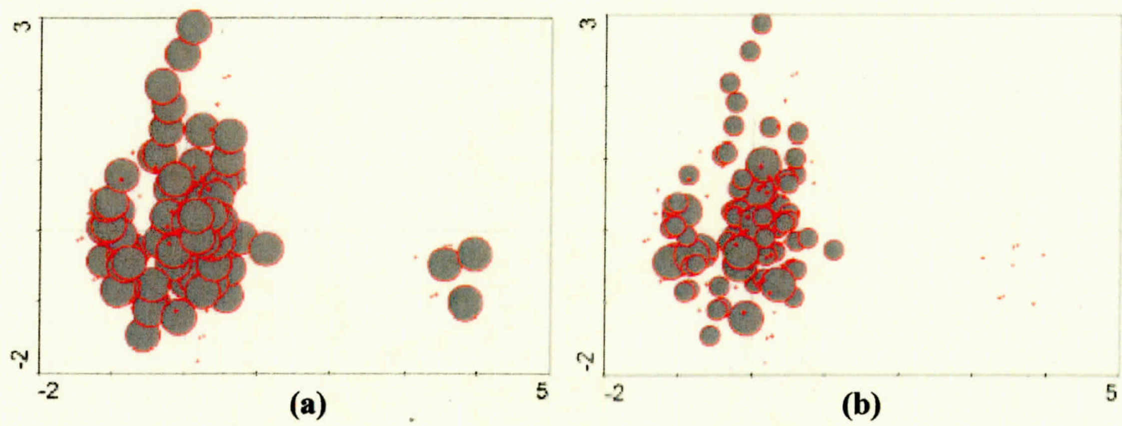


Figure 9. Ordination attribute plots for climbing (a) and for disturbance (b), face data set, axes 1 and 2

CCA was also conducted on the face data set for individual vegetation types (vascular plants, bryophytes, and lichens). Aspect was the most important variable influencing the distribution of vascular plants on the Obed cliff faces. It was even more important than variation among sites, and both the north-south and east-west components were significant. This result differs from the analysis for the large data set, indicating that aspect was more important in determining vascular plant community composition than it was in determining the composition of the vegetation as a whole. Comparison of the attribute plots for cliff-face vascular plant species richness with the environmental

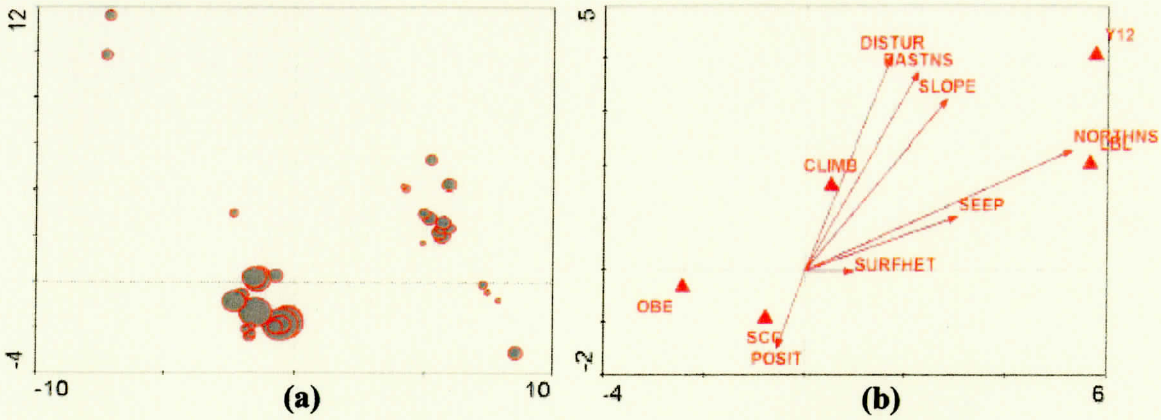


Figure 10. Ordination attribute plot for cliff-face vascular plant species richness (a) and environmental variables diagram for the face data set (b), axes 1 and 2

variables diagram (Figure 10) appears to indicate that vascular plant species richness is higher in the south-facing plots. The presence of specialized, desiccation-tolerant outcrop and cliff endemic species may contribute to the relatively high diversity of vegetation in south-facing habitats. Climbing and disturbance were insignificant for cliff-face vascular plants, suggesting that there is no difference in vascular plant species composition or species richness between climbed and unclimbed cliff faces.

Climbing did not have a significant influence on bryophyte communities on the cliff faces, but the level of disturbance was significant in this analysis. Because the amount of climber traffic is highly variable between routes, a categorical value of anthropogenic disturbance was assigned to each plot in an attempt to assess the intensity of climbing (this also allowed for assessment of impacts in the talus where disturbance is not restricted to areas directly beneath a climbed route). The attribute plots for bryophyte species richness on the faces and for disturbance on the faces (Figure 11) seem to indicate fewer bryophyte species in the most disturbed plots. However, it remains unclear if these differences in species richness are actually correlated with disturbance level or if the pattern is merely an artifact of variation among sites.

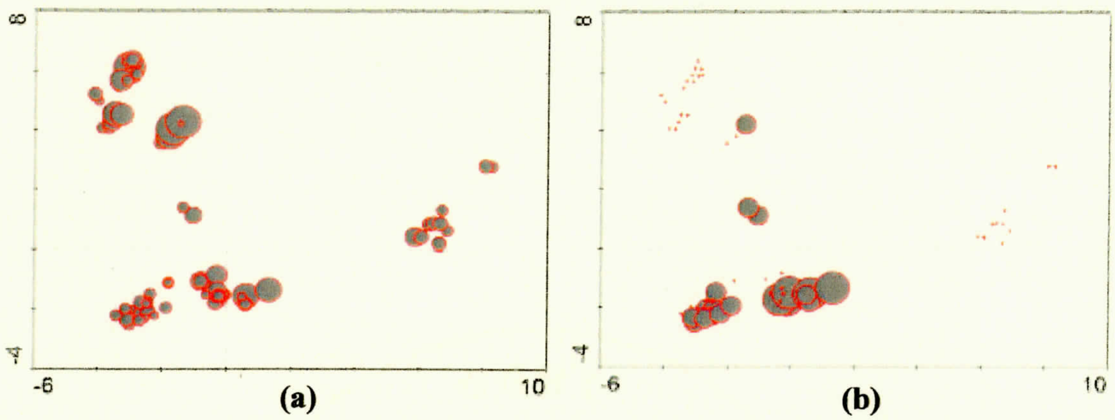


Figure 11. Ordination attribute plots for cliff-face bryophyte species richness (a) and for disturbance, cliff-face bryophyte data set (b), axes 1 and 2.

Site was the most important variable for cliff-face bryophytes. The site attribute plots for bryophytes indicate that they are the most site-specific type of vegetation there, because plots within sites are clustered very tightly and far apart from those from other sites (Figure 12). The Y12 site had the most unique bryophyte community assemblage, as indicated by the forward selection results. Northness was the second-most important variable for cliff-face bryophytes, indicating that their distributions are also driven by aspect. This is likely due to the different light and moisture requirements of particular bryophyte species.

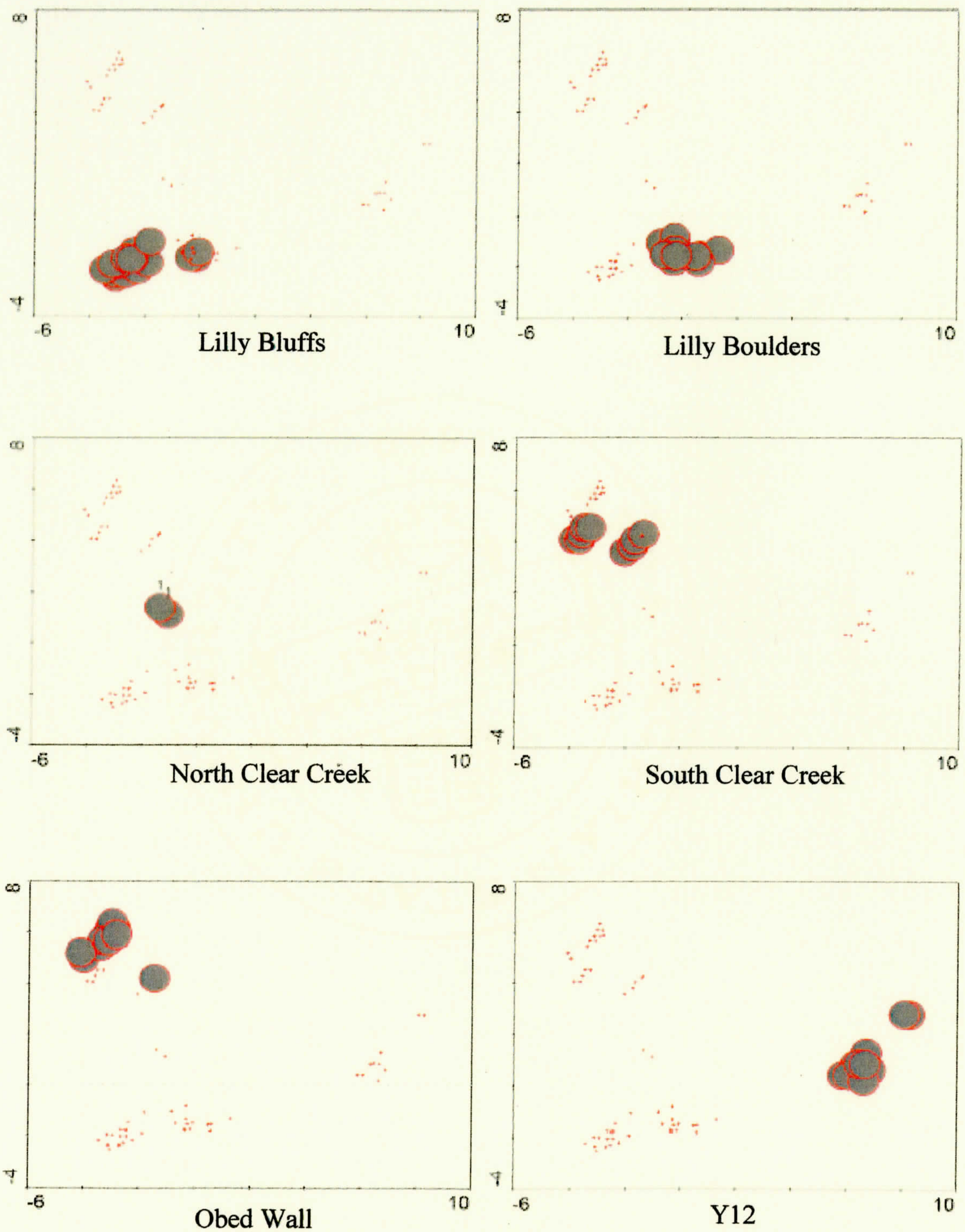
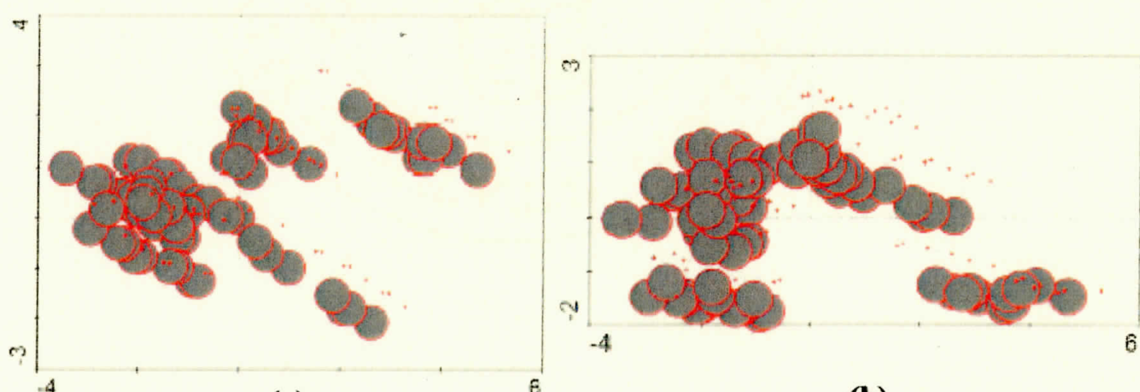


Figure 12. Ordination attribute plots for cliff-face bryophytes for each of the six sampling sites, axes 1 and 2

Climbing was a statistically significant variable influencing the cliff-face lichen communities of the Obed. However, it was the fifth most important significant variable for lichens, suggesting that its influence on lichen distribution and species composition is low relative to the other variables (Table 10). The cliff-face lichen attribute plots for climbing reveal no obvious pattern, with the exception that the unclimbed plots/transects (the small points on the diagrams) seem to lie above the climbed plots/transects (large circles) (Figure 13). This is suggestive of a *slight* shift in lichen species composition in response to climbing. The susceptibility of lichens to climbing disturbance may depend on the individual species' life form. Fruticose, foliose, and umbilicate lichens are more fragile than crustose species. Some studies (Smith 1998; Farris 1998) observed increases in crustose lichen cover in climbed areas, likely due to competitive release, while more delicate species decreased.



(a) **(b)**

Figure 13. Ordination attribute plots for climbing for the cliff-face lichen data set, axes 1 and 2 (a), and axes 1 and 3 (b)

Site was again the most influential variable for cliff-face lichens, meaning that lichen species composition varies between sites. Roof was the second-most important variable accounting for variation in lichen distribution and species composition on the cliff faces, and the lichen attribute plots for roof and for species richness (Figure14) clearly show that lichen species richness is lowest in plots beneath a roof.

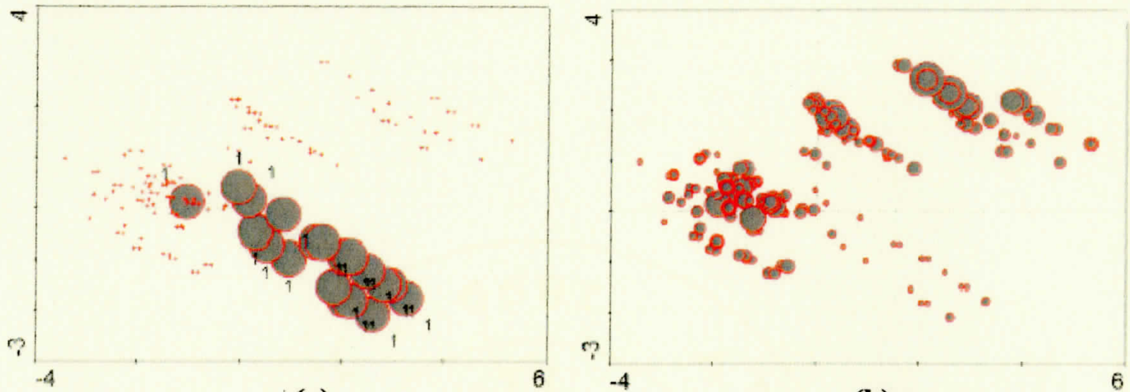


Figure 14. Ordination attribute plots for roofs, cliff-face lichen data set (a), and species richness, cliff-face lichen data set (b), axes 1 and 2

The insignificance of climbing for the edge data set was expected due to the 'no top-out' policy in the Park, which prohibits climbers from climbing up onto the plateau when reaching the top of a climbing route. Disturbance, however, was statistically significant for the edge habitat indicating that the edge vegetative communities, which are the most unique with respect to species composition, are sensitive to disturbance. These areas have very thin soils that require long periods of time to accumulate, so it is not surprising that the vegetation there is quite intolerant of disturbance in the form of trampling. The high levels of disturbance observed at a few of the edge sites (e.g. North Clear Creek) can most likely be attributed to hikers seeking a nice view rather than to climbing. Pareksit et al. (1995) found that the greatest differences in vegetation structure along the cliff-edge habitats in Bruce Peninsula National Park, Ontario, were associated with hiking intensity levels.

The only threatened plant species observed, *Phemeranthus teretifolius*, a state threatened species in Tennessee, occurs on the edge habitat above the Lilly Bluffs climbing area, which is mostly protected from trampling owing to the no top-out policy and the boardwalk at the overlook area. Site was the most important influence on edge community composition, again indicating that the vegetation in this habitat type is site-specific. When the analysis was conducted a second time with sites defined as covariables, disturbance became the most important variable accounting for variation in the edge vegetation, supporting the conclusion that cliff-edge vegetation is quite sensitive to disturbance. However, the eigenvalues for the second run of the edge data set CCA are very low, indicating that most of the variation in edge species composition is attributable to site differences.

The results for the talus are similar, because site was the most important variable organizing the vegetation, followed by disturbance. Climbing was insignificant for the talus, which is logical because impacts in the talus are not restricted to areas directly beneath a climbing route. Climbers and non-climbing hikers alike walk along the cliff bands in the talus areas, so many talus plots that were sampled along an 'unclimbed' transect were actually subjected to impacts by climbers and/or hikers. This was one of the reasons for recording the level of disturbance in addition to the climbing status for each sample plot. Sites were defined as covariables in the second run of the talus data set CCA, with the result that disturbance became the most important variable influencing the distribution of vegetation in this habitat. However, it must be noted that the eigenvalues are very low for the second run of the talus analysis, indicating that the variation observed was due more to site differences than to disturbance. Even so, disturbance remains a statistically significant factor in the talus and should be considered in management planning. The talus soils in the Obed climbing areas are visibly compacted, and the vegetation there is trampled, due to social trails and their use as staging areas for climbing.

Because the vegetation is so consistently site-specific, CCA was performed on each site individually in an attempt to understand what drives variation in the vegetation within a given site. Climbing became significant for some of the individual site analyses, whereas it was insignificant for the data set as a whole. There are two primary reasons for this. First, there are few sources of variation left in the data for an individual site. Recall that only the face plots were included in these analyses, and both aspect and seep were excluded from the analysis due to high variance inflation factors. Therefore both these variables are highly correlated with site. In other words, differences in aspect and seep are related to site differences, and are subsequently deemed irrelevant to the analysis of any single site. At some sites there is little overall variation left, as indicated by low eigenvalues (e.g. Lilly Bluffs and Lilly Boulders). The CCA must use the variables supplied, so it extracts whatever discernible pattern that remains for analysis.

The second reason climbing appears to play a more important role in the individual sites analyses is small sample size. There are a limited number of climbed and unclimbed transects within any given site. Furthermore, the vegetation is fairly transect specific, i.e. the transects usually separate out clearly in the ordination diagrams. Therefore it is difficult to determine if any pattern with respect to climbing can truly be attributed to climbing, or if the climbed transects randomly fall on one side of the graph and the unclimbed on the other side. If there was a general effect of climbing that applied equally at all sites, it would have shown up in the overall (large data set or whole face data set) analysis. The effect of climbing may in fact be site-specific, because the vegetation is so variable among sites and because there is considerable variation in climbing traffic among sites (e.g., less traffic at the Obed Wall, due to its considerable distance from a parking area). Future analyses of climbing impacts could benefit from a survey of climbing traffic for individual routes.

Climbing appears to have no effect on the cliff-face vegetation at Lilly Bluffs ($p = 0.588$). The attribute plot for climbing at Lilly Bluffs shows no apparent pattern, as climbed plots are scattered about the diagram with no discernable trend (Figure 15(a)). Disturbance was also insignificant at Lilly Bluffs (Figure 15(b)).

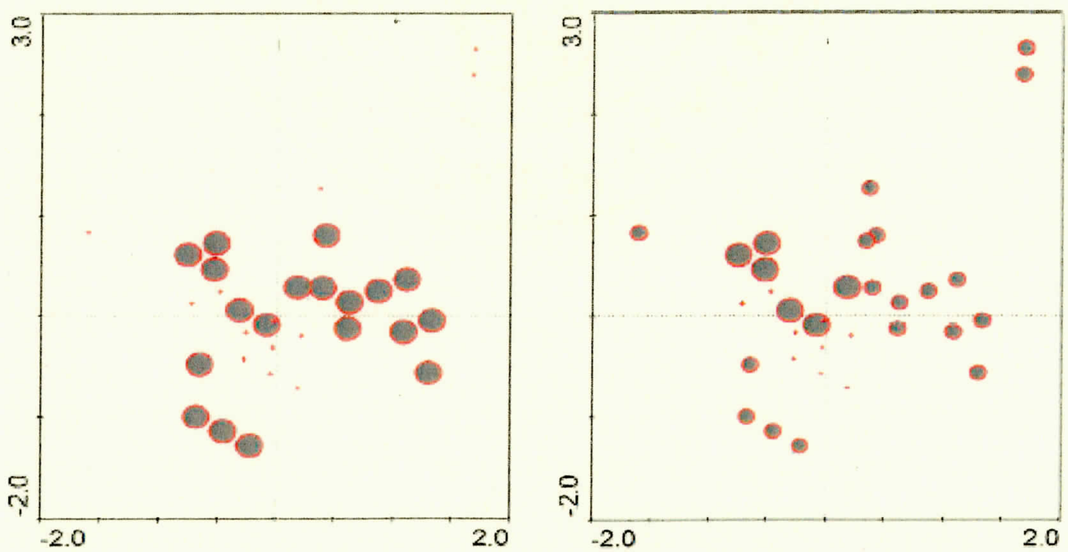


Figure 15. Ordination attribute plots for climbing (a) and for disturbance (b) at the Lilly Bluffs site, face data set, axes 1 and 2

There appears to be a significant effect of disturbance at Lilly Boulders (faces only), and disturbance is highly correlated with climbing in that analysis. However, the effect of disturbance/climbing at Lilly Boulders is not convincing, simply because there are too few data points. The small sample size, in conjunction with low eigenvalues, seems to suggest that climbing is not an important factor there. The impacts of climbing and disturbance on the vegetation at Lilly Boulders could be clarified by a more in-depth study of the boulders alone.

The eigenvalues for North Clear Creek are much higher and disturbance and climbing, which have a correlation of 1 (meaning they are exactly the same), are significant. However, the attribute plots for North Clear Creek for the climbing/disturbance variable are unconvincing (Figure 16). There are two climbed transects and one unclimbed, and the three transects are spaced equally apart. The factor that separates the transects may be unrelated to climbing.

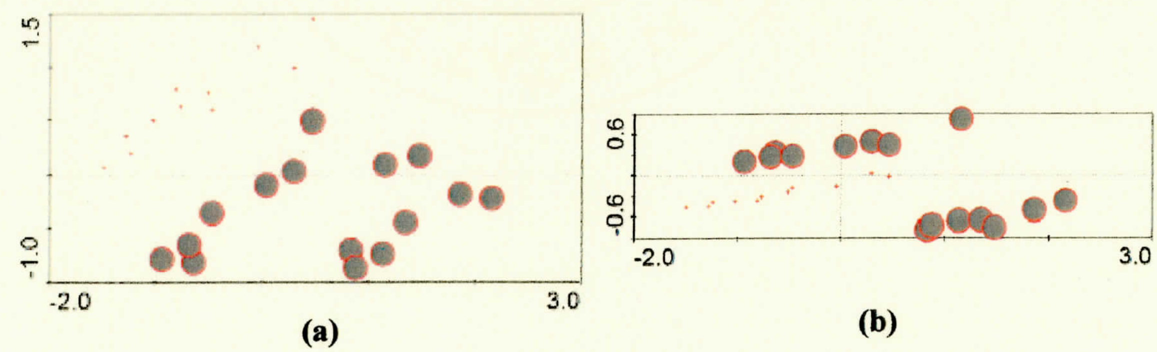
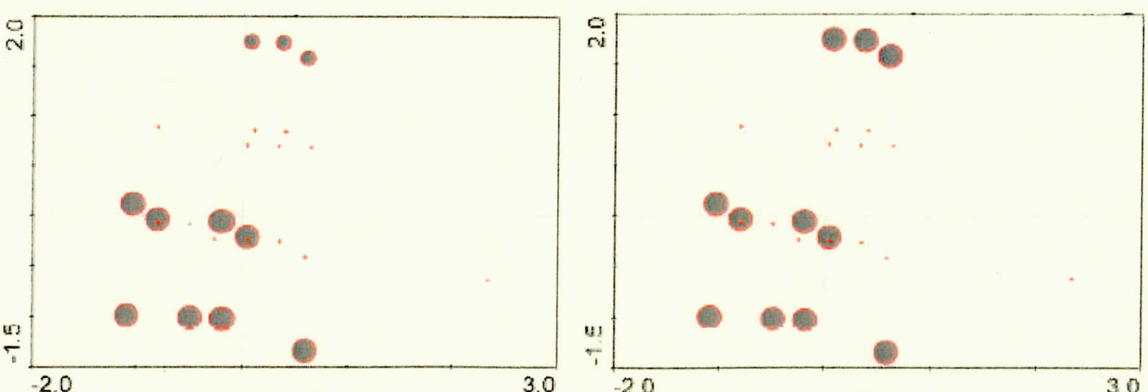


Figure 16. Ordination attribute plots for climbing, North Clear Creek face data set, axes 1 and 2 (a), and axes 1 and 3 (b)

With three transects, there is a two in three chance that the unclimbed transect will lie on either end of the axis, rather than in the middle, resulting in significance in the analysis. In the climbing attribute plot for axis 1 versus axis 3, the transects still separate out clearly, but the unclimbed transect falls in the middle instead of on one end. This renders the significance of climbing unconvincing for the North Clear Creek site.

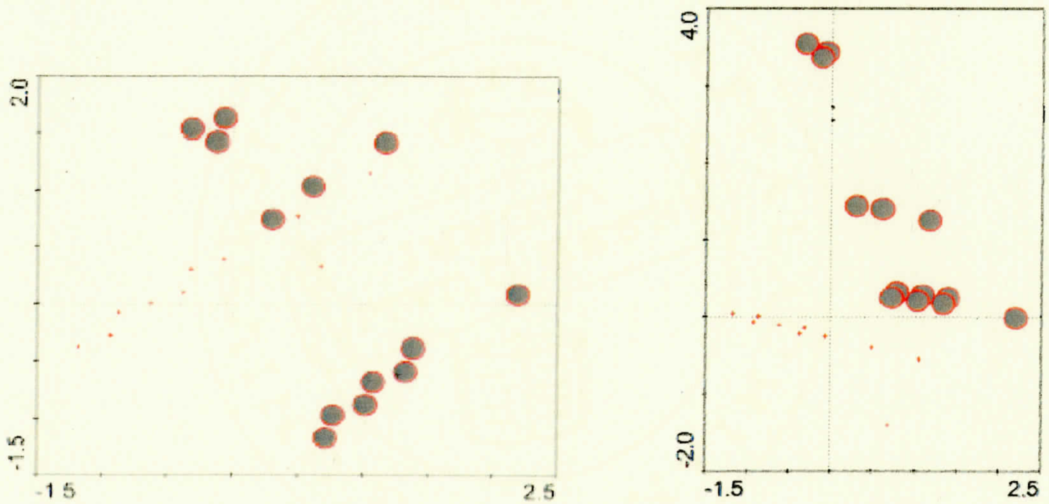
Although climbing was not significant for the South Clear Creek site according to the forward selection results, it is highly correlated with disturbance, which was the second most important variable driving variation in the cliff-face vegetation at South Clear Creek. The attribute plots for climbing and disturbance look nearly identical (Figure 17). However, the patterns in the attribute plot diagrams for South Clear Creek do not indicate any clear effect of climbing on the vegetation. The plots from each transect are lined up across the diagrams, but the disturbed/climbed transects are spaced as far apart from each other as they are from the undisturbed/unclimbed transects. This pattern could be an effect of some other unmeasured factor correlated with the location of the transect.



(a) **(b)**

Figure 17. Ordination attribute plot for disturbance (a) and for climbing (b) at South Clear Creek, face data set, axes 1 and 2

The influence of climbing is unclear for the Obed Wall site analysis. The attribute plots for climbing at the Obed Wall contain three groups of sample plots (Figure 18). The groups on either end consist entirely of climbed plots, and the three unclimbed transects align in the middle. This leaves the effect of climbing somewhat questionable. However, it could be argued that there is a real effect of climbing, because the climbed plots spread out all over the ordination space, but the unclimbed plots are closer together. This indicates that the climbed quadrats are more heterogeneous. Nonetheless, there is



(a) **(b)**

Figure 18. Ordination attribute plots for climbing, Obed Wall face data set, axes 1 and 2 (a), and axes 1 and 3 (b)

no clear and definite trend with respect to climbing at the Obed Wall. The Y12 site is similar to the Obed Wall site with respect to the climbing attribute plots: the largest group of plots in the ordination diagram consists of unclimbed quadrats, and there are two groups of climbed plots that are spaced far apart (Figure 19). However, one of these two groups is disturbed and the other is undisturbed (see Figure 19(c)), indicating that there is a significant effect of both climbing and disturbance at the Y12 site. Among the individual site analyses, the results from the Y12 site present the strongest evidence that climbing has a significant effect on cliff vegetation.

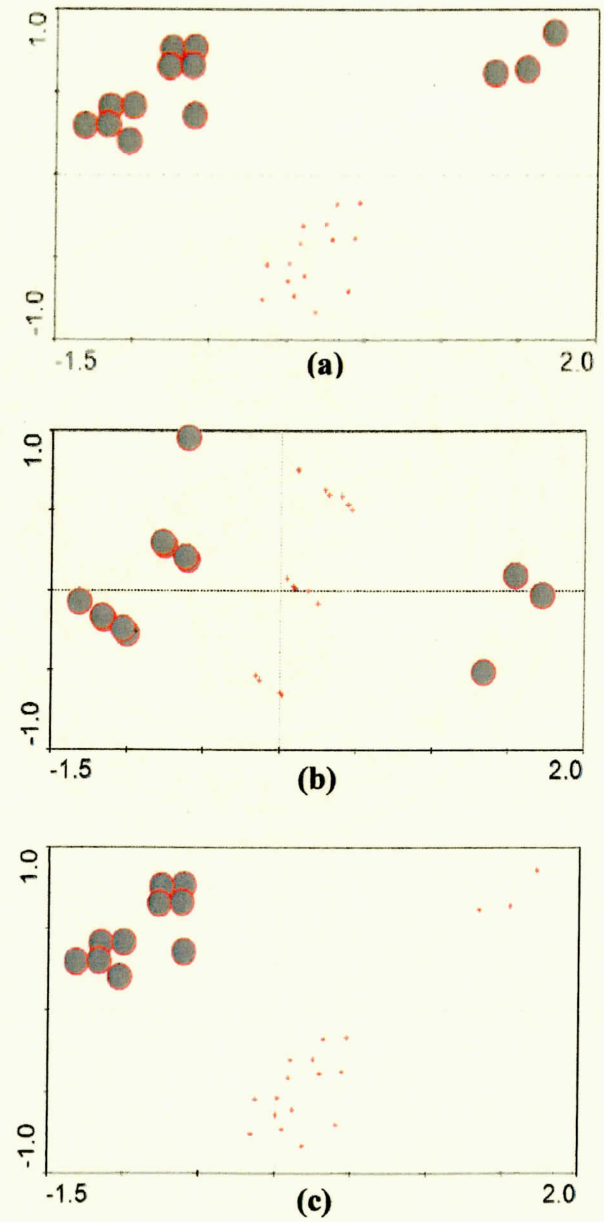


Figure 19. Ordination attribute plots for the Y12 face data set; climbing axes 1 and 2 (a); climbing axes 1 and 3 (b); and disturbance, axes 1 and 2 (c)

Analysis of variance (ANOVA) was performed on the data to ascertain whether any of the species sampled display 'preferences' for particular cliff habitats (edge, face, or talus) or if any of these species are conspicuously absent from particular habitats. Such apparent preferences for the edge, face, or talus may reflect adaptations to the unique combinations of physical conditions in cliff habitats. Studies of the cliffs of the Niagara Escarpment have revealed three distinct community types among the plateau, face, and talus slopes with consistent species assemblages in each (Booth and Larson 1998).

Ten Obed cliff species appear to have definite habitat preferences (edge, face, or talus), based on the ANOVA results. The association of Greenbrier (*Smilax glauca*) and Poison ivy (*Toxicodendron radicans*) with talus habitats, and their complete absence from the edge, perhaps suggests the intolerance of these species to shallow soils and high insolation occurring on the edge and cliff-face habitats. The absence of *Usnea ablyoclada* (a fruticose lichen) from the edge, along with its highly significant preference for the talus over the cliff-face, may be a reflection of an adaptation to less exposed habitats or an intolerance of high light levels. *Heuchera parviflora* (Littleflower alumroot), *Dicranum montanum* (a moss), and *Lejeunea laetevirens* (a liverwort) all displayed an apparent preference for the talus over the face, most likely due to these species' adaptations to shady, sheltered conditions.

Differential seed rain, rates of seed germination, and seedling survivorship among particular plant species within the three cliff habitat types may play significant roles in the differences observed in vegetation among habitat types. Booth and Larson (2000) found that seed rain, seed germination, and seedling survivorship exerted a strong influence over final community composition on the cliff faces of the Niagara Escarpment. Additional studies examining the roles of these parameters in determining community composition of cliff habitats within the Obed River Gorge would shed additional light on their ecology.

SUMMARY AND MANAGEMENT IMPLICATIONS

The Obed River Gorge system and the Cumberland Plateau are known for their high levels of plant diversity. That diversity is reflected in the results of this study. One of the most important things discovered during the course of this research is that the cliff vegetation in this area is highly heterogeneous and varies greatly from site to site, even when those sites are relatively close to one another. This is in contrast to observations made by Larson et al. on the Niagara Escarpment cliff systems (2000b).

There are several possible reasons for this. The cliffs of the Cumberland Plateau remained unglaciated during the last ice age, whereas the Niagara Escarpment was completely covered by the ice sheet. Following glacial retreat, the Niagara Escarpment was recolonized by boreal species, but never reached the level of diversity found in the unglaciated southern Appalachian region. Additionally, the Niagara Escarpment is continuous along its extent. A linear geologic feature, it composes a fairly continuous cliff-face habitat for hundreds of miles, while the cliff faces of the southern Appalachians are scattered islands of habitat that are physically separated from one another. The cliffs along the narrow river gorges of the Obed and Clear Creek are scattered fragments situated with opposite aspects which create very different environmental conditions, that can greatly influence community composition and structure.

The differences in cliff plant community structure between and within sites could be clarified by additional sampling at each site. Due to the time consuming nature of the field work required to study cliff vegetation, only three climbed and three unclimbed transects were measured at most of the six sites. Although 415 total plots were sampled, the individual site analyses would benefit from a larger sample size at each site, which were conducted because of the high level of variation in vegetative composition among sites.

Another interesting and prevalent feature of the Obed cliffs is the presence of large overhangs or roofs. These areas are sought after by skilled climbers due to the challenges they present. The results of this study consistently show lower species richness for all vegetation types on the cliff faces beneath these overhangs. The lack of vegetation there is probably an effect of very low light and moisture levels, though these were not measured in this study. This finding suggests that the impact of climbing on cliff vegetation should be of little concern in these areas.

Disturbance was significant for talus areas. The talus vegetation is visibly trampled in most areas of the six sites sampled. Because talus areas were disturbed throughout the sampling sites, regardless of the climbing status of the transect, it may be worthwhile to conduct vegetation surveys in undisturbed talus areas elsewhere in the Park in order to observe the pristine condition of these vegetative communities.

The cliff-edge habitat was found to have the most unique community assemblages. Likely due to the thin soils and harsh environment, many uncommon plants, vascular and non-vascular, were found there. Among them is the Tennessee state-threatened plant *Phemeranthus teretifolius* (Pursh) Rafinesque, the round-leaf fameflower, which grows on the edge at Lilly Bluffs. The edge environment was also shown to be quite sensitive to disturbance, but it appears that the 'no top-out' policy is working as there was no discernible effect of climbing in the edge habitat, and disturbed areas were relatively infrequent. Some cliff-edge trails, abandoned since implementation of the 'no top-out' policy, appeared to be recovering their lichen, bryophyte, and vascular flora (anecdotal observation).

Although there seems to be a slight shift in lichen species composition on the cliff faces in response to climbing, the nature of this shift remains unclear. Other than that observation, one cannot confidently conclude that there is a significant effect of rock climbing on the Obed cliff vegetation as a whole. This may be related to the observation that, while the Obed cliffs harbor some unusual plant species, they are not heavily vegetated overall.

Climbers may have purposely placed fixed routes on cliff bands with little vegetative cover. It has been suggested that because climbers who design and develop fixed-anchor routes have a high level of rock-climbing skill, they typically design challenging routes with fewer and smaller hand holds (Kuntz and Larson 2006). If cliff faces with fewer surface heterogeneities have less vegetative cover, as suggested by some of the data in this and other studies, perhaps an apparent effect of climbing is really an artifact of route siting.

However, due to the high variability among sites within the gorge and the fairly small sample sizes within each site, the effects of climbing cannot be completely ruled out for all sites. The effects of climbing are probably site-specific, because the vegetation and the amount of climbing traffic are site-specific as well, and it is likely that larger sample sizes would allow for statistically sound conclusions about the impact of climbing at each site. Of the individual site analyses, the Y12 site and the Obed Wall site present the strongest evidence for an effect of climbing on the vegetation. This is interesting because these are the most remote sites included in the study and appeared to be less disturbed when compared to some of the other climbing areas.

Based on the results of this study, it is recommended that the six climbing sites be managed individually. Due to the significant disturbance observed in talus habitats in the climbing areas, a future study of talus vegetation in undeveloped areas of the park is suggested, in order to characterize these communities in their pristine states. Depending on the results of such a study, Park managers may want to consider allowing some talus sections to recover, or to restrict future route development in undisturbed talus areas. Park managers are strongly encouraged to maintain and enforce the 'no top-out' policy, as it appears to be an effective measure to protect rare and uncommon plant species on the cliff edge. Because the impacts of climbing were most significant for the Y12 area, it is suggested that future development of additional routes there be restricted. If demand and increasing climbing traffic dictate the need for new route development in the future, cliffs with large roofs or overhangs may be good choices because they support virtually no vegetation.

Physical conditions in cliff environments vary widely on a microsite scale. Future ecological studies of cliff vegetation and rock-climbing impact could benefit from the addition of quantitative measurements of light, temperature, soil volume, soil chemistry, and moisture. Inclusion of such data may clarify the relative influences of various abiotic factors and climbing disturbance on cliff vegetation.

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APPENDIX A

Species List by Habitat and Site

Species	Site and Habitat Presence					
Vascular Plants	**LBL**	**LBO**	**NCC**	**SCC**	**OBE**	**Y12**
Acer rubrum Linnaeus *var. rubrum*	EF	E	E		T	E
Amelanchier arborea (Michaux f.) Fernald		E	E		E	
Andropogon virginicus Linnaeus *var. virginicus*				F		
Aquilegia canadensis Linnaeus			T			
Arisaema triphyllum Linnaeus	T					
Asplenium montanum Willdenow	F	E		F	F	
Asplenium platyneuron (Linnaeus) Britton, Sterns, & Poggenburg		E				E
Athyrium asplenioides (Michaux) A.A. Eaton					F	
Bignonia capreolata Linnaeus		E			FT	ET
Carex muhlenbergii Schkuhr ex Willdenow *var. muehlenbergii*				F		
Carex pensylvanica Lamarck			F			
Cercis candensis Linnaeus *var. canadensis*			T			
Chasmanthium laxum Linnaeus		E				
Chimaphila maculata (Linnaeus) Pursh	E					
Cystopteris protrusa (Weatherby) Blasdell						T
Dichanthelium dichotomum (Linnaeus) Gould *var. dichotomum*				F	F	
Diphasiastrum digitatum (Dillenius ex A. Braun) Holub			E			
Dryopteris marginalis (Linnaeus) A. Gray	E	E				
Epigaea repens Linnaeus			E			
Euonymus americanus Linnaeus	E					E
Gaultheria procumbens Linnaeus	E		E			
Heuchera parviflora Bartling	FT					FT
Hypericum gentianoides (Linnaeus) Britton, Sterns, & Poggenburg			T		FT	
Ilex opaca Aiton *var. opaca*	E	E				
Juniperus virginiana Linnaeus *var. virginiana*			T		T	
Kalmia latifolia Linnaeus			E	F	EFT	E
Liatris microcephala (Small) K. Schumann					EFT	
Liriodendron tulipifera Linnaeus *var. tulipifera*	E		E			
Lonicera japonica Thunberg					E	
Minuartia glabra (Michaux) Mattfeld	E					
Mitchella repens Linnaeus	EFT	E	E	F		
Oxydendrum aboreum (Linnaeus) A.P. de Candolle	E	E	E	F	T	
Parthenenium integrifolium Linnaeus *var. integrifolium*	E					
Pinus strobus Linnaeus	E					
Pinus virginiana P. Miller	E		E	F	EFT	
Piptochaetium avenaceum (Linnaeus) Parodi					E	
Polystichum acrostichoides (Michaux) Schott						T
Polygonatum biflorum Walter	E					
Pleopeltis polypodioides (Linnaeus) E.G. Andrews & Windham *ssp. michauxiana* (Weatherby) E.G. Andrews & Windham		E				

Species	Site and Habitat Presence					
Vascular Plants (continued)	**LBL**	**LBO**	**NCC**	**SCC**	**OBE**	**Y12**
Pteridium aquilinum (Linnaeus) Kuhn *var. latiusculum* (Desvaux) Underwood ex Heller					E	
Quercus coccinea Meunchhausen	E					
Quercus montana Willdenow	E					
Rhododendron maximum Linnaeus						E
Rhus copallinum Linnaeus			ET			
Robinia pseudoacacia Linnaeus			T			
Sassafras albidum (Nuttall) Nees	E	E				
Silene rotundifolia Nuttall					F	
Smilax glauca Walter	E	E	E		ET	E
Solidago curtisii Torrey & A. Gray	T					T
Solidago sp. Linnaeus	EFT				ET	
Symphyotrichum laeve (Linnaeus) Love & Love var laeve			E		ET	
Toxicodendron radicans (Linnaeus) Kuntze *var. negundo* (Greene) Reveal			T			FT
Tsuga canadensis (Linnaeus) Carriere	EF	ET	E			E
Vaccinium corymbosum Linnaeus	E		E		EF	
Viburnum acerifolium Linnaeus	E					
Viburnum dentatum Linnaeus *var. dentatum*	E					
Vitis sp. Linnaeus	E			F		

*E=edge; F=face; T=talus; LBL=Lilly Bluffs; LBO=Lilly Boulders; NCC=North Clear Creek; SCC=South Clear Creek; OBE=Obed Wall; Y12=Y12 Wall

Species	Site and Habitat Presence					
Bryophytes	**LBL**	**LBO**	**NCC**	**SCC**	**OBE**	**Y12**
Amblystegium serpens var. juratzkanum		T				
Anastrophyllum michauxii		F			F	
Andreaea rothii				F		F
Anomodon rostratus	T					
Aulocomnium palustre	E					
Bartramia pomiformis	FT					
Bazzania trilobata	E	EF				
Brotherella tenuirostris	ET	EF				T
Bryoandersonia illecebra						T
Calypogeia fissa	E					T
Campylium hispidulum						E
Campylopus pilifer			F	F	EFT	
Campylopus tallulensis			E	F		
Cephaloziella rubella			E	F	F	
Chilocyphus profundus	E					T
Dicranella heteromalla	T		E			
Dicranum fulvum			T			
Dicranum montanum	EFT	F	FT			F
Dicranum scoparium	E	E	T			
Dicranum spurium	E					
Diphyscium foliosum	EFT		E			
Diplophyllum apiculatium			E			
Ditrichum pallidum						E
Fissidens asplenioides						T
Fissidens bryoides		T				
Frullania asagrayana	E		T			
Frullania brittoniae						E
Grimmia apocarpa	F		E		F	
Hypnum cf. cupressiforme			T			
Hypnum curvifolium		E				E
Hypnum imponens	E	E	E			
Isopterygium distichaceum		F				
Isopterygium elegans	FT			F		T
Isopterygium pulchellum	FT					
Isopterygium tenerum		F				
Lejeunea laetevirens	T	F				
Lejeunea ulicina		F				
Leucobryum albidum	EFT	EFT	EFT	F	FT	ET
Leucobryum glaucum	ET					
Leucodon julaceous						E
Leucolejeunea clypeata		F	E			FT
Mnium ciliare						E
Mnium cuspidatum		T				
Mnium hornum	T					T
Odontoschisma denudatum	E					
Odontoschisma prostratum	F	EFT				

Species	**Site and Habitat Presence**					
Bryophytes (Continued)	**LBL**	**LBO**	**NCC**	**SCC**	**OBE**	**Y12**
Philonotis c.f. gracillima			E			
Plagiomnium cuspidatum	E					
Plagiothecium laetum		F				
Pleurozium schreberi	E	E				
Polytrichum commune	EF		E			
Polytrichum juniperinum	E		E		ET	
Polytrichum ohioense	E					
Porella pinnata						F
Rhabdoweissia crispata				F		
Rhynchostegium serrulatum	E	ET				E
Scapania nemorosa	EFT					
Sematophyllum adnatum		T				
Sematophyllum demissum						FT
Sematophyllum marylandicum						T
Solenostoma gracillimum		F				
Sphagnum compactum	E					
Syrrhopodon texanus	T					
Taxiphyllum deplanatum	F	E	E			T
Tetraphis pellucida		F				
Thuidium delicatulum	ET	E				ET

*E=edge; F=face; T=talus; LBL=Lilly Bluffs; LBO=Lilly Boulders; NCC=North Clear Creek; SCC=South Clear Creek; OBE=Obed Wall; Y12=Y12 Wall

Species			**Site and Habitat Presence**			
Lichens	**LBL**	**LBO**	**NCC**	**SCC**	**OBE**	**Y12**
Amygdalaria panaela			T			
Aspicilia cinerea			T			
Buellia spuria				F	FT	
Buellia stigmaea				F		
Chrysothrix candelaris	FT		FT	F	FT	F
Cladina arbuscula	E					
Cladina rangeferina	E	E	E		E	
Cladonia apodacarpa				F	EF	
Cladonia caroliniana			T		F	
Cladonia cervicornis	E					
Cladonia chlorophaea	E		E		ET	
Cladonia coniocraea	F		E		E	
Cladonia cristatella					ET	
Cladonia didyma	E					
Cladonia furcata		E				
Cladonia macilenta					T	
Cladonia squamosa	EF		ET		E	EF
Cladonia strepsilis			ET		F	F
Dimelaena oreina	E		FT			
Flavoparmelia baltimorensis	E		FT			
Flavoparmelia caperata			E	T		
Fuscidea recensa	E		E		E	
Hypotrachyna imbricatula			T			
Hypotrachyna revolute				F	F	
Lasallia papulosa	EF		F	F	F	
Lecanora cenisia	FT		T			F
Lepraria incana	F	F	EF	F	FT	F
Lepraria lobificans	FT	EF	EFT	F	FT	FT
Lepraria neglecta					F	
Leproloma membranaceum						F
Melanelia culbersonii			F	F		
Micarea peliocarpa			E			
Phaeophyscia rubropulchra		E				
Phlyctis argena	F		EF			FT
Physcia subtilis			T	F	FT	
Porpidia albocaeruleans						FT
Punctelia appalachiensis			E			
Punctelia rudecta			T			
Punctelia stictica			E			
Rhizocarpon eupetraeoides				F	F	
Rhizocarpon hochstetteri			T			
Rhizocarpon sp.				F	FT	
Trapeliopsis flexuosa					E	
Trapeliopsis granulosa			E			
Usnea amblyoclada			F	F	FT	F
Xanthoparmelia conspersa			E	F	FT	

Species	Site and Habitat Presence					
Lichens (Continued)	**LBL**	**LBO**	**NCC**	**SCC**	**OBE**	**Y12**
Xanthoparmelia hypomeleana			T			
Xanthoparmelia plittii			T		ET	
Xanthoparmelia tasmanica					F	

*E=edge; F=face; T=talus; LBL=Lilly Bluffs; LBO=Lilly Boulders; NCC=North Clear Creek; SCC=South Clear Creek; OBE=Obed Wall; Y12=Y12 Wall

APPENDIX B

Photographs

Figure 20. Cliff band above Clear Creek, Obed National Wild and Scenic River, Morgan County, Tennessee

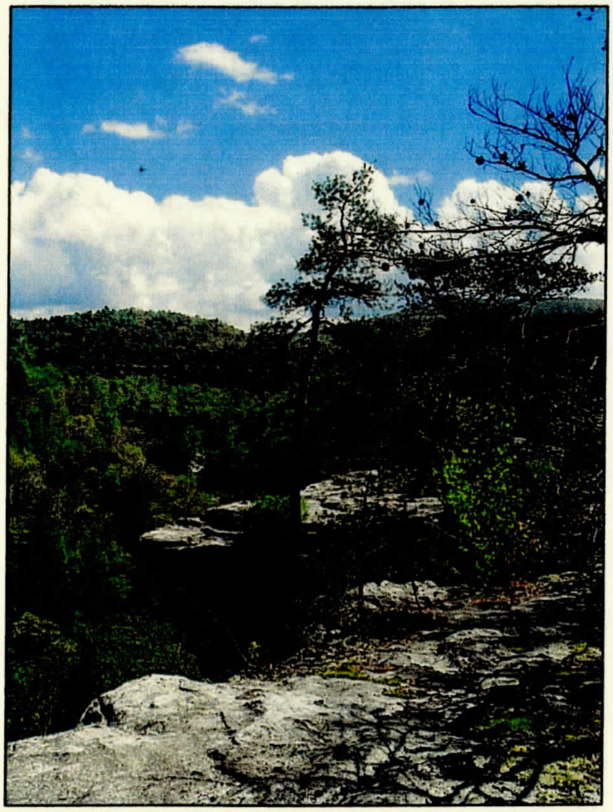

Figure 21. Cliff edge above Clear Creek, Obed National Wild and Scenic River, Morgan County, Tennessee

Figure 22. *Liatris microcephala* on the cliff face at Lilly Bluffs.

Figure 23. *Silene rotundifolia* on the cliff face at the Obed Wall

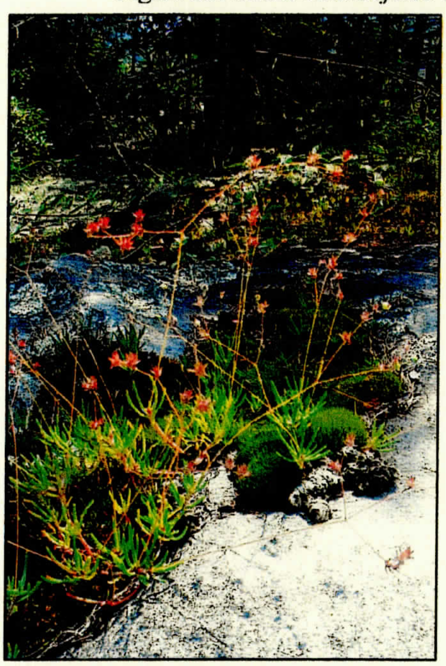

Figure 24. *Phemeranthus teretifolius* on the cliff edge at North Clear Creek

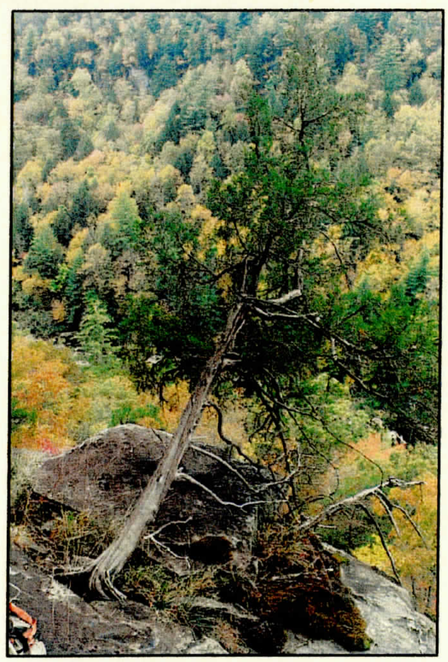

Figure 25. *Juniperus virginiana* on the cliff edge at the Obed Wall

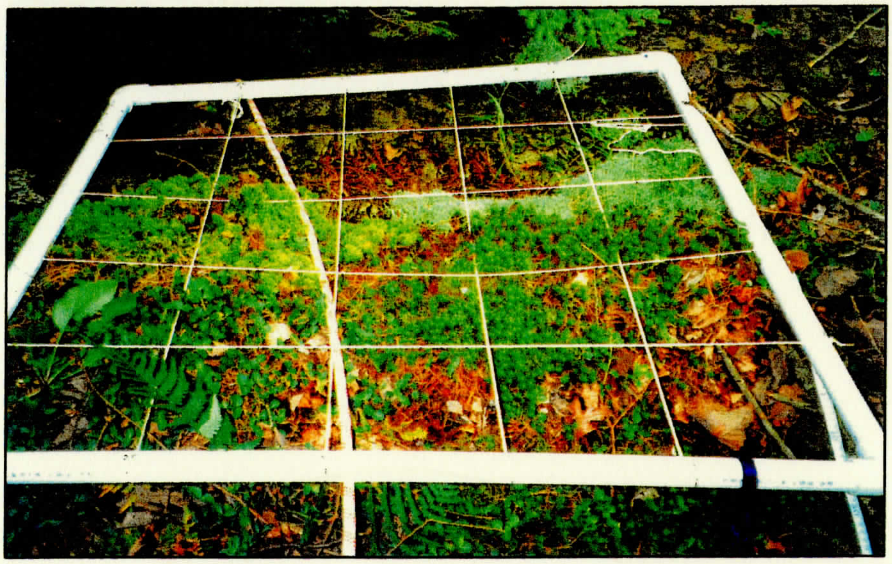

Figure 26. 1m^2 quadrat used for sampling

Figure 27. Cliff-face sampling along a transect at the Obed Wall

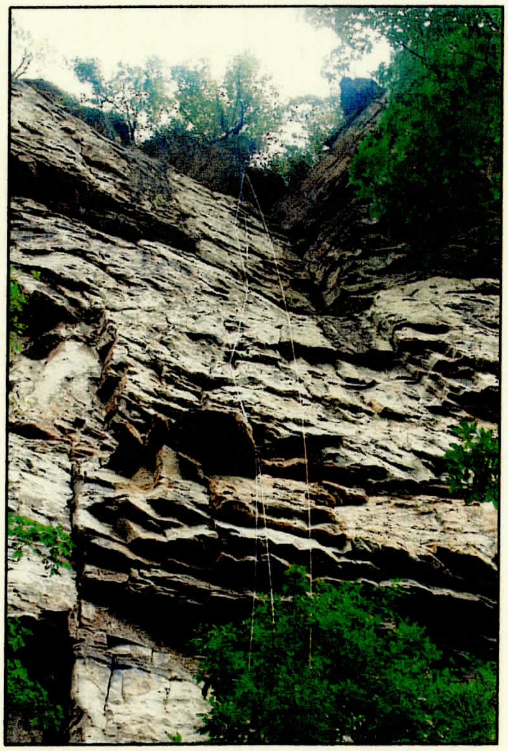

Figure 28. Ropes along a transect at North Clear Creek

BIOGRAPHICAL SKETCH

Emily Parisher Hill was born in Durham, North Carolina, on June 28, 1977. She attended elementary and middle schools in Chapel Hill, North Carolina, and graduated from Chapel Hill High School in June 1995. The following autumn, she entered the University of North Carolina at Wilmington to study Biology, and in December 1999 she was awarded the Bachelor of Arts degree in Biology with a concentration in Conservation Biology. In the autumn of 2001, she accepted a teaching assistantship, followed by a research assistantship, in the Biology Department at Appalachian State University and began study toward a Master of Science degree. During the summer of 2004 she worked for the United States Forest Service in Unicoi, Tennessee, and in September of 2004 she accepted a Project Scientist position with Environmental Services, Inc. in Atlanta, Georgia. In April of 2006, she accepted the Piedmont Biologist position with the North Carolina Department of Environment and Natural Resources, Division of Parks and Recreation in Raleigh, North Carolina. She was awarded the M.S. in Biology in May 2009.

Mrs. Hill is a member of the Association of Southeastern Biologists, the North Carolina Prescribed Fire Council, and the North Carolina Sandhills Conservation Partnership, and is a 2007 Fellow of the Natural Resources Leadership Institute. She lives in Chapel Hill, North Carolina with her husband Jon and their two cats. Her parents are Mr. and Mrs. David and Robin Henry of Chapel Hill.