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# The Effects of Rock Climbing on the Cliff Flora of Three Minnesota State Parks

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**Abstract**: I examined cliff vegetation at Blue Mounds, Interstate, and Tettegouche State Parks to test for the effects of rock climbing on the vegetation. A total of 83 transects were established and 249 permanent unmarked plots (0.25$m^2$) were located along these transects. Half of the transects and plots were found in areas frequented by climbers and half in unclimbed areas of the cliffs. Each plot was photographed and mapped for future relocation. A grid of 96 points was superimposed over each plot and the identity of each organism found under the points was determined. A total of 23,904 points were examined. Data were examined using univariate statistical techniques and multivariate techniques (ordination and classification). There were significant differences between treatments in total vegetation cover, number of species per plot, and the relative frequency of some individual species. Ordination and classification showed some differences between climbed and unclimbed areas, but the results were not consistently clear. The causal factors for the differences seen could have been climbers or differences in the habitat or environment. Each cliff has a number of areas that are essentially undisturbed and which will likely serve as refuges for species directly impacted by climbers.

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*"...I noticed that the constant tramp of feet had begun to kill out the lichens in many places so that the impression of richness is beginning to fade, and the botanist must soon seek some place near by, if such exists, where he may study this rich flora in its natural beauty."*

*- Bruce Fink, 1898, speaking about Interstate State Park at Taylor's Falls*

## INTRODUCTION

One of the few biological communities that emerged undisturbed from the colonization of Minnesota by Europeans was the cliff habitat. Beginning in the mid 1900's, rock climbing resulted in the first real intrusions on these systems. During the past decade, rock climbing has become more and more popular- a half million climbers are currently using over 500 climbing areas across the U.S. (Access Fund, 1993). As a result of these climbing activities, this habitat type is under more human pressure than ever before. At the same time, the relative inaccessibility of these habitats has prevented biologists from documenting the nature of these communities in any detail.

There is a considerable literature on the vegetation of exposed rock outcrops throughout the world (e.g. Oosting and Anderson 1937, Burbanck and Platt 1964, Goldsmith 1973, Ashton and Webb 1977, Phillips 1982, Larson et al. 1989, Wiser 1993). In particular, Walters and Wyatt (1982) contains numerous references to granite outcrop vegetation in the southern U.S. There has been only sporadic attention paid to cliff vegetation in the Great Lakes Region. Fink (1910) summarized his extensive work throughout Minnesota, which included specific publications on the lichen flora of Taylor's Falls (Fink 1898), the Lake Superior area (Fink 1899a) and southwestern Minnesota (Fink 1899b). Holzinger (1910) wrote on the mosses of the North Shore. Foote (1966) examined the lichens and bryophytes found on limestone outcrops in Wisconsin.

A number of 'listed' (endangered, threatened, or special concern) species are known to use these cliffs as a habitat (Coffin and Pfannmuller 1988). At Blue Mounds, vernal pool communities found in shallow pockets on the rock may contain several rare species (e.g.Heteranthera limosa, Bacopa rotundifolia, Limosella aquatica, Isoetes melanopoda). Other rare species are known to inhabitat cracks in the quartzite (Schedonnardus paniculatus, Opuntia macrorhiza). On the North Shore, one population of Draba arabisans may be threatened by climbing (Coffin and Pfannmuller 1988). Euphrasi hudsoniana is found in crevices along the North Shore, while Parmelia stictica is an endangered lichen that has been found once along the North Shore.

There is no apparent literature on the quantitative effects of rock climbing on cliff vegetation per se. I am aware of several studies that are currently in progress. Vicki Nuzzo (Native Landscapes, Rockford, Illinois) is currently finishing an assessment of the effects of climbing on vegetation at Mississippi Palisades State Park in Illinois. Rick Camp (Master's student at Colorado State University) is completing a similar project at Joshua Tree National Monument, California. Other projects are underway at City of Rocks (Idaho) and Pinnacles National Monument (California).There has been more work on the effects of recreational trampling on areas such as cliff tops and rocky trails (R. Sutter, pers. communication). This lies outside the scope of this proposal, but is a subject which deserves study in Minnesota.

Two studies currently in their final stages appear to have reached quite different results. Nuzzo (unpublished) worked on west-facing dolomitic outcrops above the Mississippi River. She found no difference in the vegetation on climbed and unclimbed areas, and concluded that the physical environment (type of rock, degree of weathering, aspect) was more critical in determining the plant species present. In contrast, Camp's (unpublished) work at Joshua Tree National Monument has apparently found significant effects on the vegetation due to climbers. All vegetation is restricted to cracks in the rounded granite outcrops (no lichens are present due to the harsh climate). Both the number of species and number of individuals per meter of crack were significantly lower in climbed crack systems.

## METHODS AND MATERIALS

Three cliff systems were covered by this project. Blue Mounds State Park contains a long ridge of Sioux quartzite that is frequented by climbers (but to a lesser extent that the other two areas). Interstate State Park is probably the most commonly used climbing area in Minnesota. Tettegouche State Park contains a number of cliff formations, but this project will only examine the southern aspect of Shovel Point.

There are three distinct zones of the cliff habitat that may be influenced by technical climbers: the cliff base, the cliff top, and the cliff itself. This research dealt only with the cliffs proper, because (1) the other two zones require no special technical climbing skills to access and (2) non-climbers generate a significant fraction of the human impact in these other two zones. The definition of 'climbing' used in this study is restricted to roped, technical climbing.

General Sampling Methods. The fundamental unit of data collection were 0.25 $m^2$ (61 x 41 cm) quadrats sampled along vertical transects located along the cliff face. This plot area is appropriate for the vegetation being sampled (Bonham 1989) and has the same length:width ratio as 35mm film. The plot frame was constructed of one-half inch CPVC plastic pipe and 90° elbows. The elbows were glued to only one of the two sections to make the frame collapsible. A small bubble level was attached to the top of the frame. A cord was attached to the top two corners and used to hang to frame from a skyhook or Crack'n Up. A keeper cord was attached to my climbing harness. In 1995, registration marks were added to the frame. This started 0.5 cm from each inside edge and every 5 cm thereafter. Kodak color calibration strips were attached to the frame in 1995 as well.

Each transect located vertically along the cliff face either in an area subject to climbing activity or in an area generally unclimbed. Once a transect was located (climbed or unclimbed), a fixed line was established from above. For climbed transects the rope was placed so as to intersect the climbed portions of the cliff. A flexible cloth surveyor's tape was anchored to the top of the cliff with the zero mark aligned with the cliff edge. Photographs were generally taken of the rope location for unclimbed transects.

I then rappelled down the rope, pulling the tape measure down and aligning the rope and tape as needed. The height of the cliff was recorded to the nearest meter at Interstate and Blue Mounds. Since only the top 15 m of Shovel Point is commonly used by climbers, all sampling took place within that area of the cliff at that location. Using the height of the sampled area, the cliff was divided into three vertical zones of equal size after disregarding the top 1 meter and bottom 2 meters to eliminate effects due to non-climbers (Fig. 1). Within each zone the location of a plot was randomly determined to the nearest meter.

I then jumared back up the rope to the lowest chosen sampling point. Using a skyhook or other appropriate anchor, the plot frame was placed so that the top rail was located as close to the chosen height as possible. Sometimes the rock morphology prevented exact alignment, so all plot heights should be considered to be ± 0.5m. In climbed areas, the horizontal location of the plot was non-random; it was placed so as to include areas that would commonly be used by a rock climber. In unclimbed plots the frame was located on a potentially climbable area of rock.

The plot frame was leveled using an attached bubble level. The average slope and aspect of the rock within the frame was recorded. A climber's topographic map was sketched to aid in future relocation of the plot. The transect name, date, and plot height were indicated on a card attached to the plot frame and plot was photographed. All photographs were taken with a 28mm lens, using either Kodak Kodachrome ISO 64 slide film (1994) or Kodak Lumiere ISO 100 slide film (1995). Most photographs were taken under cloudy conditions and with an electronic fill-flash unit. The procedure was repeated at the upper two plots to finish the work on each transect.

Each photograph was projected over a grid containing 96 points and the number of 'hits' for each species determined. This modified point-frame analysis allowed an accurate estimate of relative cover (Bonham 1989). Data were collected from the slides by superimposing a grid over the image (projected at life-size). Parallax errors during photography resulted in a projected image that was not exactly life-size in all dimensions (Fig. 2). The grid was adjusted to reflect the observed length of each side of the plot frame. For 1994 photographs this was done by measuring the lengths of each side and spacing the grid strings accordingly. For 1995 photographs the registration marks on the plot frame were used. In this case the grid was located midway between each grid mark on the plot frame. The 5 x 5 cm grid spacing resulted in 96 points which cover an area of $0.24m^2$ per plot. A one-centimeter wide strip was ignored on the left and bottom sides of the plot frame in 1994 and a 0.5 cm wide strip around the entire plot frame in 1995.

The original data were generally collected as morphospecies rather than formal genus-species taxa. This is important for the lichens, where several species may be superficially identical. The morphotaxon of a species found underneath a point was recorded the original data sets. In addition, I recorded each taxon found within the plot frame but not intersecting any point. The rock morphology for each point was recorded as being a face, crack, ledge, or overhang.

Representative samples of all morphospecies were collected for identification. No rock and only minor amounts of vegetation was removed from any area currently being used by climbers. Taxonomic names of lichens were assigned according to Wetmore (1988). Voucher specimens of all samples were deposited in the Hamline University herbarium. The University of Minnesota herbarium accepted specimens that were not adequately represented in their collections.

Data analysis. Each cliff system was analyzed separately. A total of 31 transects were established at Blue Mounds (16 climbed, 15 unclimbed) and 20 transects at Shovel Point (11 climbed and 9 unclimbed). Sampling was somewhat limited at Shovel Point because there are few heavily travelled climbs and because I was concerned about damaging the umbilicate lichens in unclimbed areas. At Interstate I established 16 transects in climbed areas and 12 in unclimbed areas. In addition, 12 individual plots were located on small outcrops in the area. This resulted in a total of 48 unclimbed plots and 48 climbed plots at Interstate.

For each taxon the relative frequency of occurrence in climbed and unclimbed plots was compared using a 2 x 2 contingency table (Causton 1988). Differences in slope and aspect of climbed and unclimbed plots were examined with t-tests.

Community structure in the two treatments was assessed using both classification and ordination techniques. Classification was conducted using TWINSPAN (Hill 1979). TWINSPAN attempts to arrange samples (and species) into similar groups by dividing the samples into smaller and smaller groups. This procedure was used to determine if climbed and unclimbed plots (and transects) could be separated on the basis of their vegetative characteristics. Ordination (detrended correspondence analysis, DCA) was conducted using the program DECORANA (Hill and Gouch 1980). Ordination uses species abundance data to construct synthetic axis which indirectly summarize the important environmental variation that determines changes in species abundance. The resulting 2 or 3-dimensional graphs show the scores of individual samples on these axes (species can be represented as well). Samples (or species) which lie close together are similar in species composition and abundance. Thus this method provides another way, using different mathematical approaches, to assess differences between climbed and unclimbed plots.

# RESULTS

## Environmental Data

Rock morphology differed significantly between climbed and unclimbed plots in each location (Table 1). Cracks were less frequent in unclimbed areas, while ledges were somewhat overrepresented. The sampling methods probably discriminated against inclusion of large ledges and large roofs in the plots.

The aspect and slope of climbed and unclimbed plots were not significantly different at Blue Mounds and Interstate (Table 2). At Shovel Point, the slope and aspect of climbed and unclimbed plots were significantly different. Climbed plots faced southwest (238°) on average, while unclimbed plots faced nearly due south (177°). Unclimbed plots were nearly twice as steep as climbed plots at Shovel Point. Climbed transects were taller at both Blue Mounds and Interstate (Table 3); all transects (except one) were 15 m long at Shovel Point due to the experimental design.

## Taxa observed

Lichens comprised a vast majority of all flora observed within the sample plots. Tables 4-6 contain the taxonomic groupings used in this study, abbreviations used in this report, and descriptions of the categories. A total of 26 taxa were defined for Blue Mounds, 29 for Interstate, and 33 for Shovel Point. These numbers certainly underrepresented the total number of species present within the sample plots.  Special note should be made of white cedars on the cliffs of Shovel Point. There are well over 200 white cedar growing on that cliff, along with a few white spruce.

## Univariate Comparisons

Presence/absence data provide the most fundamental measure of the differences between climbed and unclimbed plots. At each location, significantly more points had taxa in unclimbed plots than would be expected by random chance (Table 8). A total of 12,384 points were sampled in climbed plots and 30.7% of these intersected taxa. In unclimbed plots 44.3% of the 11,520 points sampled contained taxa. The most skewed results were seen at Interstate, where only 3% of points in climbed plots intersected taxa.

Unclimbed plots have significantly more taxa per plot in all three locations (Table 9). At both Blue Mounds and Shovel Point there were about 1.4 times as many species in unclimbed plots relative to climbed plots. At Interstate the difference was much greater, with nearly 5 times as many species in unclimbed plots when compared to climbed plots.

Some taxa at each location were nonrandomly distributed between climbed and unclimbed plots (Tables 10-12). At Blue Mounds, three lichen taxa (Rhizocarpon group 1, Aspicilia group 1, and Lecanora muralis) and the group of unidentified grasses were relatively more common in unclimbed plots. At Interstate nearly half of the taxa were nonrandomly distributed between treatment levels (Table 11); all of these taxa were lichens. At Shovel Point seven of 33 taxa were nonrandomly distributed, all lichens (both Physcia groups, three Parmelia groups, Lecanora muralis, and Umbilicaria muhlenbergii). The other Umbilicaria present (U. vellea) was present at the expected proportions in both climbed and unclimbed plots. The only taxon that was nonrandomly distributed in all three locations was Lecanora muralis. A total of 88 contingency table tests were conducted in Tables 10-12, of which 5% ( or 4.4 tests) were expected to be significance based on random chance alone. Twenty-four of the 88 tests were significant.

**Multivariate Results**

Ordination and clustering were conducted on frequency data (number of 'hits') at both the plot level and the transect level. Relative frequencies (number of hits per species/number of all hits per plot) were used as abundance data. For transects, values for each species were averaged over the plots in the transect that contained species. Transect analyses tended to have less noise and provide slightly more interpretable results.

**Plot Analyses**

There was no clear grouping of plots according to treatment in the Blue Mounds plot DCA (Fig. 3). This agreed with the univariate results, which found only a few species with distinct frequency differences between plots. The three unclimbed plots loading highest on Axis 2 were located close to one another in a rather shaded area (transects 25, 26, 27). There appeared to be slightly more variability in the scores of plots from unclimbed transects. No correlations were seen between the plot scores and the three environmental factors measured on each plot (distance from top, aspect, slope) (Table 13a). When the species loadings on the axes were examined, a group of rare species loaded strongly on axis 2 (Fig. 4). These species included Dermatocarpon miniatum, the Lecanora finkii group, unknown mosses, and some other crusts. The angiosperms were grouped together, as would be expected since several were found in the same plots. The TWINSPAN analysis did not reveal any obvious clustering of plots or associations between groups of plots and species (Fig. 5).

There was also considerable overlap in the Interstate DCA results (Fig. 6). Two plots (2063 and 2121) were eliminated from the analysis as they resulted in an unstable analysis due to rare species. Site scores varied little along the second DCA axis, except for one outlier (plot 2-41-1). This is an individual plot, not part of a transect, that contained the only columbine (Aquiligea canadensis) found in a Interstate plot. A group of unclimbed plots loaded highly on Axis 1; most of these plots were part of the individual, non-transect plots. Again, the slope, aspect and height of the plot were essentially uncorrelated with the four DCA axes (Table 13b). The species loadings on the first two axes revealed little (Fig. 7). The mosses and fern were grouped in the lower left, along with some crustose lichens. The position of the angiosperms reflected their rarity rather than any significant ecological differences.

The TWINSPAN analysis was difficult to interpret (Fig. 8a). The most widely separated taxa on the diagram (lca901= "Lecanora thysanophora" and lca902= Aspicilia group 1) were difficult to distinguish and certainly shared some members. The analysis was repeated after combining these two taxa (Fig. 8b). In this case the foliose lichens and the angiosperms are grouped in the lower half of the diagram. Interestingly, Lecanora muralis, Woodsia ilvensis, and a moss all grouped at one end of the diagram and formed one discrete group in the hierarchical analysis. Neither analysis separated climbed and unclimbed plots into any clear groupings.

The Shovel Point DCA showed some separation between climbed and unclimbed plots (Fig. 9). Climbed plots showed more variability at Shovel Point than at the other two locations. For example, the most extreme plot scores on Axis 1 were for climbed plots. This was due to the presence of rare species in these plots. The species loadings showed one group of non-lichen species (grasses, a moss, and a fern) which had low loadings on Axis 2 (Fig. 10). Other non-lichen species were scattered throughout, however. Slope, aspect and height of transect were not associated significantly with the four DCA axes (Table 13c)

The TWINSPAN classification analysis was also somewhat successful at separating the climbed and unclimbed plots, at least at the third division (Fig. 11). The first and second divisions did not separate climbed and unclimbed plots effectively.

**Transect Analyses**

The Blue Mounds DCA revealed some separation between treatment groups (Fig. 12,13). Unclimbed transects generally had low loadings on Axis 1 and higher loadings on Axis 2. As with the plot data, unclimbed areas occupy a larger volume of the ordination space, indicating that they contain a wider variety of species in different combinations. Species loadings reflect the relative rarity of the angiosperms (Fig. 14).

The TWINSPAN classification analysis showed some structure at the transect level (Fig. 15). Most angiosperms grouped together at one end of the table while the foliose lichens grouped at the other end. Transects sort out along treatments at the third level of division to some extent.

The individual (non-transect) plots were grouped as a single transect in the Interstate DCA analysis. This composite transect was located relatively far away from the main grouping of unclimbed transects. The unclimbed transects in general grouped more closely together than the climbed transects (Fig. 16,17,18). The 3-D view shows some minor groupings of both climbed and unclimbed transects.

The TWINSPAN classification analysis separated the climbed and unclimbed plots at the second and third division (Fig. 19). A number of species were generally absent in the climbed plots, including mosses and a number of crustose lichen groups.

The Shovel Point DCA on transect data from this location showed the most complete separation of climbed and unclimbed plots found in any of the analyses conducted for this study (Fig. 20-22). This separation is most obvious on the 3-D diagram.

The TWINSPAN classification analysis separated a majority of the climbed and unclimbed plots into separate groups during the first division and separated all treatments into separate groups after four divisions (Fig. 23). Most angiosperms and mosses, both fruticose lichens, and one umbilicate lichen (Lasalia pappulosa) were absent in climbed plots and provided most of the discriminatory power in the analysis.

## DISCUSSION

### Rock morphology, general cliff structure, and the environment

The three cliff systems differ in the type of rock, rock morphology, cliff height, and cliff structure. Blue Mounds is composed of a very compact sandstone with horizontal seams of softer pipestone. Cracks tend to be formed by fractures of large pieces of rock and these cracks tend to be large (>10cm wide). Ledges tend to be very small (<10 cm) or larger (80 cm), with few intermediate sized ledges. Horizontal roofs greater than 50cm wide are common. The cliff faces generally southeast and extends for nearly one kilometer. The cliff is broken up into a series of buttresses 10-20 m wide (see Farris 1995, included with this report, for photographs of all three cliffs). Several areas of the cliff face are actually large blocks detached from the main cliff face. This forms cavelike chimneys that have quite different environments than most of the exposed rock at Blue Mounds. These chimney areas were not examined in this study. Much of cliff is obscured by trees at the base. The major exception is the 'Prairie Walls' area (p. 26, Farris 1995), where there is no significant tree cover. This is also one of the most heavily travelled climbing areas at Blue Mounds.

Interstate has the most complex structure of the three areas. The rock is basalt and has cracks of various sizes in both horizontal and vertical dimensions. There is only one area that forms a continuous cliff zone; this is the main climbing area in the park (see pages 75-77, Farris 1995). The Potholes area contains a number of potholes, small cliffs, and other exposed rock that is a popular scrambling area for the general public. This area was not examined. There are a large number of small to medium sized outcrops found along the trail leading from the parking area to the overlook on Highway 8 and on towards the campground. A number of these outcrops were used as unclimbed areas in this study. The primary climbing area faces south to southeast and receives considerable amounts of direct sun throughout the year.

Shovel Point is a relatively simple area. Most of the cliffs falls directly into the water and is 50 m tall at the beginning of the water and tapers down to 0m at the end of the point. The rock is a porphyritic rhyolite intrusion that is somewhat brittle in areas. The upper section of the cliff forms a series of dihedrals, while the lower half contains more loose rock and has a series of overhangs. The cliff faces southeast, but the dihedrals provide considerable habitat facing west and northwest. The dihedrals usually have thin cracks in the corners, and the rock seems to have numerous small ledges (<15 cm). The aspect of many areas and the white cedar trees provide more shade than might be expected on such an exposed cliff. Disturbance by non-climbers is limited to the top of the cliff, for obvious reasons.

The differences seen in rock morphology, cliff height, aspect, and slope (Tables 1-3) between climbed and unclimbed plots were not unexpected. The decades-long climbing history at all of these locations would suggest that the vast majority of rock favorable to climbing is (and has been) utilized for many years. While serious attempts were made to locate unclimbed areas that mirrored the general environmental conditions of climbed areas, in many cases this could not be done. This was most evident at Interstate. A total of 12 plots were established on small outcrops that were too small to be of any interest to climbers. These differences in environment and rock morphology may have a significant impact in the interpretation of the results (see below).

**Taxonomy and identification**

The sampling methods and taxa present combined to provide substantial difficulties in identifying all species present. Reproductive structures, necessary for identifying almost all plants and lichens, are often available during a limited period each year. The plots are time-consuming to resample and it was not possible to obtain reproductive parts on all mosses, ferns, and angiosperms seen in the plots.

Lichens, which form a majority of the flora seen, often require microscopic examination of spores and other parts to determine the genus and species. While many lichen species can be identified directly from the photographs, the size of the plots was too large to resolve fine details clearly on a number of confusing crustose groups (e.g. Aspicilia). The plot size chosen was a compromise between the ability to resolve individual species and the need to include a reasonable surface area within the sample. Given the uncertain status of many lichen taxa, the lack of taxonomic resolution was not considered to be a significant problem. This type of problem is common in remote sensing studies. Most of the groups were confidently identified to genus.

The only species seen that were listed as rare, threatened, or special concern (Coffin and Pfannmuller 1988) were Opuntia macrorhiza, which was seen scattered along the clifftop at Blue Mounds, and Draba arabisans, which was collected once along the top of Shovel Point. The cold, wet spring experienced at Blue Mounds during 1995 prevented my observation of any vernal pool species that apparently grow there.

**Comparison of climbed and unclimbed areas**

The results generally support the hypothesis that vegetation in climbed areas differed from vegetation in unclimbed areas. In general points in unclimbed plots were about 50% more likely to intersect an organism than points in climbed areas (Table 8). There were major differences between locations, however. Climbed areas at Shovel Point had nearly twice the plant coverage of unclimbed areas at both Blue Mounds and Interstate. Vegetation was most sparse at Interstate, which is the area that receives the most climbing pressure. These differences between total vegetation cover at each site should be a consideration when management plans are developed (see Recommendations below).

The contingency table analyses (Tables 10-12) showed a fairly small group of taxa that differed in frequency between unclimbed and climbed plots. Lecanora muralis differed in frequency in all three locations. More important were the significant differences in the number of crustose lichens such as Aspicilia and Rhizocarpon between treatments. These two genera form relatively thin, tough thalli that would seem to more resistant to climbing damage than other genera that also showed significant differences (e.g. Physcia, Parmelia). These analyses were done on presence/absence data at the plot level, and the total elimination of the crust forms in whole plots due to climbing damage seems quite unlikely.

The multivariate analyses (DCA and TWINSPAN) showed some structural differences between climbed and unclimbed plots or transects, although these differences were generally not strong (Table 13; Figs. 3-22). The ordinations showed more variability among unclimbed plots than among climbed plots. One reason for this was that significantly more taxa were found in unclimbed plots at all three locations (Table 9). If all unclimbed plots had the same species frequencies, however, they would not vary significantly from one another. The larger number of species allowed for more combinations of species and led to more variability among unclimbed plots.

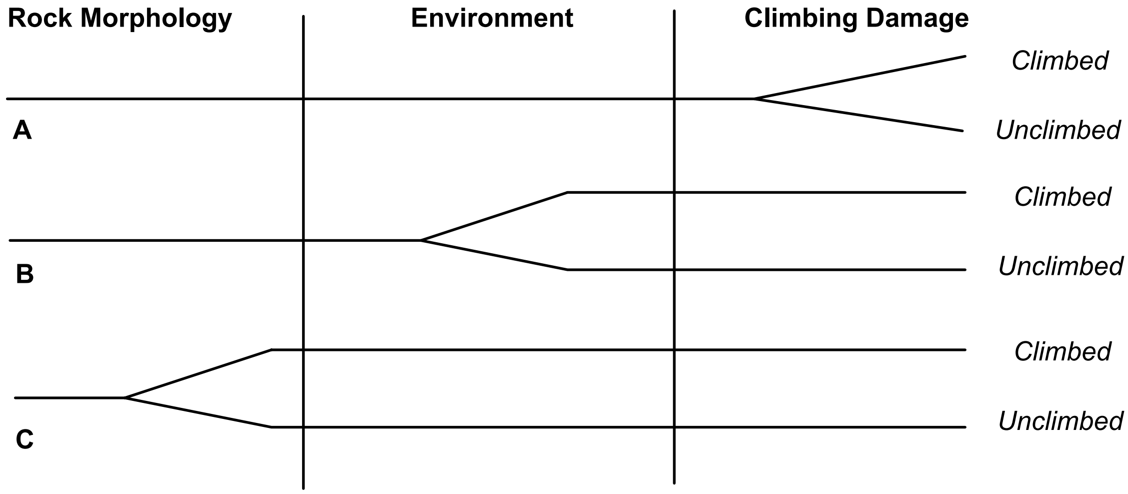
The TWINSPAN analyses attempted to classify each plot according to vegetation similarity. The Shovel Point transect data showed the best separation between climbed and unclimbed plots, but in general the classification attempts were not successful. There appeared to be too much overlap in species composition among plots to sort the plots along a meaningful environmental gradient (such as human disturbance).

While the results show numerous clear differences between climbed and unclimbed plots at all three locations, the actual cause of these differences is still not shown. There are three plausible explanations for differences between climbed and unclimbed plots:

a) climbing damages and removes vegetation, causing the differences.

b) differences in the environment (sunlight, moisture, etc.) cause differences in species composition in different areas, with climbers preferring areas that have less vegetation.

c) differences in rock morphology cause differences in the species composition of different areas, with climbers preferring areas that have less vegetation.




This study can only look at the outcome of any of these three possible causal agents. All three hypotheses have positive and negative points. I will discuss these from a biological viewpoint and from a climber's viewpoint.

The main assumption of the 'climbing' hypothesis is that their are no differences in species composition prior to disturbance of the environment by climbers. The most obvious example of this situation would be a large steep slab, unbroken by cracks or large ledges and covered with umbilicate lichens. Climbing up such a slab will result in the loss of umbilicate lichens in the areas disturbed by the climbers.

The 'environment' hypothesis assumes that rock morphology and climbing have no effect on vegetation. Instead, differences in the physical environment (except for substrate) produce differences in the distribution of species and differences in the patterns of rock use by climbers. For example, a north-facing, damp cliff would likely harbor a number of bryophytes, ferns and angiosperms. It would also see little climbing damage due to the moisture. Conversely a dry, sunny cliff might support fewer plants but be preferred by climbers.

The 'rock morphology' hypothesis would assumes no major influence of climbers or environment. For cliff species, the rock morphology determines the availability of colonization sites and will also influence the environment experienced by the organisms. For example, cracks serve both to collect soil and to channel moisture down the cliff. Areas that are more broken, at lower angle and with more ledges will have more potential colonization sites and may support more species. Similarly, climbers tend to prefer certain types rock morphology. Steep faces and cracks, dihedrals, and areas unbroken by large numbers of ledges are preferred by climbers.

All three of these causal relationships probably function to determine community structure on the three cliffs examined in this study. While climbers certainly cause some of the differences between climbed and unclimbed areas, it is my opinion that a significant fraction of the differences seen were due to a combination of rock morphology and physical environment. I base this on the following observations. First, there is a very patchy distribution of organisms on cliffs, especially at Blue Mounds and Interstate. Casual observation at both locations will reveal areas of rock totally devoid (or nearly so) of vegetation. These areas are not correlated with climbing activity, and may be related to the geological age of the rock exposure. Second, a number of the unclimbed plots at Blue Mounds and Interstate are found in shaded, more mesic areas than most of the climbed plots. Even small differences in moisture availability will have major impacts on the ability of organisms to survive in the generally xeric cliff habitat. At Shovel Point, climbers may cause more of the differences seen, primarily due to the presence of very fragile species (e.g. umbilicate lichens).

**State of the cliff flora**

These three cliffs have been affected by climbers but all have certain characteristics that will aid in preserving the flora. The size of Blue Mounds is its biggest advantage. There are a large number of potential climbs that are too short and too easy to attract much attention from climbers. The chimney-grottos probably harbor a number of unusual species that will be disturbed more often by hikers than climbers.

Interstate has many small outcrops that are too small to climb. These outcrops are scattered throughout the park and should preserve a number of species that are uncommon now on the rocks in the main climbing area. The Potholes area is mostly off-limits to climbers, and should probably be carefully censused in the near future.

Shovel Point has a relatively small number of established climbs. Much of the rock on the lower section of the cliff is somewhat loose, and there is essentially no disturbance on the cliff itself from non-climbers. Few climbers are willing to venture onto unexplored areas of the cliffs.

**Other concerns**

This study was only concerned with vegetation growing in areas exposed to technical rock climbing. The cliff zone makes up only a portion of the entire cliff habitat, with the cliff top and cliff base making up the rest. Although no data were collected on trampling damage at the top and bottoms of these cliffs, it was very obvious that certain areas are highly disturbed by humans. The top of Shovel Point and the top and bottom of the main area at Interstate have suffered the most damage. My primary concern is that further erosion will cause the loss of more trees in these areas. Further erosion on top of Shovel Point and Interstate could change the amount of runoff reaching the cliff face. A loss of trees at the base of Interstate (or Blue Mounds) will further increase the amount of solar radiation reaching some areas of the cliffs.

**Conclusions**

1) The cliff systems at Blue Mounds, Interstate, and Shovel Point have different geological histories and different floral compositions.

2) The rock morphology and some environmental variables differed between climbed and unclimbed plots.

3) Unclimbed plots contained more species per plot and a higher frequency of organisms per plot than climbed plots.

4) Most of the organisms observed were lichens.

5) Multivariate analyses showed some differentiation between climbed and unclimbed plots and transects.

6) The actual cause of differences between climbed and unclimbed plots is likely a combination of rock morphology, environment, and climbing pressure.

7) While climbers have an impact on the cliff flora, each cliff system appears to have a significant component of relatively undamaged cliff flora that will not likely be disturbed in the near future by climbers. Shovel Point would be the most likely cliff to suffer damage due to climbers because of the possibility of new routes and the frequency of umbilicate lichens.

8) Preservation of the cliff base and cliff top habitat may be the most important short term management goal.

**Recommendations**

1) The current state of cliff top and cliff base vegetation should be studied at Interstate and Shovel Point and a management plan enacted to preserve trees and other native vegetation.

2) The proposed climbing management plan places limits on the ability of climbers to place fixed protection (bolts and pitons) in state parks. Vegetation at all three parks would suffer if climbers were permitted to place bolts on any of these cliffs. Exceptions could be made for top rope anchors at Interstate and Shovel Point only if those anchors helped to preserve trees or other vegetation.

3) There were no areas that need to be closed to climbing due to the presence of rare species.

## LITERATURE CITED


Access Fund. 1993. Brochure. Boulder, CO.

Ashton, D. H. and R. N. Webb. 1977. The ecology of granite outcrops at Wilson's Promontory, Victoria. Australian Journal of Ecology 2: 269-296.

Bonham, C. D. 1989. Measurements for terrestrial vegetation. New York: John Wiley and Sons.

Burbanck, M. P. and R. B. Platt. 1964. Granite outcrop communities of the Piedmont Plateau in Georgia. Ecology 45: 292-306.

Causton, D. R. 1988. An introduction to vegetation analysis: principles, practice and interpretation. London: Unwin Hyman.

Coffin, B. and L. Pfannmuller. 1988. Minnesota's endangered flora and fauna. Minneapolis: University of Minnesota Press.

Farris, M.A. 1995. Minnesota rock: selected climbs. Mossy Rock Press, Northfield, MN.

Fink, B. 1898. Contributions to a knowledge of the lichens of Minnesota 3. The rock lichens of Taylor's Falls. Minnesota Botanical Studies 2: 1-18.

Fink, B. 1899a. Contributions to a knowledge of the lichens of Minnesota 4. Lichens of the Lake Superior region. Minnesota Botanical Studies 2: 215-76.

Fink, B. 1899b. Contributions to a knowledge of the lichens of Minnesota 5. Lichens of the Minnesota valley and southwestern Minnesota. Minnesota Botanical Studies 2: 277-329.

Fink, B. 1910. The lichens of Minnesota. Contributions from the United States National Herbarium 14: 1-250.

Foote, K. G. 1966. The vegetation of lichens and bryophyes on limestone outcrops in the driftless area of Wisconsin. Bryologist 69: 265-292.

Goldsmith, F. B. 1973. The vegetation of exposed sea cliffs at South Stack, Anglesy. I. The multivariate approach. Journal of Ecology 61: 787-818.

Hill, M.O. 1977. TWINSPAN- A FORTRAN program for arranging multivariate data in an ordered two way table by classification of individuals and attributes. Cornell University, Ithaca, NY.

Hill, M.O. and H.G. Gauch. 1980. Detrended correspondence analysis, an improved ordination technique. Vegetatio 42:47-58.

Holzinger, J. M. 1910. Moss flora of the North Shore of Lake Superior in Minnesota. The Bryologist 13:55-56.

Kershaw, K. A. and J. H. H. Looney. 1985. Quantitative and dynamic plant ecology, 3rd edition. 3rd ed. London: Edward Arnold.

Larson, D. W., S. H. Spring, U. Matthes-Sears, and R. M. Bartlett. 1989. Organization of the Niagara Escarpment cliff community. Canadian Journal of Botany 67: 2731-2742.

Oosting, O. T. and L. E. Anderson. 1937. The vegetation of a barefaced cliff in western North Carolina. Ecology 18: 280-292.

Phillips, D. L. 1982. Life forms of granite outcrop plants. American Midland Naturalist 107: 206-208.

Walters, T. W. and R Wyatt. 1982. The vascular flora of granite outcrops in the central mineral region of Texas. Bulletin of the Torrey Botanical Club 109: 344-364.

Wiser, S. K. 1993. Vegetation of high-elevation rock outcrops of the southern Appalachians. Ph.D., University of North Carolina.

Table 1. Distribution of rock morphology types in climbed and unclimbed plots. In all three areas, rock morphology differed significantly between treatments.

| | Blue Mounds | | Interstate | | Shovel Point | |
|---|---|---|---|---|---|---|
| | Climbed | Unclimbed | Climbed | Unclimbed | Climbed | Unclimbed |
| Face | 4452 | 4200 | 4334 | 4424 | 3094 | 2578 |
| Crack | 128 | 71 | 235 | 104 | 73 | 14 |
| Overhang | 14 | 12 | 6 | 17 | 1 | 0 |
| Ledge | 14 | 30 | 33 | 60 | 0 | 0 |

Table 2. Comparison of environmental factors in climbed and unclimbed plots. Significant differences are noted with asterisks (**P<0.01, ***P<0.001). n=36 for Interstate Unclimbed height from top data (individual plots were excluded). Aspect and slope are presented in degrees.

| | Blue Mounds | | Interstate | | Shovel Point | | |
|---|---|---|---|---|---|---|---|
| | Climbed | Unclimbed | Climbed | Unclimbed | Climbed | Unclimbed | |
| Aspect | 102±6.6 | 103±4.6 | 154 ± 5.8 | 154 ±7.2 | 238 ± 5.8 | 176 ± 5.1 | *** |
| Slope | 6.3 ±1.1 | 5.8 ± 1.3 | 4.5 ± 2.09 | 7.1 ± 2.0 | 19.7± 1.3 | 10.8 ± 2.0 | *** |
| Height from top | 5.9 ± 0.5 | 5.5 ± 0.5 | 7.3 ± 0.7 | 4.9 ± 0.4** | 8.6 ± 0.9 | 7.9 ± 0.8 | |
| *n* | *45* | *44* | *48* | *48* | *33* | *27* | |

Table 3. Mean heights of transects at Blue Mounds and Interstate. Heights were significantly different at Interstate (P<0.01). All transects were 15m long at Shovel Point.

| | Blue Mounds | Interstate | Shovel Point |
|---|---|---|---|
| Climbed | 13.4± 0.36 *n=16* | 16.4 ± 0.63 *n=16* | NA |
| Unclimbed | 12.5± 0.31 *n=15* | 11.92± 0.39 *n=12* | NA |

Table 4. Morphotaxon identification key for Blue Mounds. The table includes the six character key used in data files and some output; the putative identification; the plot number in which the taxon was first defined; and a description.

| Key | Identification | Plot | Description |
|---|---|---|---|
| adcisp | Cirsium sp. | 1312 | thistle, no flowers |
| adanca | Anemone canadensis | 1312 | Canada anemone |
| adun01 | Arabis divericarpa | 1153 | Rock cress, stellate hairs on basal leaves, frts. > 30 degrees, white pets. |
| adun03 | Celtis occidentalis | 1312 | hackberry seedling |
| amgr01 | GrassX | 1213 | grass |
| amgr02 | GrassX | 1283 | grass |
| amgr03 | GrassX | 1262 | grass |
| amgr04 | Agropyron trachycaulum | 1312 | wider blades; subsp. unknown |
| amgr05 | GrassX | 1312 | narrow blades |
| amgr06 | GrassX | 1363 | grass, narrow blade |
| lca901 | Rhizocarpon gr1 | 1283 | gray crust, areolate, black edge. |
| lca902 | Aspilicia gr1 | 2251 | gray crust, irregular small to large, no detail. might be lcan01 |
| lca903 | Aspilicia caesiocinerea | 1252 | lighter gray than lca901, dark edges |
| lcan01 | Caloplaca sideritisX | 1062 | A diverse group.gray brown crust, thin, irregular. Might be Caloplaca sideritis, or just Physcia |
| lcb901 | Black gr1 | 1211 | black, small specks2-5 mm diameter, round |
| lcea01 | Dimelaena oreina | 1073 | green gray, green on edges, grayer in middle, small to large. Dimelaena oriena. |
| lcea02 | Lecanora muralis | 1252 | Lecanora muralis |
| lclefi | Lepraria finkii | 1251 | Lepraria finkii, or other sorediate Lepraria crusts |
| lcyg01 | Acarospora chlorophana | 1223 | yellow gold, small, irregular shape. Some of these are likely Xanthoria elegans. |
| lfa901 | Physcia gr1(lfa90X) | 1073 | gray, mottled, round to irregular, up to 5 cm, Physcia halei/subtilis |
| lfa902 | Physcia gr1(lfa90X) | 1223 | gray, speckled (salt and pepper), irregular shaped. Likely Physcia halei/subtilis |
| lfa903 | Physcia gr1(lfa90X) | 1012 | gray foliose, very scattered, gen. darker than P. halei (but might be the same) |
| lfaw01 | Physcia gr 2 | 1251 | white gray physcia, whiter, broader lobes than lca901 etc. |
| lfcasa | Caloplaca saxicola | 1322 | orange foliose, caloplaca saxicola, round, loose centers, rare |
| lfea01 | Parmelia gr1 | 1252 | Parmelia;loosely attached, no apo, maybe sorediate/isidiate |
| lfn901 | Parmelia substygia | 1243 | brown foliose, parmelia or dermatocarpon (or moss) |
| lfon01 | lfon01 | 1241 | orange-brown, not sure what it is! |
| lfyg01 | Xanthoria elegans | 1153 | xanthoria elegans, gold foliose |

| | | | |
|---|---|---|---|
| ludemi | Dermatocarpon miniatum | 1251 | Dermatocarpon miniatum |
| omoss1 | Moss sickle | | sickle-leaved moss |
| omoss2 | Moss velvet | 1102 | velvet-moss |

Table 5. Morphotaxon identification key for Interstate. The table includes the six character key used in data files and some output; the putative identification; the plot number in which the taxon was first defined; and a description.

| Key | Identification | Plot | Description |
|---|---|---|---|
| adam01 | Polyganum amphibium var. stipulaceum | 2063 | Water smartweed; land form (Flora of Great Plains; p. 224-225) |
| adaqca | Aquiligea canadensis | 2411 | columbine |
| adsoli | Solidago sp. | 2072 | goldenrod(s), not flowering. |
| adun01 | Houstonia longifolia | 2303 | angiosperm dicot, near top of noahs ark |
| amgr01 | Digitaria sanguinalis | 2063 | crabgrass |
| amgr02 | grassX | 2121 | unknown grass on piece of pie- very small (missing in 1995) |
| lca901 | Lecanora thysanophora | 2072 | gray crust- very tight on rock, thin, irregular margin, lighter than lca903 |
| lca902 | Aspicilia gr2 | 2022 | gray, somewhated lobed at margins, may be same as lca901 |
| lca903 | Ascpicilia gr3 | 2222 | gray crust, very thin, large, looks like gray porch paint |
| lcab01 | Lecanora sp | 2263 | gray-black, 1cm diam or larger, slate colored, prob. present earlier |
| lcan02 | Rhizocarpon grande | 2441 | gray brown cente, dark brown/black margin- Rhizocarpon? |
| lcaw02 | Aspicilia gr1 | 2231 | white-gray, slightly bubbly, feathery margin (aspicilia?) |
| lcaw03 | Lepraria lobificans | 2231 | white,subcrustose, foliose margin, generally follows cracks. whiter but more irregular in color than lcaw02 |
| lcaw04 | lcaw04 | 2312 | gray white,foliose?crustose?, thin intermittent but with some hint of a margin. |
| lcb901 | Lecidea | 2122 | black crust, circular, 1cm |
| lcea03 | Lecanora muralis | 2231 | Lecanora muralis (gray to olive green) |
| lcea04 | Dimelaena oriena | 2292 | Dimeleana oreina |
| lclefi | Lepraria finkii | 2072 | green white powder, on dirt/moss etc in cracks; any purely sorediate form is included |
| lcon01 | lcon01 | 2261 | orange-brown, gray margin, irregular shape |
| lcyg01 | lcyg01 | 2103 | yellow gold crust-common. sort of powdery, in pockets |

| | | | |
|---|---|---|---|
| lcyg02 | Acarospora chlorophana | 2163 | somewhat more yellow than fcyg01, and more definite body. foliose/crustose |
| lfey01 | Parmelia gr2 | 2212 | foliose, green yellow, 5cm2, small lobes, tight to rock, a Parmelia |
| lfey03 | Parmelia gr1 | 2241 | Parmelia, yellow green, somwhat scattered, loose centers, darker green |
| lfparu | Parmelia rudecta | 2231 | Parmelia rudecta . gray foliose, larger |
| lfyg01 | Xanthoria fallax | 2311 | foliose,yellow gold, xanthoria fallax (its oranger though) |
| ofun01 | Woodsia ilvensis | 2232 | very small fern. see closeup |
| omun01 | moss1 | 2232 | grass', looks like scraggly turf (long narrow leaves) |
| omun02 | moss2 | 2302 | moss, brown, distinct stems (like ind. spikes, about 1 cm long). called 'bud'; like small spruce buds. |
| omun03 | moss3 | 2233 | dark green leaves, long white awns, on stalks,='awned |

Table 6. Morphotaxon identification key for Shovel Point. The table includes the six character key used in data files and some output; the putative identification; the plot number in which the taxon was first defined; and a description.

| Key | Identification | Plot | Description |
|---|---|---|---|
| adaqca | Aquilegia canadensis | 3021 | columbine- Aquilegia canadensis |
| adcaro | Campanula rotundifolia | 3081 | harebell, Campanula rotundifolia |
| adso01 | Solidago hispida | 3021 | solidago sp.- common |
| adun01 | Campanula rotundifolia | 3071 | leaves, herb, arrow to heart shape, 1cm wide |
| adun04 | dicot1 | 3021 | dissected leaves- rel. common |
| amgr01 | Agrostis scabra | 3081 | unk. grass |
| amgr02 | Poa sp2 | 3021 | unk. grass |
| lca901 | Aspicilia gr1 | 3061 | gray, black fringe, lighter bumby center, to 4 cm. Intergrades into lca902 and lcaw01. Probably includes Aspcilia spp. |
| lca902 | Aspicilia gr2 | 3061 | gray, no surface texture, small, spotty. This was useds as a catch-all category and certainly contains different taxa. |
| lcaw01 | Aspiclia gr3 | 3072 | white-gray, thin, aereolate, irregular shape. Compare with lca901 |
| lcaw02 | Aspilicia gr4 | 3272 | thick crust, parts are missing |
| lcb901 | Rhizocarpon gr1 | 3061 | black, sooty, irregular, some surface texture. Generally well defined, with a dark edge. Rhizocarpon grande, disporum, etc.?? |
| lcey02 | Lecanora muralis | 3061 | green, bubbly crust left of point5-4 (52), darker green than lcey01. Lecanora muralis. Some of lfey01 is certainly this as well. |
| lclefi | Lepraria finkii | 3103 | Lepraria finkii. Possibly confusing with lcaw01, which might have some of the same. |
| lfa902 | Physcia gr1 | 3081 | a physcia (halei or subtilis). Could be phaea or the like as well. |
| lfaw01 | Physcia gr2 | 3073 | white grey foliose (prob. Physcia). Attempts were made to keep this distinct from lfa902. Lobes are larger, and much whiter. P. caesia, P. phaea |
| lfey01 | Parmelia gr1 | 3063 | yellow green foliose, scattered in cracks, check w/lfey02. Overlaps with lfa901 as colors don't always show up that well. Mostly Parmelia spp. with some Lecanora muralis as well. |
| lfey02 | Parmelia gr2 | 3061 | yellow green, maybe foliose, small, scattered, in cracks (may be lcey01). A combination of Parmelia spp., Dimaleana oriena, and Lecanora muralis |
| lfey03 | Parmelia gr3 | 3081 | Parmelia spp. |

| | | |
|---|---|---|
| lfey04 | Parmelia gr4 | 3243 parmelia, broader lobes than lfey03 |
| lfn901 | Parmelia substygia | 3052 brown parmelia? |
| lfxael | Xanthoria elegans | 3021 xanthoria elegans- orange foliose very common |
| lra901 | Anaptychia setifera | 3293 smokey gray fruticose, whiter at base |
| lrey01 | Ramalina intermedia | 3241 fruticose yellow green |
| lulapu | Lasallia papulosa | 3262 Lasalia papulosa, umbilicate, pustulate. Obvious when focus is correct. Small individuals could be confused with Umbilicaria muhlenbergii. |
| luummu | Umbilicaria muhlenbergii | 3072 umbilicaria muhlenbergii. Small individuals could be confused with Lasalia papulosa or U. vella. |
| luumve | Umbilicaria vellea | 3071 umbillicaria vella. Small individuals could be confused with U. muhlenbergii. |
| of9901 | Woodsia ilvensis | 3081 fern, common one (all that I saw were like this, i think). |
| omunk1 | **change to mossX | 3081 moss, hard to ID |
| omunk2 | **omoss5 | 3052 moss (red stalks, small spikes) |
| omunk3 | **omoss1 | 3261 moss, very scattered, see closeup pic. (sickle2) |
| omunk4 | **omoss3 | 3042 moss, see picture (close up) |
| omunk5 | **change to omossX | 3261 moss, tufts, small , prob. same as another moss |
| omunk6 | **change to omossX | 3262 moss in crack |
| omunk7 | **change to omossX | 3293 moss |
| oubl01 | **omoss1 | 3021 a moss |

Table 7. There is no table 7.

Table 8. Number of points containing taxa in climbed and unclimbed plots. Percentages expressed as a fraction of the total number of sample points in each treatment at each location. All three contingency table analyses were highly significant (P< 0.001).

| | Blue Mounds | | Interstate | | Shovel Point | |
|---|---|---|---|---|---|---|
| | + taxa | - taxa | + taxa | - taxa | + taxa | - taxa |
| Climbed | 863 | 3745 | 158 | 4450 | 1921 | 1247 |
| | (18%) | (82%) | (3%) | (97%) | (61%) | (39%) |
| Unclimbed | 1494 | 2826 | 1663 | 2945 | 1950 | 642 |
| | (35%) | (65%) | (36%) | (64%) | (75%) | (25%) |

Table 9. Mean number of taxa per plot in climbed and unclimbed areas. There are significantly differences between climbed and unclimbed plots at all three locations.

| | Blue Mounds | Interstate | Shovel Point |
|---|---|---|---|
| Climbed | 2.88± 0.24 | 0.88± 0.17 | 6.97± 0.39 |
| | *n=48* | *n=48* | *n=33* |
| Unclimbed | 3.98± 0.35 | 4.35± 0.29 | 10.18± 0.44 |
| | *n=45* | *n=48* | *n=27* |

Table 10. Contingency table analyses of taxa at Blue Mounds. Values are the number of plots with or without species in climbed and unclimbed plots. * indicates the null hypothesis of independence was rejected.

| | With Taxon | | Lacking Taxon | | | |
|---|---|---|---|---|---|---|
| | climbed plots | unclimbed plots | climbed plots | unclimbed plots | Chi-square | Significance |
| Cirsium sp. | 0 | 2 | 48 | 43 | 2.18 | NS |
| Anemone canadensis | 0 | 1 | 48 | 44 | 1.08 | NS |
| Arabis divericarpa | 1 | 1 | 47 | 44 | 0.00 | NS |
| GrassX | 0 | 4 | 48 | 41 | 4.46 | * |
| Agropyron trachycaulum | 1 | 0 | 47 | 45 | 0.95 | NS |
| Rhizocarpon gr1 | 1 | 8 | 47 | 37 | 6.54 | * |
| Aspilicia gr1 | 2 | 9 | 46 | 36 | 5.58 | * |
| Aspilicia caesiocinerea | 4 | 10 | 44 | 35 | 3.50 | NS |
| Caloplaca sideritisX | 5 | 8 | 43 | 37 | 1.05 | NS |
| Black gr1 | 24 | 21 | 24 | 24 | 0.10 | NS |
| Dimelaena oreina | 21 | 28 | 27 | 17 | 3.18 | NS |
| Lecanora muralis | 0 | 6 | 48 | 39 | 6.84 | * |
| Lepraria finkii | 1 | 1 | 47 | 44 | 0.00 | NS |
| Acarospora chlorophana | 20 | 15 | 28 | 30 | 0.69 | NS |
| Physcia gr1(lfa90X) | 41 | 40 | 7 | 5 | 0.25 | NS |
| Physcia gr 2 | 0 | 1 | 48 | 44 | 1.08 | NS |
| Caloplaca saxicola | 0 | 1 | 48 | 44 | 1.08 | NS |
| Parmelia gr1 | 0 | 1 | 48 | 44 | 1.08 | NS |
| Parmelia substygia | 0 | 1 | 48 | 44 | 1.08 | NS |
| lfon01 | 0 | 2 | 48 | 43 | 2.18 | NS |
| Xanthoria elegans | 14 | 12 | 34 | 33 | 0.07 | NS |
| Dermatocarpon miniatum | 0 | 1 | 48 | 44 | 1.08 | NS |
| Moss "sickle" | 2 | 2 | 46 | 43 | 0.00 | NS |
| omossX | 0 | 2 | 48 | 43 | 2.18 | NS |
| Moss "velvet" | 1 | 2 | 47 | 43 | 0.41 | NS |

Table 11. Contingency table analyses of taxa at Interstate. Values are the number of plots with or without species in climbed and unclimbed plots. * indicates the null hypothesis of independence was rejected.

| | With climbed plots | Taxon unclimbed plots | Lacking climbed plots | Taxon unclimbed plots | Chi-square | Significance |
|---|---|---|---|---|---|---|
| Polyganum amphibium var. stipulaceum | 1 | 0 | 47 | 48 | 1.01 | NS |
| Aquiligea canadensis | 0 | 1 | 48 | 47 | 1.01 | NS |
| Solidago sp. | 1 | 2 | 47 | 46 | 0.34 | NS |
| Houstonia longifolia | 0 | 1 | 48 | 47 | 1.01 | NS |
| Digitaria sanguinalis | 1 | 0 | 47 | 48 | 1.01 | NS |
| grassX | 1 | 0 | 47 | 48 | 1.01 | NS |
| Lecanora thysanophora | 9 | 25 | 39 | 23 | 11.66 | * |
| Aspicilia gr2 | 3 | 22 | 45 | 26 | 19.52 | * |
| Ascpicilia gr3 | 0 | 6 | 48 | 42 | 6.40 | * |
| Lecanora sp | 0 | 5 | 48 | 43 | 5.27 | * |
| Rhizocarpon grande | 0 | 4 | 48 | 44 | 4.17 | * |
| Aspicilia gr1 | 2 | 28 | 46 | 20 | 32.78 | * |
| Lepraria lobificans | 0 | 19 | 48 | 29 | 23.69 | * |
| lcaw04 | 0 | 3 | 48 | 45 | 3.10 | NS |
| Lecidea | 0 | 5 | 48 | 43 | 5.27 | * |
| Lecanora muralis | 8 | 21 | 40 | 27 | 8.35 | * |
| Dimelaena oriena | 1 | 3 | 47 | 45 | 1.04 | NS |
| Lepraria finkii | 1 | 10 | 47 | 38 | 8.32 | * |
| lcon01 | 0 | 1 | 48 | 47 | 1.01 | NS |
| lcyg01 | 12 | 24 | 36 | 24 | 6.40 | * |
| Acarospora chlorophana | 2 | 7 | 46 | 41 | 3.07 | NS |
| Parmelia gr2 | 0 | 4 | 48 | 44 | 4.17 | * |
| Parmelia gr1 | 0 | 3 | 48 | 45 | 3.10 | NS |
| Parmelia rudecta | 0 | 5 | 48 | 43 | 5.27 | * |
| Xanthoria fallax | 0 | 2 | 48 | 46 | 2.04 | NS |
| Woodsia ilvensis | 0 | 2 | 48 | 46 | 2.04 | NS |
| moss1 | 0 | 2 | 48 | 46 | 2.04 | NS |
| moss2 | 0 | 1 | 48 | 47 | 1.01 | NS |
| moss3 | 0 | 3 | 48 | 45 | 3.10 | NS |

Table 12. Contingency table analyses of taxa at Shovel Point. Values are the number of plots with or without species in climbed and unclimbed plots. * indicates the null hypothesis of independence was rejected.

| | With climbed plots | Taxon unclimbed plots | Lacking climbed plots | Taxon unclimbed plots | Chi-square | Significance |
|---|---|---|---|---|---|---|
| Aquilegia canadensis | 1 | 0 | 32 | 27 | 0.83 | NS |
| Campanula rotundifolia | 3 | 2 | 30 | 25 | 0.06 | NS |
| Solidago hispida | 4 | 3 | 29 | 24 | 0.01 | NS |
| Campanula rotundifolia | 3 | 4 | 30 | 23 | 0.47 | NS |
| dicot1 | 1 | 0 | 32 | 27 | 0.83 | NS |
| Agrostis scabra | 1 | 0 | 32 | 27 | 0.83 | NS |
| Poa sp2 | 2 | 0 | 31 | 27 | 1.69 | NS |
| amgr0X | 2 | 0 | 31 | 27 | 1.69 | NS |
| Aspicilia gr1 | 26 | 25 | 7 | 2 | 2.22 | NS |
| Aspicilia gr2 | 27 | 24 | 6 | 3 | 0.58 | NS |
| Aspiclia gr3 | 2 | 0 | 31 | 27 | 1.69 | NS |
| Aspilicia gr4 | 0 | 1 | 33 | 26 | 1.24 | NS |
| Rhizocarpon gr1 | 28 | 23 | 5 | 4 | 0.00 | NS |
| Lecanora muralis | 19 | 24 | 14 | 3 | 7.17 | * |
| Lepraria finkii | 1 | 2 | 32 | 25 | 0.60 | NS |
| Physcia gr1 | 26 | 27 | 7 | 0 | 6.48 | * |
| Physcia gr2 | 1 | 8 | 32 | 19 | 8.24 | * |
| Parmelia gr1 | 24 | 21 | 9 | 6 | 0.20 | NS |
| Parmelia gr2 | 2 | 6 | 31 | 21 | 3.36 | NS |
| Parmelia gr3 | 6 | 14 | 27 | 13 | 7.58 | * |
| Parmelia gr4 | 0 | 5 | 33 | 22 | 6.67 | * |
| Parmelia substygia | 3 | 21 | 30 | 6 | 29.19 | * |
| Xanthoria elegans | 9 | 11 | 24 | 16 | 1.21 | NS |
| Anaptychia setifera | 0 | 1 | 33 | 26 | 1.24 | NS |
| Ramalina intermedia | 0 | 2 | 33 | 25 | 2.53 | NS |
| Lasallia papulosa | 0 | 2 | 33 | 25 | 2.53 | NS |
| Umbilicaria muhlenbergii | 16 | 19 | 17 | 8 | 2.93 | NS |
| Umbilicaria vellea | 13 | 22 | 20 | 5 | 10.82 | * |
| Woodsia ilvensis | 2 | 2 | 31 | 25 | 0.04 | NS |
| omossX | 2 | 3 | 31 | 24 | 0.50 | NS |
| omoss5 | 3 | 0 | 30 | 27 | 2.58 | NS |
| omoss1 | 2 | 3 | 31 | 24 | 0.50 | NS |
| omoss3 | 1 | 0 | 32 | 27 | 0.83 | NS |

Table 13. Correlations between DCA plot scores and plot environmental data (distance from top of cliff, aspect, and slope).

a) Blue Mounds

| | Axis 1 | Axis 2 | Axis 3 | Axis4 | distance | aspect | slope |
|---|---|---|---|---|---|---|---|
| Axis 1 | 1 | -.155 | .149 | .105 | .225 | -.109 | -.081 |
| Axis 2 | -.155 | 1 | -.689 | .5 | .006 | .166 | .124 |
| Axis 3 | .149 | -.689 | 1 | -.692 | .139 | -.13 | -.099 |
| Axis4 | .105 | .5 | -.692 | 1 | -.159 | .044 | .101 |
| distance | .225 | .006 | .139 | -.159 | 1 | -.005 | -.067 |
| aspect | -.109 | .166 | -.13 | .044 | -.005 | 1 | -.132 |
| slope | -.081 | .124 | -.099 | .101 | -.067 | -.132 | 1 |

b) Interstate

| | Axis 1 | Axis 2 | Axis 3 | Axis4 | distance | aspect | slope |
|---|---|---|---|---|---|---|---|
| Axis 1 | 1 | -.152 | -.535 | .182 | -.045 | .062 | -.135 |
| Axis 2 | -.152 | 1 | .06 | .051 | -.156 | -.158 | .043 |
| Axis 3 | -.535 | .06 | 1 | -.421 | .173 | .092 | .161 |
| Axis4 | .182 | .051 | -.421 | 1 | -.078 | -.018 | -.182 |
| distance | -.045 | -.156 | .173 | -.078 | 1 | .135 | -.073 |
| aspect | .062 | -.158 | .092 | -.018 | .135 | 1 | .032 |
| slope | -.135 | .043 | .161 | -.182 | -.073 | .032 | 1 |

c) Shovel Point

| | Axis 1 | Axis 2 | Axis 3 | Axis4 | distance | aspect | slope |
|---|---|---|---|---|---|---|---|
| Axis 1 | 1 | .053 | -.132 | -.171 | .043 | -.231 | -.543 |
| Axis 2 | .053 | 1 | .002 | -.324 | -.277 | -.09 | -.119 |
| Axis 3 | -.132 | .002 | 1 | .24 | .038 | -.378 | -.03 |
| Axis4 | -.171 | -.324 | .24 | 1 | -.076 | -.146 | -.194 |
| distance | .043 | -.277 | .038 | -.076 | 1 | -.092 | -.044 |
| aspect | -.231 | -.09 | -.378 | -.146 | -.092 | 1 | .382 |
| slope | -.543 | -.119 | -.03 | -.194 | -.044 | .382 | 1 |

Fig. 1. A schematic diagram of the sampling method. Plots were randomly located within each of the three zones on the cliff.

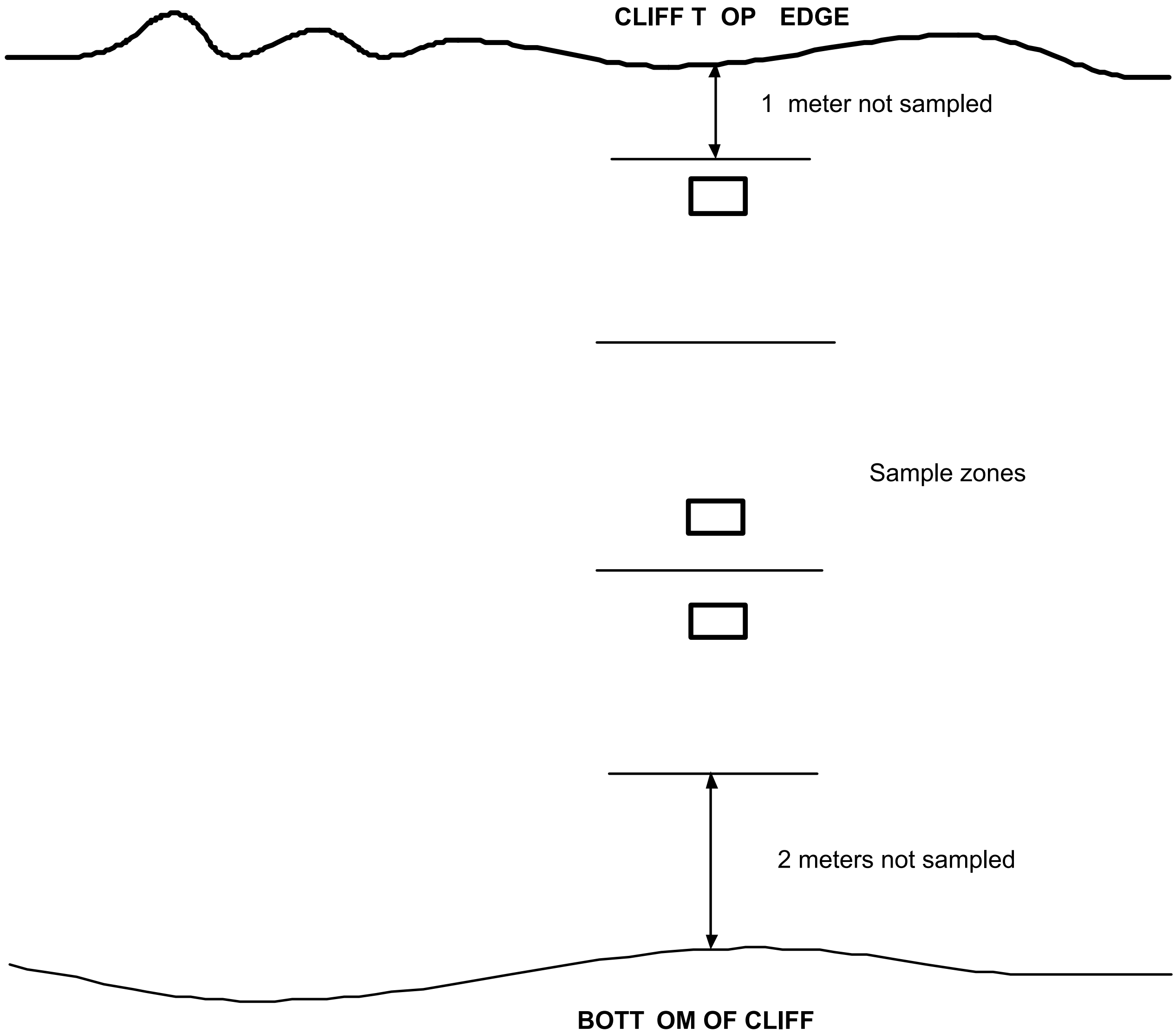


Fig. 2. Examples of adjustments for parallax error when projecting slides of plots. If the plot was photographed in proper parallax. The grid superimposed to locate the 96 sample points would form a series of squares. If the plot was photographed in a skewed manner,  the grid lines followed the distortion of the plot.

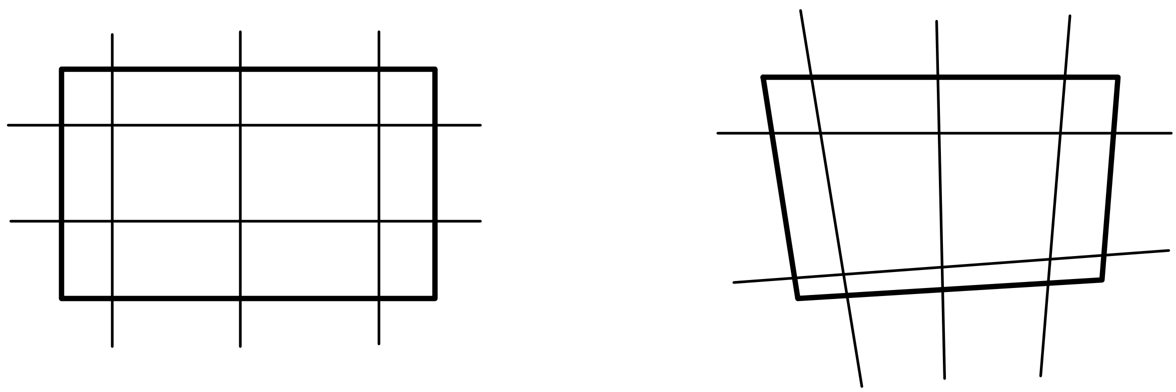


Fig. 3. Plot scores for Blue Mounds DCA analysis. Open circles represent climbed plots, closed circles respresent unclimbed plots

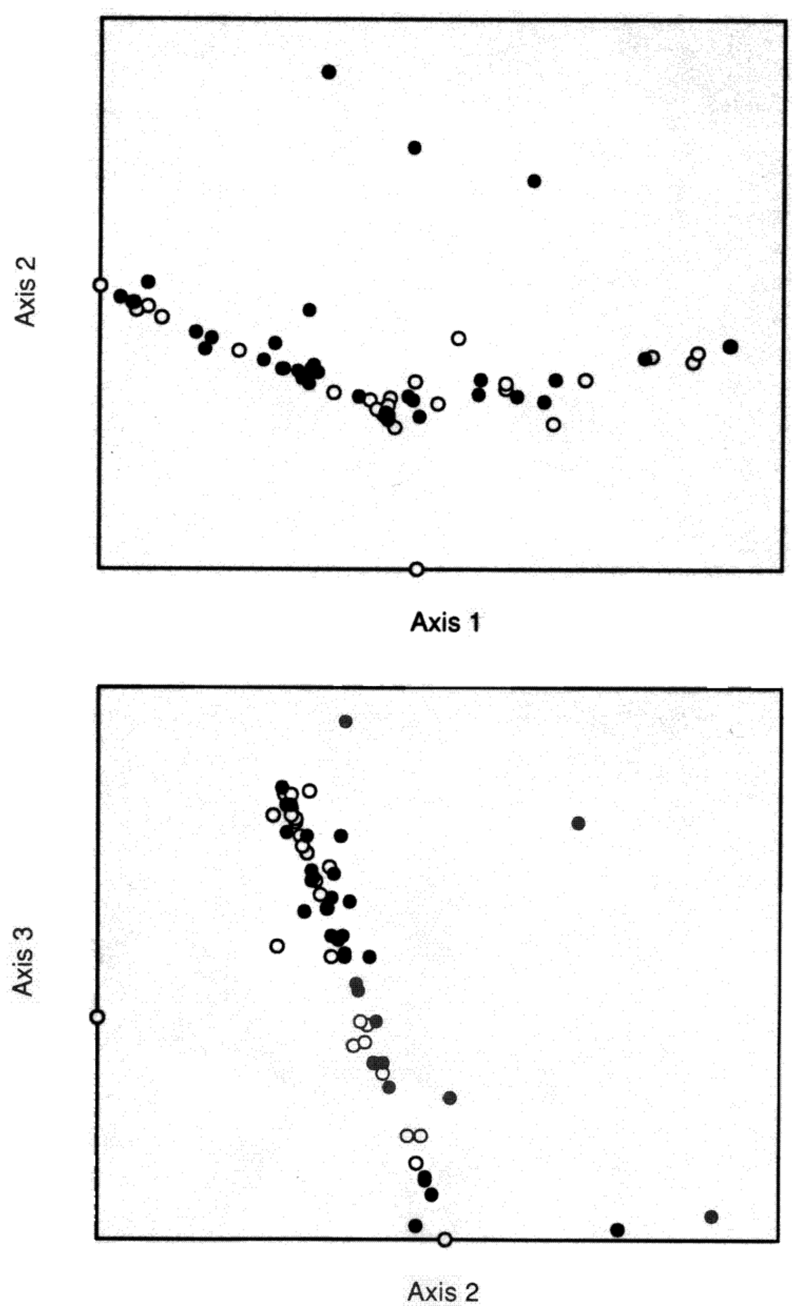


Fig. 4. Species loadings for Blue Mounds DCA plot analysis.

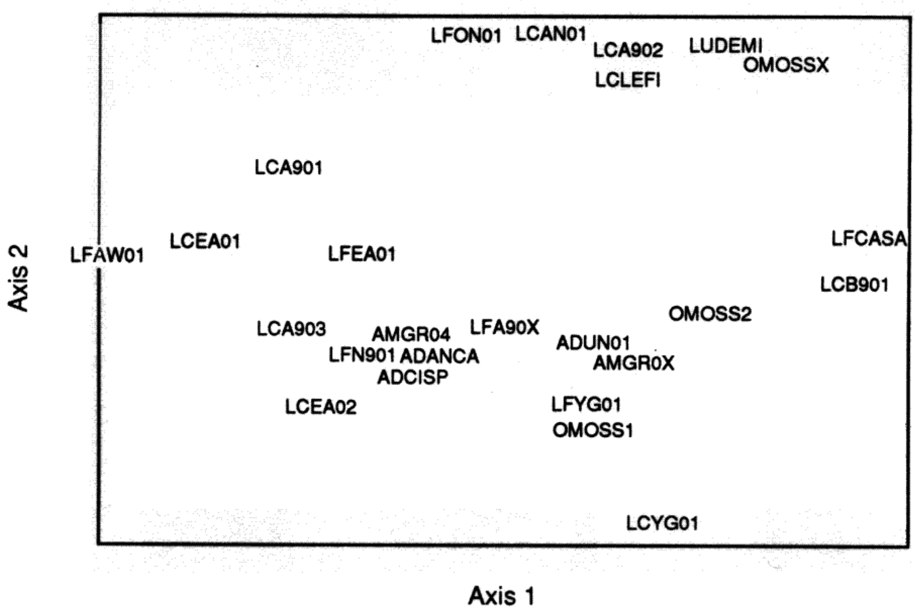


Fig. 5. TWINSPAN analysis for Shovel Point Plot data. Species are listed along the vertical axis, plots along the horizontal axis. Each row of zeros and ones along the bottom represents a division between the groups (0=one group, 1= the other). The top row represents the first division, the second row the second division, and so forth. See Fig. 11 for a breakdown of a TWINSPAN table into groups.

```
 ORDER OF SAMPLES
   57    U1261 |  60    U1271 |  27    C1103 |  21    C1073 |  66    U1291 |  67    U1292 |  69    U1301 |  55    U1252
   59    U1263 |  71    U1303 |  84    U1351 |  34    C1131 |  38    C1142 |  39    C1143 |  41    C1152 |  56    U1253
   61    U1272 |  64    U1282 |  65    U1283 |  68    U1293 |  77    U1323 |  86    U1353 |  89    U1363 |   1    C1011
    2    C1012 |   3    C1013 |   4    C1021 |   6    C1023 |   7    C1031 |   8    C1032 |   9    C1033 |  11    C1042
   14    C1052 |  15    C1053 |  18    C1063 |  19    C1071 |  20    C1072 |  22    C1082 |  23    C1083 |  24    C1092
   25    C1093 |  28    C1111 |  29    C1112 |  30    C1113 |  35    C1132 |  40    C1151 |  49    U1222 |  50    U1223
   52    U1242 |  53    U1243 |  62    U1273 |  70    U1302 |  75    U1321 |  78    U1331 |  80    U1333 |  82    U1342
   83    U1343 |  85    U1352 |  87    U1361 |  88    U1362 |   5    C1022 |  43    C1161 |  73    U1312 |  13    C1051
   10    C1041 |  12    C1043 |  26    C1102 |  37    C1141 |  72    U1311 |  79    U1332 |  48    U1213 |  16    C1061
   42    C1153 |  44    C1162 |  45    C1163 |  58    U1262 |  63    U1281 |  74    U1313 |  81    U1341 |  31    C1121
   32    C1122 |  33    C1123 |  36    C1133 |  46    U1211 |  47    U1212 |  76    U1322 |  17    C1062 |  51    U1241
   54    U1251 |

                5622666557833345666788        11111222222233445556777888888 4711123774144456783333447155
                70716795914489161458769123467891458902345890509023205802357853330267298624583411236676714

   1   AD CISP  --------------------2-----------------------------------------4--------------------------  0000
   2   AD ANCA  --------------------------------------------------------------2--------------------------  0000
   5   AM GR04  ---------------------------------2-------------------------------------------------------  0000
  12   LC EA02  -------2332----------21------------------------------------------------------------------  0000
  16   LF AW01  ---------------------------------------------------2-------------------------------------  0000
  18   LF EA01  -------1---------------------------------------------------------------------------------  0000
  19   LF N901  --------2--------------------------------------------------------------------------------  0000
   8   LC A903  -------24141-----5--1------------1----1----------------------21------------111-----------  0001
   6   LC A901  ---2-4-2234-----1-3---------------------------------------------------------------------2  001
   7   LC A902  5----4-32-2---------1--4--------------------------2----------2-----------------------2--5  001
  11   LC EA01  4-555555453455553555555--5----11312---1--2-122-51355--1-15-----3----1-5-21111------------  001
  21   LF YG01  --------1-12223113-12----------111--------11----------------222--1--3-1-1-11-3-----------  010
  23   OM OSS1  ----------------3-----1---------------1-----------------------------------2--------------  010
   3   AD UN01  --------------------------------------------------------------4---------2----------------  011
  15   LF A90X  -4-444455555453554545555555555555555555555555555555555555555553553555-54555555---3--4553  011
  25   OM OSS2  -------------------------------------------------4-1--------------3----------------------  011
   9   LC AN01  55-----2--1----------------------11--------------2----------------------12-4----------434  100
  13   LC LEFI  --------------------------------1-------------------------------------------------------1  100
  20   LF ON01  3--------------------------------------------------------------------------------------2-  100
  10   LC B901  --2-1--22--151--413-2-----1-11--2-1---------22--1-----1---------1555535555455555555555334  1010
  17   LF CASA  -------------------------------------------------------------------------------------4---  1010
  22   LU DEMI  ----------------------------------------------------------------------------------------2  1010
  24   OM OSSX  -------------------------------------------------------------------------------------1--1  1010
   4   AM GR0X  ------------------3---1---------------------------------------1-------5------------------  1011
  14   LC YG01  --2----1-----1-1--1-1--1121211-211----1------2-21-1---1211-----5433533---1--1-----------1  11

                00000000000000000000000000000000000000000000000000000000000000011111111111111111111111111
                00000001111111111111111111111111111111111111111111111111111111100000000111111111111111111
                00111110000000000000011111111111111111111111111111111111111111100000000100000000000000111
                  011110000111111111111000000000000000000000000000000000000011101111111 000000001111111
```

**Fig. 6. Plot scores from the DCA analysis of the Interstate data. Open circles represent climbed plots, closed circles represent unclimbed plots.**

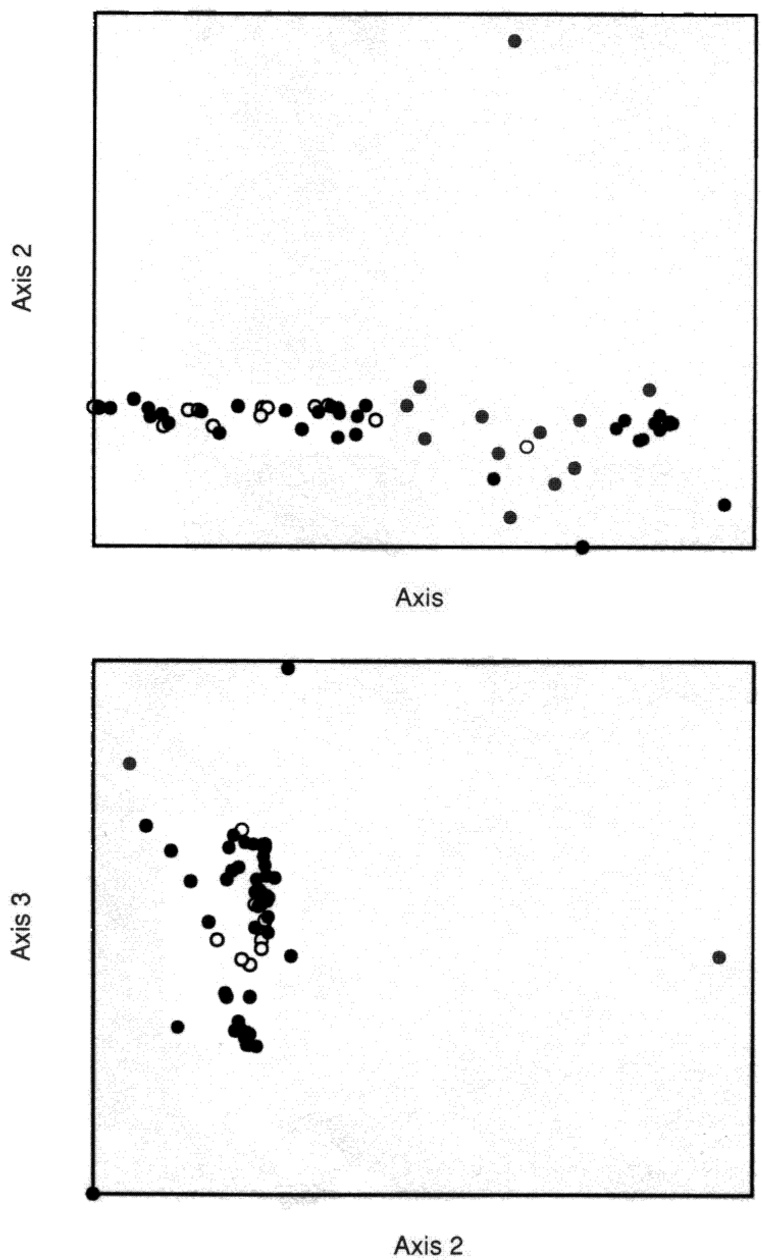


Fig. 7. Species loadings from the DCA analysis of the Interstate plot data.

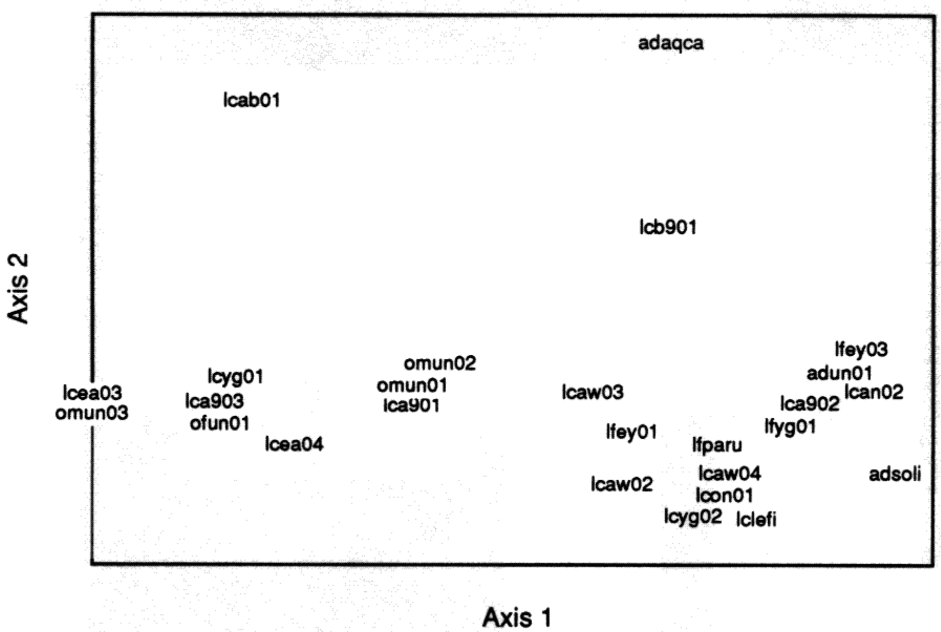


Fig. 8a. TWINSPAN analysis for Interstate Plot data. Species are listed along the vertical axis, plots along the horizontal axis. Each row of zeros and ones along the bottom represents a division between the groups (0=one group, 1= the other). The top row represents the first division, the second row the second division, and so forth. See Fig. 11 for a breakdown of a TWINSPAN table into groups.

```
ORDER OF SAMPLES
    2    C2012 |  13    C2091 |  49    U2293 |  59    U2411 |   1    C2011 |   4    C2021 |  44    U2281 |  45    U2282
   48    U2292 |  50    U2301 |  56    U2321 |  60    U2421 |   3    C2013 |   7    C2033 |  16    C2103 |  23    C2163
   25    U2212 |  26    U2221 |  27    U2222 |  36    U2252 |  37    U2253 |  42    U2272 |  46    U2283 |  51    U2302
   40    U2263 |  43    U2273 |  47    U2291 |  55    U2313 |  58    U2323 |  68    U2511 |   6    C2023 |   8    C2043
   10    C2071 |  12    C2083 |  19    C2132 |  20    C2133 |  22    C2161 |  28    U2223 |  29    U2231 |  30    U2232
   31    U2233 |  34    U2243 |  57    U2322 |  33    U2242 |  52    U2303 |  14    C2101 |  15    C2102 |  18    C2123
   21    C2141 |  35    U2251 |  54    U2312 |  64    U2471 |   5    C2022 |  39    U2262 |  41    U2271 |  61    U2431
   62    U2441 |  63    U2451 |  65    U2481 |  66    U2491 |  32    U2241 |  38    U2261 |  69    U2521 |  53    U2311
   67    U2501 |  11    C2072 |  24    U2211 |

                  145  444556  1222233445444556  11122223335351112356 34666663365612
                 2399144580603763567672610375886802902890147324581544591123562893714

    7   lc a901  1111222224-3232554455444542--2-------2222---------------3------2-2-  000
   15   lc b901  ---1--2-2--2----------------------------------------------------2--  000
   21   lc yg02  --------3-1---22---21---------------------1------21----------------  000
   28   om un02  -----------------------2-------------------------------------------  000
    2   ad aqca  ---2---------------------------------------------------------------  0010
    4   ad un01  --------------------------------------------3----------------------  0010
    9   lc a903  ------------------42-----------------24----22----------------------  0010
   17   lc ea04  --------2-------------------2--------------2---1-------------------  0010
   26   of un01  -------1-------------------------------2---------------------------  0010
   27   om un01  -----------------------2---------------1---------------------------  0010
   29   om un03  --------------------------------------122--------------------------  0010
   10   lc ab01  ---1--------------------4--22-------------------------1------------  0011
   16   lc ea03  ---------------3-4-2-21-24555213253224555555----------------22-22--  0011
   20   lc yg01  1-----------1324---332223235532--2---22221-42111321-1-11---11------  0011
   12   lc aw02  -------222-3---2--3-222-434-35----2---34---------122-22-21232522---  01
   13   lc aw03  --1---22-2-2--------2--32-------------2212212-----21--2-4----------  01
   18   lc lefi  -------11-1--------1-----1-------------2---------111----------1--2-  10
   22   lf ey01  ----------------2---------------------------1----------------2-1---  10
   14   lc aw04  ------------------------------------------2-------3--------1-------  110
   25   lf yg01  -----------------------------3---------------------------------4---  110
    3   ad soli  ---------1-------------------------------------------------------22  1110
   11   lc an02  --------------------------------------------------------1--2--2-1--  1110
   19   lc on01  -------------------------------------------------------------2-----  1110
   23   lf ey03  ------------------------------------------------------------522----  1110
   24   lf paru  --------------------------------------2----------------------2211--  1110
    8   lc a902  -----------2--2----1-----2-2-5-----------1-35----3244-545455345552-  1111

                 0000000000000000000000000000000000000000000000000111111111111111111
                 0000000000000000000000001111111111111111111111111000000000000000011
                 00001111111111111111111100000000000000000001111110000000000011111
                     0000000011111111111100000011111111111110011110001111111100011
```

Fig. 8b. TWINSPAN analysis for Interstate Plot data after combining two taxa (LCA901 and LCA902).

```
ORDER OF SAMPLES
   18    C2123 |   6    C2023 |  14    C2101 |  15    C2102 |  21    C2141 |   8    C2043 |  10    C2071 |  19    C2132
   20    C2133 |  22    C2161 |  30    U2232 |  31    U2233 |  34    U2243 |  57    U2322 |  12    C2083 |  23    C2163
   28    U2223 |  29    U2231 |  33    U2242 |  36    U2252 |  43    U2273 |  47    U2291 |  55    U2313 |  58    U2323
    1    C2011 |   2    C2012 |   3    C2013 |   4    C2021 |   5    C2022 |   7    C2033 |  13    C2091 |  16    C2103
   25    U2212 |  26    U2221 |  27    U2222 |  32    U2241 |  35    U2251 |  38    U2261 |  40    U2263 |  42    U2272
   46    U2283 |  48    U2292 |  52    U2303 |  53    U2311 |  61    U2431 |  63    U2451 |  64    U2471 |  65    U2481
   66    U2491 |  67    U2501 |  68    U2511 |  69    U2521 |  37    U2253 |  39    U2262 |  41    U2271 |  44    U2281
   45    U2282 |  49    U2293 |  50    U2301 |  51    U2302 |  54    U2312 |  59    U2411 |  60    U2421 |  62    U2441
   56    U2321 |  11    C2072 |  24    U2211 |

                  1 112 112233351222334455      1122233344445566666666334444555566512
                  8645180902014723893637581234573656725802682313456789791459014902614

   14   lc ea03   -3---5555555555455535555---------5-1-132---2-----12----------------  0000
   24   of un01   ----------1---------------------------------------------1----------  0000
   27   om un03   ----------22-------------------------------------------------------  0000
    7   lc a903   ----------------4423--------------5-------3------------------------  0001
   15   lc ea04   5-----------------1----1-----------------4-------------------------  0001
   18   lc yg01   55555-----11--2532543355-53--5-5----5-424-2-------4-4------2-------  0001
    8   lc ab01   ----------------------31--------------4----------------------2-----  0010
   10   lc aw02   -------4--5----3-3--44-3----------51155254-2--434-51352-5-3-5-52---  0010
   12   lc aw04   -------------2----------------------------------------------5------  0010
   22   lf paru   -----------------1-------------------2-------------1---------------  0010
   11   lc aw03   ----------2-12---1--------------------1---1---------4-3555353-35---  0011
   19   lc yg02   ---------------1---2-----------4----4----5----------------------5--  0011
    2   ad aqca   -------------------------------------------------------------5-----  0100
   13   lc b901   -----------------------------------------3-------2-----4-----24----  0100
   25   om un01   -----------------------------------------------------------2-------  0100
   26   om un02   -----------------------------------------------------------2-------  0100
    4   ad un01   ------------------------------------------3------------------------  0101
    9   lc an02   ------------------------------------------------2--1---------------  0101
   17   lc on01   -------------------------------------1-----------------------------  0101
   20   lf ey01   --------------------------------2----2-----------------------------  0101
   21   lf ey03   -----------------------------------5-1-------------1---------------  0101
   23   lf yg01   -------------------------------------------5------4----------------  0101
   16   lc lefi   ----------1-------------------------1-------------------1-------54-  011
   28 LCA9 012    ----------21---54145521-55555555555455555355555555555-5555555255-5-  011
    3   ad soli   -----------------------------------------------------------------55  1

                  0000000000000000000000000000000000000000000000000000000000000000011
                  00000000000000000000000011111111111111111111111111111111111111111
                  00000111111111111111111100000000000000000000000000000000000000001
                  0111100000000011111111110000000000000000000000000001111111111111
```

Fig. 9. Plot scores for Shovel Point DCA analysis. Open circles represent climbed plots, closed circles respresent unclimbed plots.

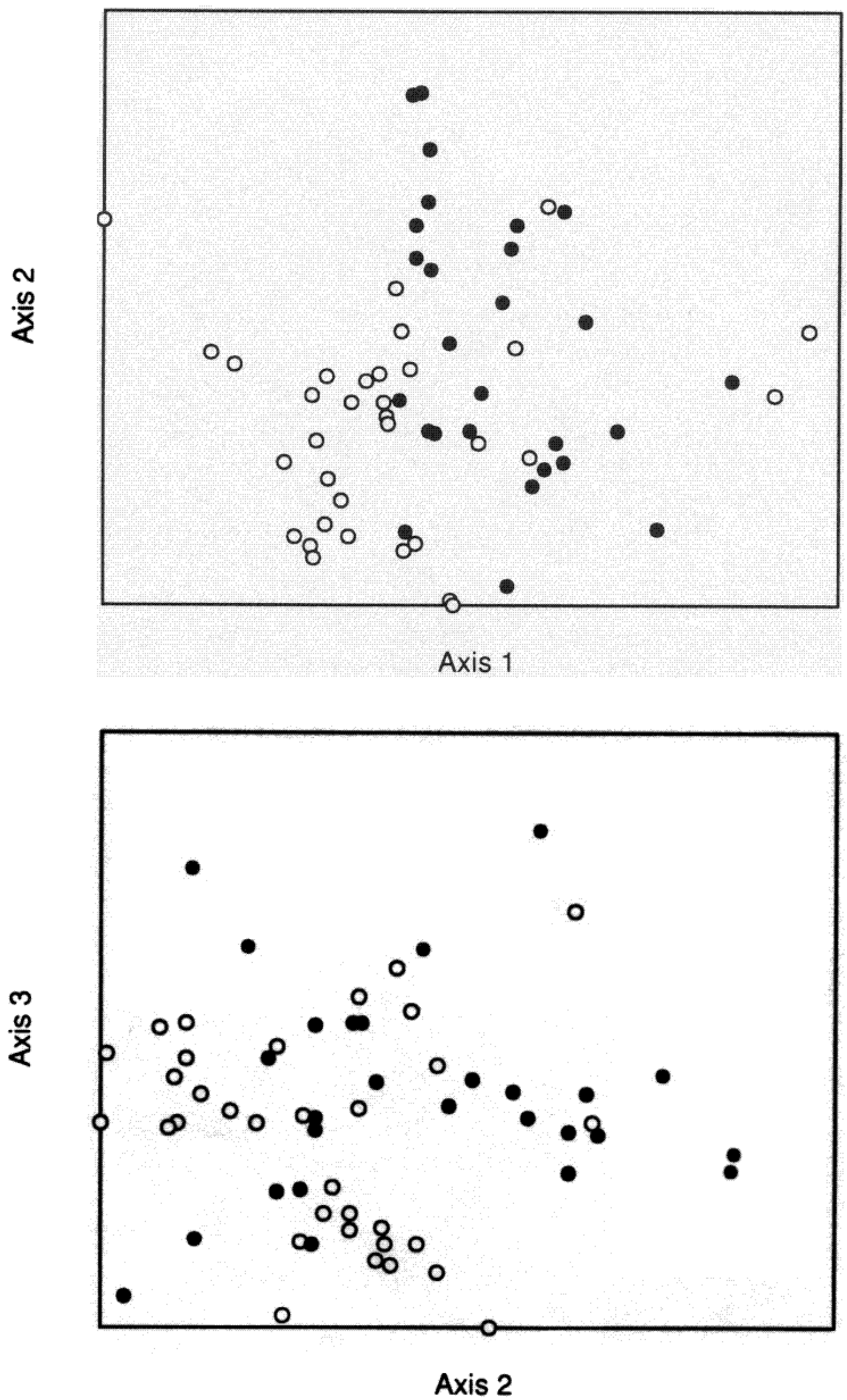


Fig. 10. Species loadings for the Shovel Point DCA plot analysis.

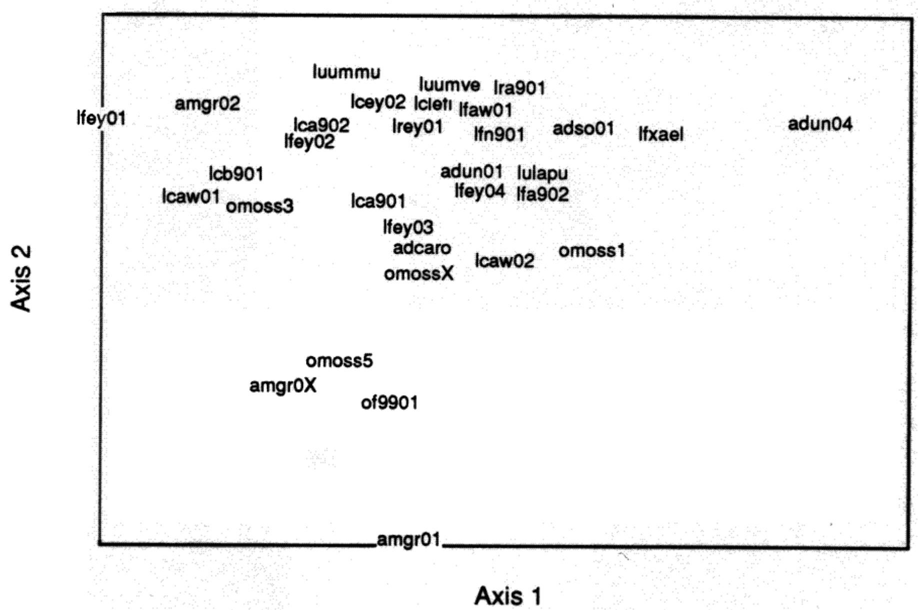
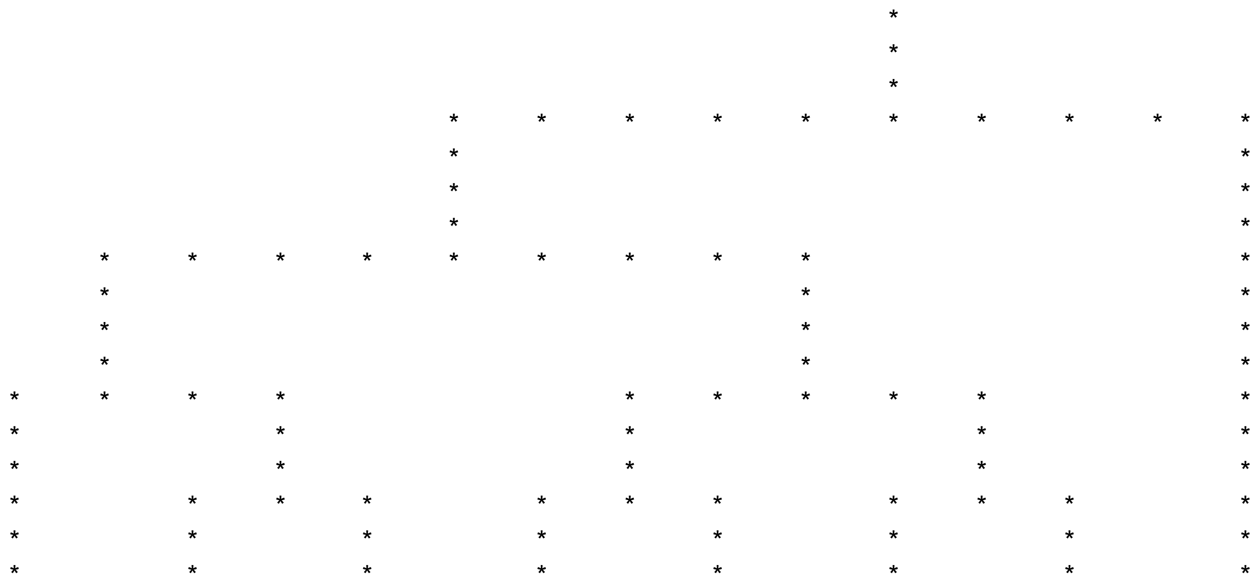


Fig. 11a. TWINSPAN analysis for Shovel Point Plot Data. The breakdown of the table is shown in Fig. 11b.

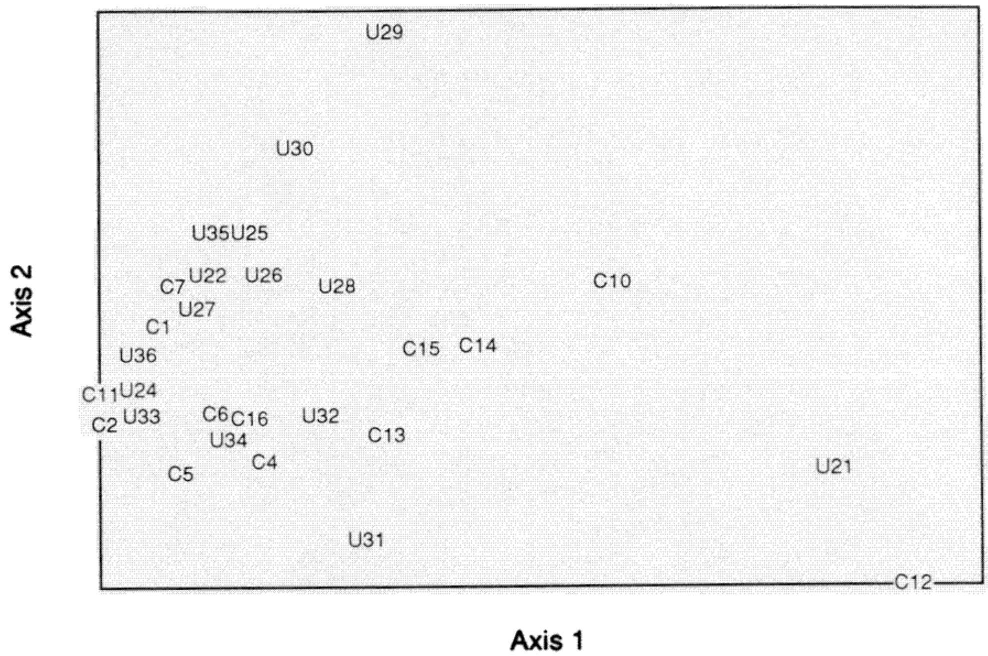
```
 ORDER OF SAMPLES
   18    C3063 |  26    C3092 |  27    C3093 |  43    U3241 |  16    C3061 |  17    C3062 |  33    C3113 |   9    C3033
   31    C3111 |  32    C3112 |  21    C3073 |  49    U3261 |  50    U3262 |  56    U3282 |   6    C3023 |   7    C3031
    8    C3032 |  10    C3041 |  11    C3042 |  12    C3043 |  13    C3051 |  14    C3052 |  15    C3053 |  20    C3072
   22    C3081 |  23    C3082 |  24    C3083 |  25    C3091 |  28    C3101 |   1    C3011 |   2    C3012 |   3    C3013
   37    U3221 |  38    U3222 |  39    U3223 |  46    U3251 |  47    U3252 |  48    U3253 |  52    U3271 |  57    U3283
   19    C3071 |  29    C3102 |  30    C3103 |  34    U3211 |  35    U3212 |  36    U3213 |  40    U3231 |  41    U3232
   42    U3233 |  45    U3243 |  51    U3263 |  53    U3272 |  54    U3273 |  58    U3291 |  59    U3292 |  60    U3293
    4    C3021 |   5    C3022 |  44    U3242 |  55    U3281 |

                  1224113 332455   111111222222   333444551233334444555556  45
                  867367391219066780123450234581237896782799045601251348904545
  13   lc b901  -5555555555445555455544555555522--3423223-123552-2422-12---22  0000
  18   lf ey01  55535141332222-2-2-212-2-2221--22232-33-221232121222--2---1-  0000
   9   lc a901  -3442334-3-32254242453535542444224324-32--2-325434322543--11  0001
  10   lc a902  -243424555-544355555455423-24555555455455-5--34243423443---2  0001
  14   lc ey02  -4442222121123-22-1212---3-2-2-224352-53---533332323212----2  0001
  19   lf ey02  ---222-----4------------------------222-----------1---------  001
  20   lf ey03  --25-------2222--1-1----1-2--------1--42----22-2-2--142-----  001
  25   lr ey01  ---2--------------------------------------------------3-----  001
  27   lu ummu  ------12-1-113-21212-1-1----133255455545-32--1--24422--2--2-  0100
  28   lu umve  ---------2-1121---21--1-1-2121--2342342-255454--33545355---1  0100
   2   ad caro  ------------------1-----21---------------------1-2----------  0101
   6   am gr01  ------------------------1-----------------------------------  0101
   8   am gr0X  --------------------11--------------------------------------  0101
  11   lc aw01  -----------------------21-----------------------------------  0101
  12   lc aw02  ---------------------------------------------------2--------  0101
  15   lc lefi  ----------------------------------2-------12----------------  0101
  21   lf ey04  --------------------------------------2----------2-222------  0101
  24   lr a901  -------------------------------------------------------2----  0101
  26   lu lapu  ------------2-------------------------------------2---------  0101
  29   of 9901  -------------2----------21-------------------1--------------  0101
  30   om ossX  -----------11--------2--2------------------------------2----  0101
  31   om oss5  --------------2---1--2--------------------------------------  0101
  33   om oss3  -------------------1----------------------------------------  0101
  16   lf a902  --22--1-1-4555432323412352153252222322435552455554355432-455  011
  17   lf aw01  ----------1212-------------------------1----------222------1  011
  22   lf n901  ---3--------1----2---2---------2-132--21---521343321442---21  011
   3   ad so01  ------------1----2---2---1-------------------1----2-----3---  10
   4   ad un01  ----------1--2------1--------------------------1-11-----1---  10
  32   om oss1  -----------25-------------------------------------------44-4  10
   1   ad aqca  --------------------------------------------------------1---  11
   5   ad un04  --------------------------------------------------------3---  11
   7   am gr02  --3-----------------------------------------------------1---  11
  23   lf xael  --1-----------21------1-1-1-------------2--1-2452-2-33-35555  11

                000000000000000000000000000000000000000000000000000000001111
                00000000001111111111111111111111111111111111111111111111
                00001111110000000000000000000111111111111111111111111111
                    0001110000111111111111111000000000001111111111111111
```

Fig. 11b. Breakdown of groups from TWINSPAN analysis from Shovel Point.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C3063 | C3061 | C3033 | C3073 | C3023 | C3011 | C3071 | C3021 |
| C3092 | C3062 | C3111 | U3261 | C3031 | C3012 | C3102 | C3022 |
| C3093 | C3113 | C3112 | U3262 | C3032 | C3013 | C3103 | U3242 |
| U3241 | | | U3282 | C3041 | U3221 | U3211 | U3281 |
| | | | | C3042 | U3222 | U3212 | |
| | | | | C3043 | U3223 | U3213 | |
| | | | | C3051 | U3251 | U3231 | |
| | | | | C3052 | U3252 | U3232 | |
| | | | | C3053 | U3253 | U3233 | |
| | | | | C3072 | U3271 | U3243 | |
| | | | | C3081 | U3283 | U3263 | |
| | | | | C3082 | | U3272 | |
| | | | | C3083 | | U3273 | |
| | | | | C3091 | | U3291 | |
| | | | | C3101 | | U3292 | |
| | | | | | | U3293 | |

**Fig. 12. Transect scores for the Blue Mounds DCA analysis. Open circles represent climbed transects, closed circles represent unclimbed transects.**



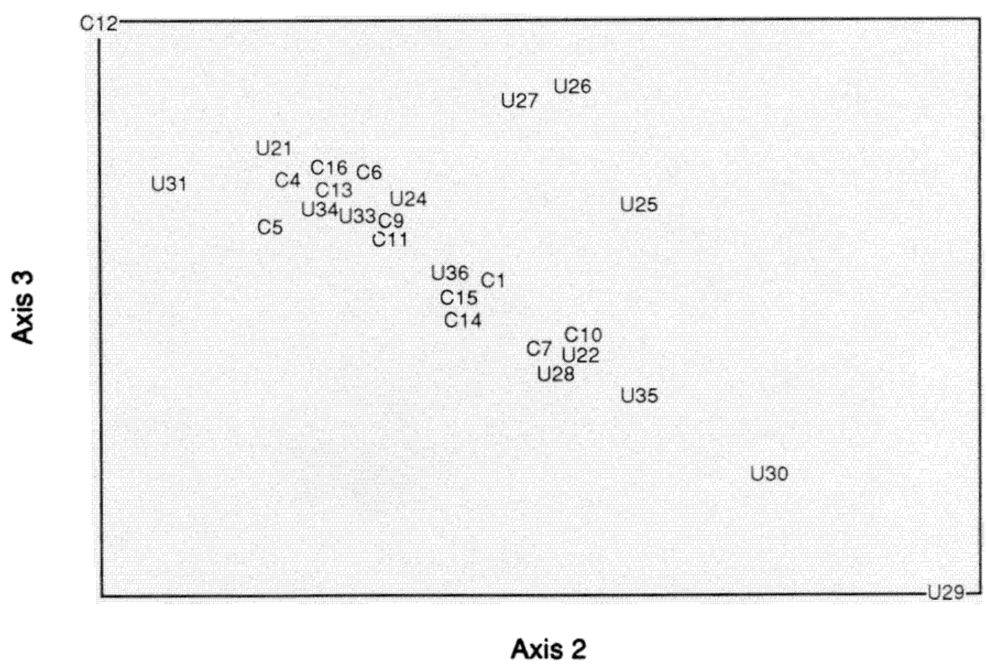



Fig. 13. Transect data from Blue Mounds projected in a three-dimensional view. Open circles represent climbed transects, closed circles represent unclimbed transects.

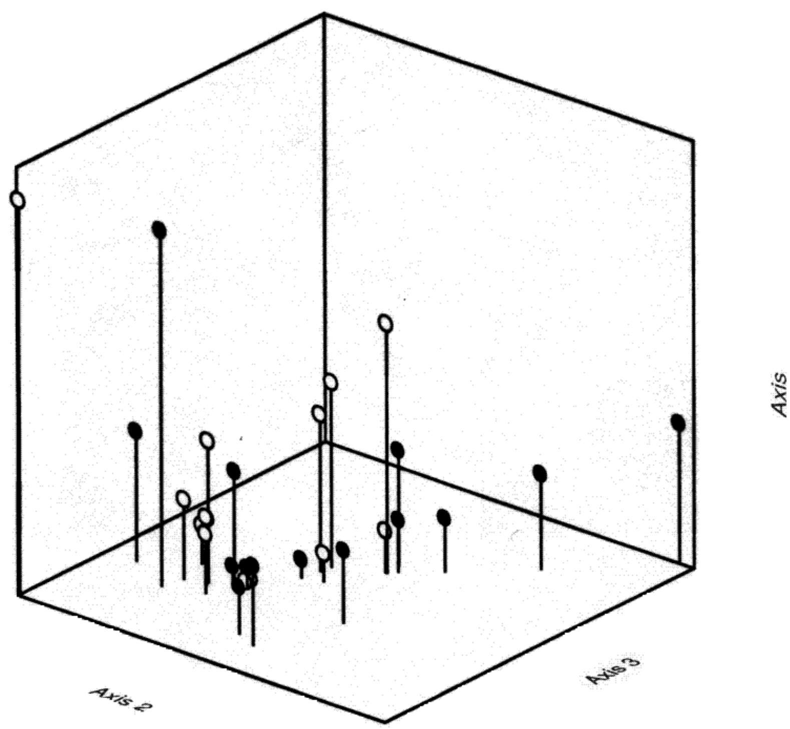


Fig. 14. Species loadings on the DCA axes from the Blue Mounds transect data.

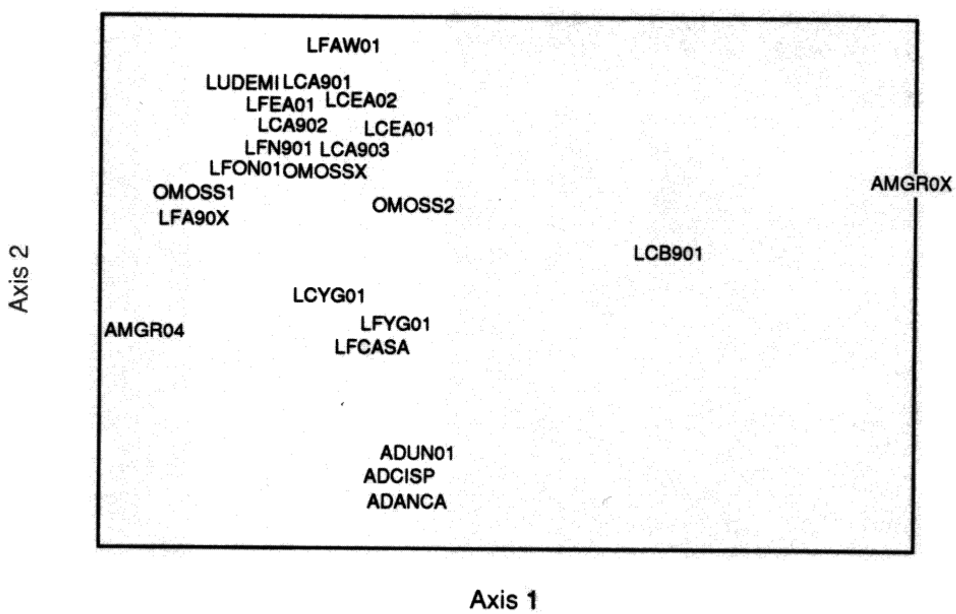
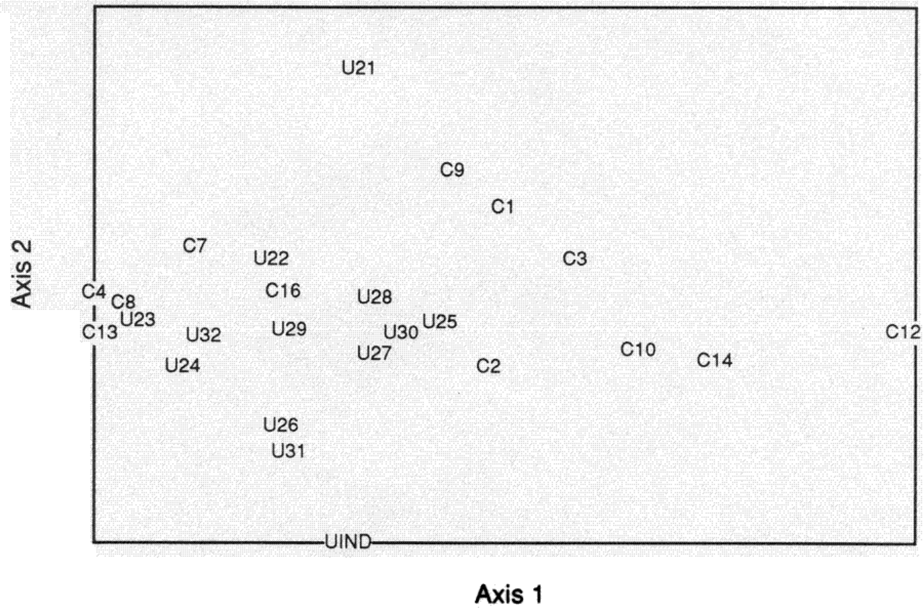


Fig 15. TWINSPAN analysis of transect data from Blue Mounds.

```
ORDER OF SAMPLES
 20 U25      |  21 U26      |  22 U27      |  25 U30      |  30 U35      |   1 C1       |   7 C7       |  18 U22
 24 U29      |  31 U36      |  19 U24      |   3 C3       |   8 C8       |   9 C9       |  11 C11      |   5 C5
 14 C14      |  15 C15      |   2 C2       |   4 C4       |   6 C6       |  16 C16      |  28 U33      |  29 U34
 13 C13      |  26 U31      |  27 U32      |  10 C10      |  12 C12      |  17 U21      |  23 U28      |

               22223  1231   1 11   1221221112
               0125017841938915452466893670273

 23   OM OSS1  --2------1--1--------1---------  1111
  9   LC AN01  355-1-----2----1-1--32---------  1111
 22   LU DEMI  1------------------------------  1110
 20   LF ON01  -2--------1--------------------  1110
 19   LF N901  -2-----------------------------  1110
 18   LF EA01  1------------------------------  1110
 16   LF AW01  ---1---------------------------  110
 12   LC EA02  12-22----1---------------------  110
  7   LC A902  531-12--2------------1----1----  110
  6   LC A901  22123-2-2---------------------2  110
 25   OM OSS2  ---1------2----------------2---  10
 11   LC EA01  4345545554211-2355-121113135-45  10
  8   LC A903  22-13-------1--1-----1--111---3  10
 24   OM OSSX  1-------------------------1----  01
 15   LF A90X  5555555554555555555555555552--5  01
 13   LC LEFI  1--------------1---------------  01
 21   LF YG01  111-1---1-----112221-1--231--12  001
 14   LC YG01  1-1-11-1--111--54113-121-212--1  001
 10   LC B901  332-----1-21---2551444245555554  001
  4   AM GR0X  ---------1---------------1---32  001
  5   AM GR04  ---------------2---------------  0001
 17   LF CASA  --------------------------3----  0000
  3   AD UN01  -----------------1-------2-----  0000
  2   AD ANCA  -------------------------2-----  0000
  1   AD CISP  -------------------------21----  0000

               0000000000000001111111111111111
               0001111111111110000000000001111
                  000000011111000000000111
                  001111101111000111111
```

Fig. 16. Transect scores from DCA of Interstate Data. Numbers of climbed (C) and unclimbed (U) transects are given.



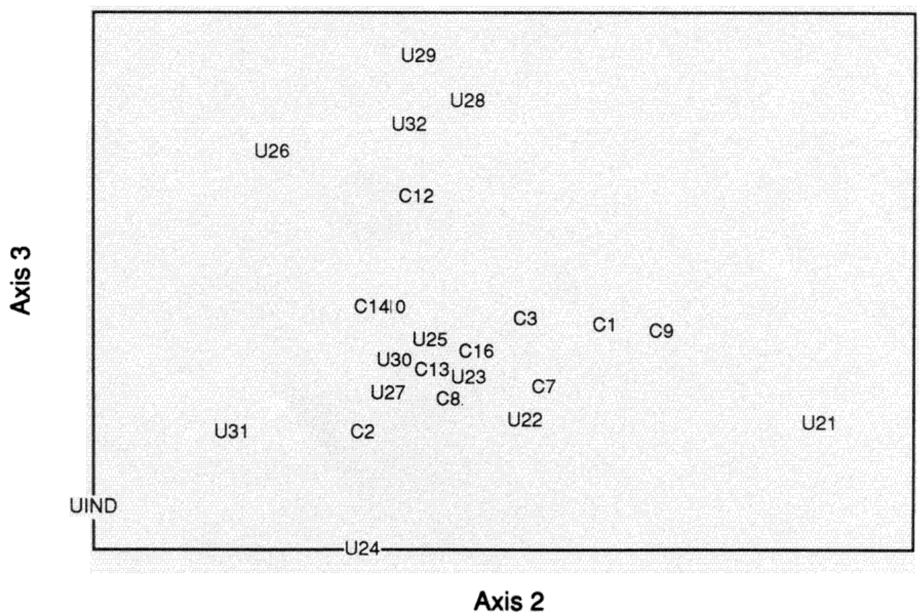



**Fig. 17. Transect** scores from DCA analysis of Interstate data projected in three **dimensions.**

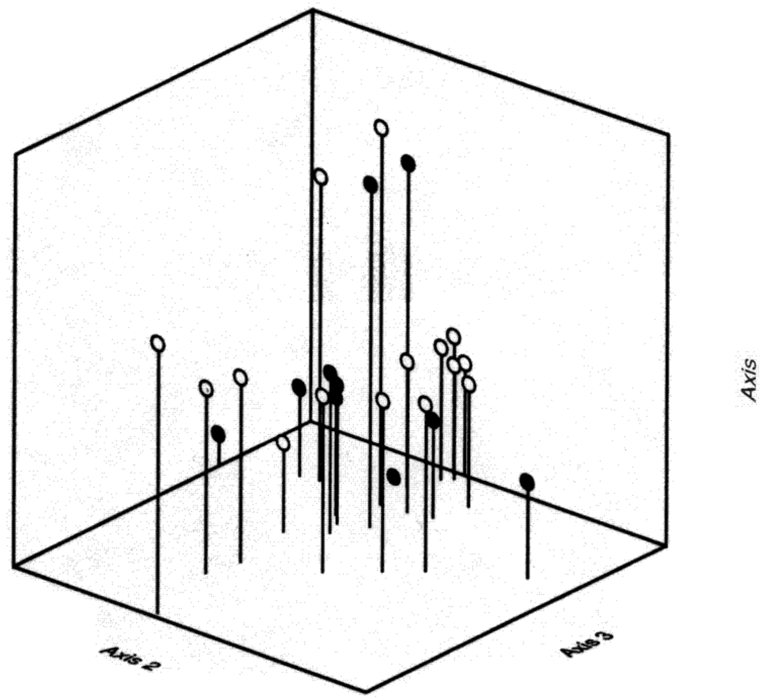


Fig. 18. Species loadings from the Interstate DCA transect analysis.

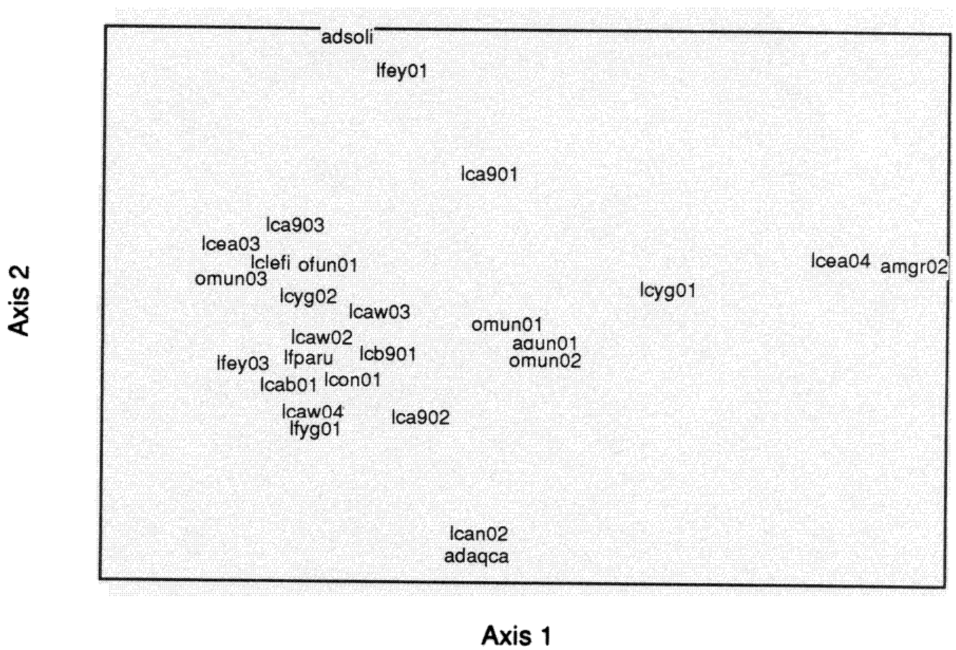
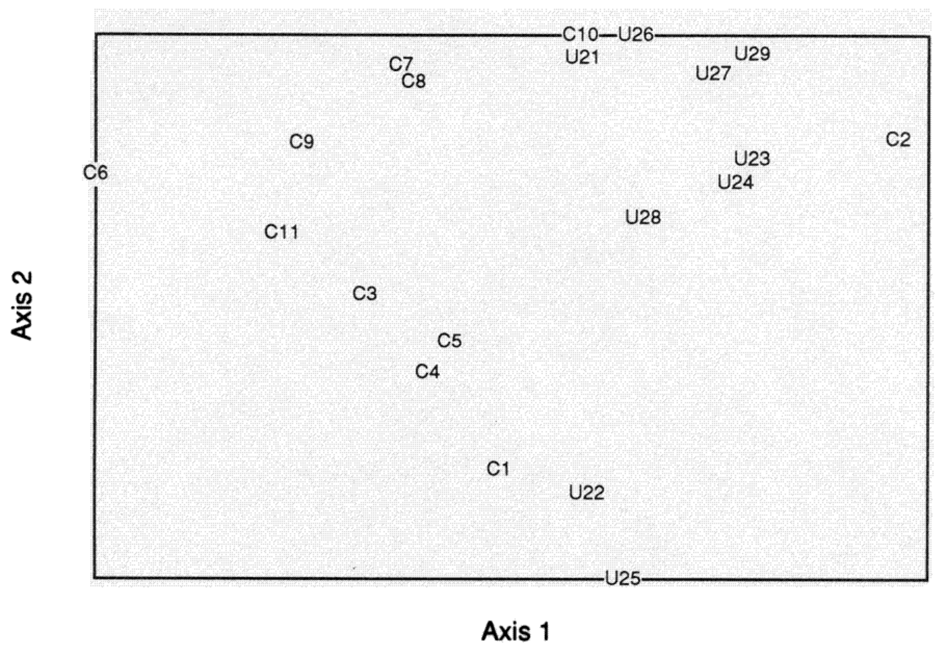


Fig. 19. TWINSPAN analysis for the transect data from Interstate.

```
ORDER OF SAMPLES
   17 U24      |   4 C4       |   7 C8       |  11 C13      |  13 C16      |  25 U32      |  15 U22      |  16 U23
   18 U25      |  21 U28      |  22 U29      |  23 U30      |  19 U26      |  20 U27      |  24 U31      |  26 UIND
    2 C2       |   9 C10      |   1 C1       |   3 C3       |   8 C9       |   6 C7       |  14 U21      |  10 C12
   12 C14      |

                 1  1121112221222      111
                 7471355681239046291386402

    9   lc a903  2-----432--2-------------  0000
    4   ad un01  -----------2-------------  0001
   13   lc aw03  1----1-225441222---------  0001
   15   lc b901  ---------22----2---------  0001
   26   of un01  -------1-1---------------  0001
   27   om un01  -------1---2-------------  0001
   28   om un02  -----------2-------------  0001
   29   om un03  -------2-----------------  0001
    2   ad aqca  ---------------4---------  0010
   10   lc ab01  -----1------3121---------  0010
   11   lc an02  ---------------1---------  0010
   19   lc on01  ------------1------------  0010
   24   lf paru  -------1----2-11---------  0010
   25   lf yg01  --------------3----------  0010
   12   lc aw02  1--3223324425333---------  0011
   14   lc aw04  -----1--------41---------  0011
   23   lf ey03  5-----------1------------  0011
   16   lc ea03  55555555215-23512----5---  010
   21   lc yg02  ----14--3-4---1--2-------  010
    8   lc a902  3-------5--5355553---3---  0110
   18   lc lefi  -----4-1111--111-----3---  0110
    3   ad soli  -----------1---------55--  0111
    7   lc a901  ----5-52555545235455545--  0111
   22   lf ey01  -----------12-1-------2--  0111
    6   am gr02  -----------------------5-  1
   17   lc ea04  1----1----3------------5-  1
   20   lc yg01  3-2-4422422222315545---55  1

                 0000000000000000000000011
                 00000000000000001111111
                 00000011111111110000011
                 011111000000111100111
```

Fig. 20. Transect scores from the DCA analysis of Shovel Point Data. Transect numbers are plotted (C=climbed, U=unclimbed).



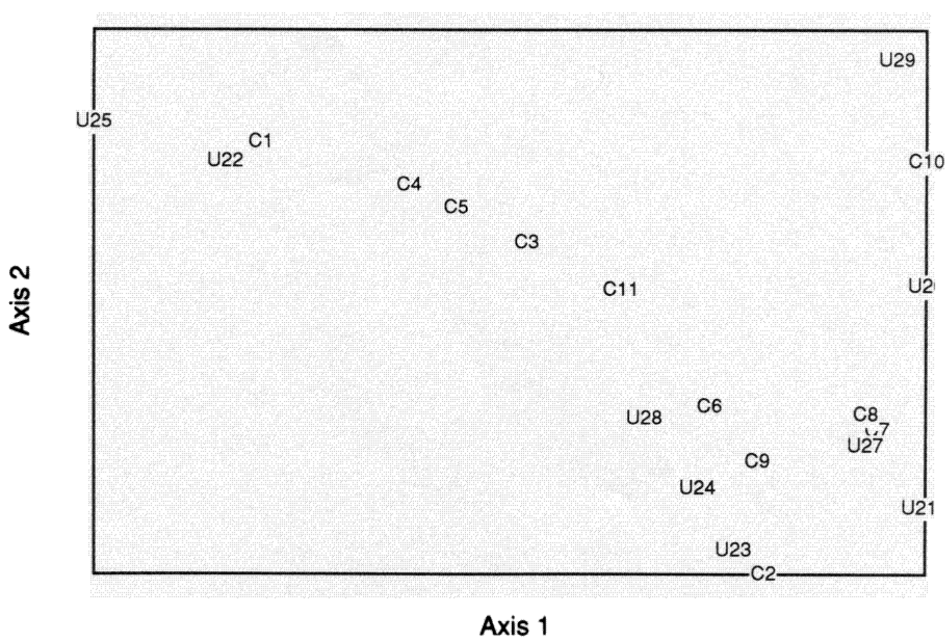



**Fig. 21. Transect scores from the DCA analysis of Shovel Point data. Open circles represent climbed transects, closed circles represent unclimbed transects.**

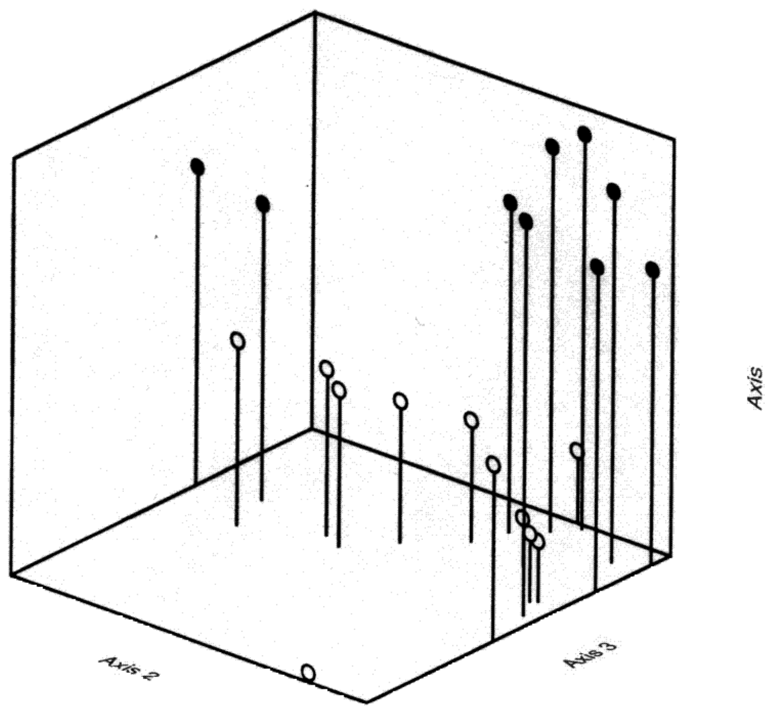


Fig. 22. Species loadings for the DCA of Shovel Point transect data.

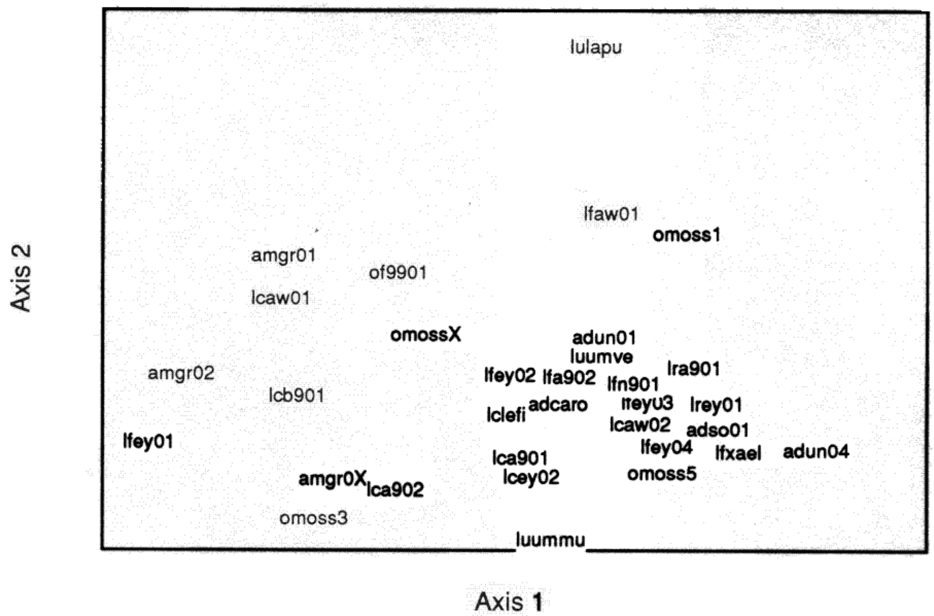


Fig. 23. TWINSPAN analysis of transect data from Shovel Point.

```
ORDER OF SAMPLES
    2 C2        |  20 U29      |  12 U21      |  14 U23      |  15 U24      |  18 U27      |  19 U28      |  13 U22
   16 U25       |  17 U26      |   1 C1       |   4 C4       |   5 C5       |  10 C10      |   7 C7       |   8 C8
    3 C3        |   6 C6       |   9 C9       |  11 C11      |

                  211111111   1     1
                 20245893671450783691

    1   ad aqca  1-------------------  0000
    5   ad un04  2-------------------  0000
   31   om oss5  1----------11-------  0000
   32   om oss1  3-----2--4----------  0000
    8   am gr0X  ------------1-------  0001
   12   lc aw02  -----2--------------  0001
   15   lc lefi  --1----1-----1------  0001
   21   lf ey04  -2--12--------------  0001
   22   lf n901  -343231211111-------  0001
   24   lr a901  -2------------------  0001
   25   lr ey01  -2--1---------------  0001
   26   lu lapu  ---------2----------  0001
   33   om oss3  -----------1--------  0001
    3   ad so01  2-1------1-21--1----  001
   27   lu ummu  -11133455332121-1--1  001
   28   lu umve  1542241334111511--11  001
   17   lf aw01  -----21--2----1-----  0100
    2   ad caro  ---11------1---1----  0101
   10   lc a902  24242345555554425235  0101
   14   lc ey02  -243343332211-122232  0101
   16   lf a902  434545522443355 42-41  0101
   19   lf ey02  ----11--22-------2--  0101
   30   om ossX  -1-------1--1--1----  0101
    4   ad un01  1--11-1--1--1-1-----  011
   20   lf ey03  1321322-12-1---1--2-  011
   23   lf xael  5214523--2--1-111-1-  011
   29   of 9901  --1---1--------1----  011
    9   lc a901  44244223334352253233  10
   13   lc b901  31514243242555555555  110
   18   lf ey01  -1312212221212221554  110
    6   am gr01  ---------------1----  111
    7   am gr02  1-----------------2-  111
   11   lc aw01  --------------11----  111

                 00000000000000111111
                 01111111111111001111
                  0000001111111
                  0111110001111
```

## APPENDIX I. Glossary of climbing terms

Anchor- Any method of secure attachment for a rope, etc. May be a tree, rock, or mechanical device wedged in a crack.

Chimney- a crack larger than 6" wide

Climb, climbing route, route- a path of ascent up a particular section of cliff. Each route has a name and technical rating. All names and locations are from Farris (1995), Minnesota Rock: Selected Climbs, except as noted.

Climbed Area- a climb or route. Has experienced significant climbing pressure.

Crack- a gap in the rock of varying width; hairline to 6" wide.

Crack'n Up - climbing anchor used in thin (<2mm) vertical cracks. No longer made, but other substitutes available.

Dihedral- an inside corner on the rock face, generally oriented vertically. Described as left-facing or right facing.

Dynamic rope- Rope with higher elasticity used by all technical climbers.

Fixed line or rope- A rope achored from above that can be used to ascend a cliff.

Jumar- Brand name, often applied generically (like "Kleenex") to various mechanical devices that are used to ascend a fixed line. Also used as a verb (e.g. "he jumared the rope").

Ledge- any roughly horizontal area large enough to stand on comfortably.

Overhang- a section of rock at an angle of over 45° past vertical

Protection- an anchor (natural or not).

Rappel- A method of descending a rope using friction to control the descent.

Rating, grade- the difficulty of a route. Ratings range from 5.0 (easiest) to 5.14 (hardest).

Roof- a horizontal overhang, usually more than one foot wide.

Skyhook- a small hook shaped piece of metal used to affix over small flakes and rugosities.

Static line or rope- Rope with virtually no stretch, used for fixed lines or rescue work.

Topo, topo map- As referred to by climbers, a schematic map of the salient features of the area of rock in question. Specific symbols are used.

Unclimbed Area- an area that has seen little or no climbing pressure in recent knowledge.

**APPENDIX II. Topographic maps of plot and transect locations.**

These maps are provided in a topographic format that was in standard use by climbers in 1995. The maps are not to scale. Experience has shown that a combination of the maps, a copy of the original photograph, and a measure of the distance measure from the top of the cliff allow relocation of the original plots.

THESE MAPS ARE AVAILABLE UPON REQUEST, PLEASE CONTACT THE NATURAL HERITAGE & NONGAME RESEARCH PROGRAM IN THE MINNESOTA DEPARTMENT OF NATURAL RESOUCES (CONTACT INFORMATION AVAILABLE ON REPORTS WEBSITE)