

# Effects of recreational rock climbing and environmental variation on a sandstone cliff-face lichen community

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**Abstract:** Lichen community composition was evaluated for both lichen cover and richness on a cliff face commonly used for recreational rock climbing. The sandstone outcrop is located on the Sibley Peninsula, which extends from the north shore of Lake Superior. One-hundred and twenty plots were examined. Each plot was 1 m<sup>2</sup> in size, with 60 plots located on unclimbed cliff sections and 60 more located where recreational rock climbing regularly occurs. Lichen richness and cover were significantly lower on the rock climbing sections compared with unclimbed sections. Linear regression models indicated significant relationships with cover and richness to environmental response variables and climbing treatment. Detrended correspondence analysis indicated a separation of lichen community groups on this cliff, and major separations occurred between plots in each climbing treatment. Canonical correspondence analysis indicated a significant amount of community group variation between climbed and unclimbed locations related to climbing treatment and aspect of the plots. Climbing is found to have an impact on this sandstone cliff-face lichen community.

*Key words:* lichen, community analysis, rock climbing, sandstone cliff, correspondence analysis.

**Résumé :** Les auteurs ont évalué la composition des communautés lichéniques, à la fois pour la couverture et pour la richesse en lichens, sur la face d'une falaise souvent utilisée pour l'escalade récréative de rochers. L'affleurement de grès se retrouve sur la péninsule de Sibley, laquelle s'étend à partir de la rive nord du lac Supérieur. Les auteurs ont examiné 120 parcelles. Les parcelles étaient chacune d'un mètre carré, 60 parcelles étant localisées sur des portions de la falaise non escaladées et 60 autres là où il y a une utilisation fréquente pour l'escalade récréative. On observe une réduction significative de la richesse et de la couverture en lichens dans les sections escaladées comparativement aux sections témoins. Les modèles de régression linéaire indiquent des relations significatives avec la couverture et la richesse, en réaction aux variables environnementales et l'activité d'escalade. L'analyse des correspondances hors tendance (detrended) indique une séparation des groupes de communautés de lichens sur cette falaise, les séparations majeures se retrouvant entre les parcelles dans chaque traitement avec escalade. L'analyse par correspondances canoniques indique une quantité significative de variation des groupes de communautés entre les localisations escaladées et non escaladées reliée au traitement escalade, et l'aspect des parcelles. On constate que l'escalade exerce un impact sur la communauté lichénique de cette falaise de grès.

*Mots-clés :* lichen, analyse des communautés, escalade de rochers, falaise de grès, analyse des correspondances.

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## Introduction

Cliff vegetation, in general, must be able to adapt to water stress, skeletal soils, and a vertical substrate (Larson et al. 2000). This vegetation must also be able to re-establish repeatedly after either exogenous or endogenous disturbance (Coates and Kirkpatrick 1992). Because of these characteristics, cliff florae are often very different from florae growing on nearby level ground (Jarvis 1974), and cliffs can function as refugia within the regional landscape (Graham and Knight 2004; Müller et al. 2006). Lichen species are often one of the primary colonizers on rock substrates following extreme disturbances, such as glacial retreat or mass wasting events, with growth initiating within 100 years of the disturbance event

(Fahselt et al. 1988; Sancho and Valladares 1993). Lichens, as primary colonizers, are commonly overrun by other vegetation types as time progresses, often leading to an eventual eradication from the area (Robinson 1959).

Rock cliffs provide a substrate of positive, vertical, and negative inclinations. Inclination of a substrate will reduce the ability of many forms of vegetation to occur. Vegetation establishment requirements, such as soil development, will not occur on a negative inclination (Kuntz and Larson 2006b). Rock cliffs create a refuge for lichens because of the limited competition from other vegetation species. Cliff lichen species may therefore be rare to an area because they may be a relic of a glacial period (Müller et al. 2006), may not have a competitive ability against the flat-land dwelling

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plants (Robinson 1959), may be very intolerant to disturbance (Coates and Kirkpatrick 1992; Larson et al. 2000), or they may not have been previously identified in that habitat (McMillan and Larson 2002). For example, *Acrocordia conoidea* (Fr.) Körb. is a lichen that grows on the Niagara Escarpment in Milton, Ontario, Canada. At the time *A. conoidea* was found on the cliffs, it had not been included in the lichen identification manual for the region (McMillan and Larson 2002).

Cliff vegetation characteristics, such as richness and cover, are often different between sections of a cliff that are climbed and sections of the same cliff face that are not used for rock climbing (unclimbed) (Camp and Knight 1998; Farris 1998; Kuntz and Larson 2006b; McMillan and Larson 2002; Müller et al. 2004; Nuzzo 1995, 1996; Rusterholz et al. 2004). However, the cause of this observed difference is often attributed to both natural variation in environmental conditions and impacts from recreational rock climbing.

A study on the Niagara Escarpment limestone found cliff vegetation community changes observed between climbed and unclimbed cliff sections were caused by changes in the cliff's microtopographic controls (ledge size, soil deposits, etc.). Using a community approach, researchers determined that climbers on advanced climbing routes chose routes with already reduced vegetation communities, and that reduced vegetation conditions are related to the preferable conditions of a climbing route's cliff-face microtopography. Neither lichen richness nor cover was different between climbed and unclimbed plots. The vegetation community that exists on those climbed cliffs is a subcommunity of the entire cliff community (Kuntz and Larson 2006a).

In the Swiss Jura Mountains significantly different lichen communities were found between climbed and unclimbed sections of the cliffs. Increasing use of the cliff for climbing increased the differences between climbed and unclimbed sites. Lichens that grew more exposed on the rock were found to be reduced with climbing occurrence (Baur et al. 2007). Baur et al. (2007) also suggested that species richness and composition are not likely caused by microsite characteristics between climbed and unclimbed locations, but that climbing occurrence is the causal agent.

Limestone cliffs have been the main focus of cliff vegetation research—particularly on the Niagara Escarpment and in the Swiss Jura Mountains. The small body of literature suggests that analysis of climbing impacts to the cliff must incorporate cliff-face microtopographic controls (environmental, geological, etc.) in the vegetation analyses, as they have been found to be significantly responsible for differences seen in vegetation response (Kuntz and Larson 2006a). However, the link between microtopography and vegetation response is not always present (Baur et al. 2007).

This research project was initiated as a result of communications with the local climbing community indicating that many of the route developers use metal wire brushes to remove the vegetation that was growing on the vertical cliffs. Preliminary inquiries concluded that the Pass Lake outcrop of the Pass Lake formation, which is part of the Sibley Group, is very weak and therefore easily eroded. The cliffs used for climbing had continuous vertical inclination and the vegetation community was limited to lichen. The lack of vascular plants on climbed cliff areas is likely due to the ability

of microtopographic features to constrain their growth (Kuntz and Larson 2006b).

## Materials and methods

### Study site

Pass Lake outcrop is located on the Sibley Peninsula, which extends from the northern shore of Lake Superior (UTM Zone 16N 372008 mE and 5380565 mN). The outcrop is composed of sedimentary layers of buff arenite from the Sibley Group (Franklin et al. 1980). The other known outcrops of buff arenite are limited to a few metres in height. The cliff height reaches to about 20 m, and transects up to 18 m were measured in this project. Vegetation does not grow directly beside the base of the cliff resulting in a buffer of up to 10 m from the cliff. The base of climbed sections is a layer of sand, and the unclimbed sections have large rocks at the base. Next to the scree/sand is a mix of deciduous and coniferous trees, extending up to 30 m. A single set of railway tracks is located adjacent to the trees, and a roadway is adjacent to the tracks. Conifers dominate the vegetation assemblage found on the cliff top, with most trees and other plants being at least 3–5 m back from the edge of the cliff face in all sections.

Recreational rock climbing began at Pass Lake outcrop, Ontario, Canada, in the 1980s and most of the routes are for sport climbing, which requires drilling into the rock to affix permanent safety equipment to clip the rope into as the climber ascends the cliff (Joseph and Reed 2005). Recently, the local climbing association webpage, which tracks new climbing route development, suggests climbing route development to be active in the region (Alpine Club of Canada Thunder Bay Section 2010). Pass Lake outcrop is not located within a park and there are no established hiking areas, and use near the cliff is likely limited to people accessing the cliff for climbing. Climbing occurs on sections of the cliff face with a generally southerly aspect; the cliff has a consistent height, about 20 m, for about 0.6 km. There are 57 climbing routes located at Pass Lake.

### Sampling locations

We sampled 12 transects in total, 6 on known climbing routes and 6 on unclimbed routes. The number of plots per transect differed. We chose climbed transects by identifying all intermediate level climbing routes (5.8–5.11 on the climbing difficulty scale) with at least a one star rating in the guidebook (Joseph and Reed 2005). We selected six routes to sample at random from the total population of routes. Routes that have star ratings are considered the choice climbs at a cliff, and they are likely to be climbed most often.

We chose unclimbed transects to be representative of similarly estimated difficulty levels, if they were to be developed and climbed. Estimation of climbing route difficulty was conducted in agreement with local climbers. Samples from unclimbed cliff plots were collected 200 m away from the climbed sections of the cliff. The cliff face spans about 600 m, in an east–west extent.

Plot placement was a continuous sampling from the top of the cliff to the bottom. All plots were sampled in each vertical transect. Continuous sampling was chosen to reduce the impact to unclimbed plots, as some lichen damage is possible

even when reasonable precautions are taken. The damage is therefore limited to a few transects and less extensive than if only  $n$ -plots were sampled per transect.

Unclimbed sections were sites not indicated in the local climbing guide (Joseph and Reed 2005) and presented no evidence of climbing as determined in agreement with local climbers (personal communication). Possible indicators of climbing included chalk marks (chalk is used by climbers to reduce hand moisture), pieces of climbing equipment, or trampling of vegetation at the base or top of the cliff. Sampling plots were 1 m high by 1 m wide for an area of 1 m<sup>2</sup>. A 1 m<sup>2</sup> plot should encompass areas of high and low activity by the climbers because it would encompass hand and foot hold areas, as well as areas not used as holds.

### Response variables

Lichen response variables for the evaluation of the cliff community included cover and richness for epilithic lichen. Lichen cover was evaluated with an overlay grid of 1 cm<sup>2</sup> grid cells. For each 1 m<sup>2</sup> sampling plot, 10 000 grid cells were evaluated. Type samples were collected for species determination in the laboratory. This was necessary as not all the lichen species could be correctly identified in the field. Lichen richness was evaluated based on the number of species present per plot. Lichen species were described and identified using standard reference texts (Brodo et al. 2001; Hale 1969).

### Plot characteristics

Five environmental response variables were measured that included aspect, bedding unit thickness, plot fracturing, plot height, and ledge size. Aspect (aspect) was measured at the centre of each plot. For purposes of statistical analysis, the compass reading was transformed prior to analysis into a north-south component (north) {cosine [(compass reading) \*  $\pi$ ]} and east-west component (east) {sine [(compass reading) \*  $\pi$ ]}. This was done to allow for similar treatment of aspect values of 0° and 359°. The same method of data processing was applied in studies by (Matthes et al. 2000; McMillan and Larson 2002; Roberts 1986). Bedding unit thickness (bedding) was measured with half-decimetres units. Thickness measurements were taken at the centre of the plot. Plot fracturing (fracturing), the frequency of visible rock fractures consisted of three categories. Category 1 contained plots with fractures less than 10 cm in length. In category 2, some fractures were greater than 10 cm, but fractures were not intersecting. Category 3 included all plots with intersecting fractures greater than 10 cm resulting in the general appearance of stacked blocks. Plot heights (height) were measured at the bottom of the plot as the height from the base of the cliff in metres. Ledges (ledge) were categorized by the largest ledge found within the plot. Ledge categories are ordinal and included: category 1 with ledges less than 5 cm deep, category 2 with ledges greater than 5 cm but less than 10 cm deep, and category 3 with ledges greater than 10 cm deep. Climbing treatment (climbing) was a matter of differentiating between unclimbed and climbed plots. Since no statistics were available for climbing route usage this was the only available and valid method of plot differentiation.

### Data analysis

The Shapiro–Wilk test ( $\alpha = 0.05$ ) was used to examine data normality (Shapiro and Wilk 1965) and the Mao Tau technique, a sample rarefaction method, to test if the number of plots sampled were sufficient to capture the majority of species (Colwell et al. 2004). Data were transformed to approximate normal distributions. The two-sample  $t$  test was used to identify significant differences between the unclimbed and climbed plots for total lichen cover, total lichen richness, and individual lichen species' cover.

Detrended correspondence analysis (DCA) was used to examine community composition for the 120 cliff-face plots (Hill and Gauch 1980), a method applied by Kuntz and Larson (2006b). Community group separation was visually examined by symbolically highlighting both the unclimbed and climbed plots.

Stepwise linear regression was used to explore linear explanatory relationships to lichen response variables by the environmental response variables. Factors significant at  $\alpha = 0.05$  were included in the regression and partial  $r^2$  statistics were generated for each. A Bonferroni correction was applied to account for testing of two response variables with the same data set and produced a familywise error rate of  $\alpha = 0.05/2 = 0.0025$ . Climbing, ledge, and fracturing were included as dummy variables in the regression (Suits 1957).

Finally, canonical correspondence analysis (CCA) was used to examine the change in community composition that could be attributed to environmental response variables and climbing treatment. CCA is a direct gradient analysis method, which allows direct relations between species and environmental data. CCA allows a visual evaluation of the effect of each variable on the separation of the community composition. Each environmental response variable has a vector plotted on the graph with an origin at 0, 0. Vectors that align close to an axis indicate a dependence of community separation along that axis because of that vector's response variable, and increased vector length suggests greater influence. As the data collected used a combination of interval, ordinal, and one binary environmental variable it was appropriate for CCA (Ter Braak 1986).

R: a language and environment for statistical computing (R Development Core Team 2011) was used for statistical analysis, including the vegan package (Oksanen et al. 2011).

### Results

Mean lichen richness on the 120 cliff-face plots was  $3 \pm 0.1$  species per 1 m<sup>2</sup>. Mean lichen cover was  $39\% \pm 2.8\%$  per 1 m<sup>2</sup>. Species richness appeared low, but examination of the species accumulation curve suggested the collected species were suitable. The number of plots each species were present in, for each of climbed and unclimbed plots, is found in Table 1.

Two-sample  $t$  tests identified significant differences at  $\alpha = 0.05$  between climbed and unclimbed plots for 8 of the 16 species' cover (Table 2). Two-sample  $t$  tests indicated lichen richness was significantly different ( $t = 5.8974$ ,  $df = 118$ ,  $p = < 0.001$ ) between climbed plots (mean 25%) and unclimbed plots (mean 54%). Two-sample  $t$  tests indicated lichen cover was significantly different ( $t = 2.0361$ ,  $df = 116$ ,

**Table 1.** Counts for the number of plots each lichen species was present in for both climbed and unclimbed plots.

	Unclimbed	Climbed
<i>Aspicilia cinerea</i> (L.) Körber	3	10
<i>Caloplaca arenaria</i> (Pers.) Müll. Arg.	1	0
<i>Caloplaca citrina</i> (Hoffm.) Th. Fr	3	22
<i>Caloplaca flavovirescens</i> (Wulfen) Dalla Torre & Sarnth.	0	1
<i>Cladonia chlorophaea</i> (Flörke ex Sommerf.) Sprengel	1	0
<i>Dimelaena oreina</i> (Ach.) Norman	5	11
<i>Lecanora cenisia</i> Ach.	2	15
<i>Lepraria lobificans</i> Nyl.	7	12
<i>Ramalina intermedia</i> (Delise ex Nyl.) Nyl.	7	0
<i>Rhizocarpon disporum</i> (Nägeli ex Hepp) Müll. Arg.	59	60
<i>Rhizoplaca melanophthalma</i> (DC.) Leuckert & Poelt	1	0
<i>Rhizoplaca subdiscrepans</i> (Nyl.) R. Sant.	32	1
<i>Umbilicaria americana</i> Poelt & T. Nash	49	15
Sterile Black Crustose	2	3
<i>Xanthoria elegans</i> (Link) Th. Fr.	4	29
<i>Xanthoria sorediata</i> (Vainio) Poelt.	33	2
Total No. of species in all plots	15	12
Mean No. of species in all plots	3.5	3

**Table 2.** Two-sample *t* test results for individual species cover between climbed and unclimbed plots.

Species	Plot mean % $\pm$ SE		<i>t</i>	df	<i>p</i>
	Unclimbed ( <i>n</i> = 60)	Climbed ( <i>n</i> = 60)			
<i>Aspicilia cinerea</i>	0.71 $\pm$ 0.44	2.24 $\pm$ 0.94	-1.6357	98	0.105
<i>Caloplaca arenaria</i>	0.0003	0	1	59	0.321
<i>Caloplaca citrina</i>	0.23 $\pm$ 0.13	4.74 $\pm$ 1.94	-3.0042	71	0.004
<i>Caloplaca flavovirescens</i>	0	0.17 $\pm$ 0.17	-1	59	0.321
<i>Cladonia chlorophaea</i>	0.013 $\pm$ 0.013	0	1	59	0.321
<i>Dimelaena oreina</i>	1.40 $\pm$ .76	0.75 $\pm$ 0.30	-0.3281	113	0.744
<i>Lecanora cenisia</i>	0.88 $\pm$ .80	3.14 $\pm$ 1.00	-2.9314	88	0.004
<i>Lepraria lobificans</i>	0.50 $\pm$ 0.36	2.58 $\pm$ 1.33	-2.0633	88	0.042
<i>Ramalina intermedia</i>	1.05 $\pm$ 0.59	0	-2.2799	59	0.026
<i>Rhizocarpon disporum</i>	7.08 $\pm$ 0.62	5.08 $\pm$ 0.40	1.563	113	0.121
<i>Rhizoplaca melanophthalma</i>	0.17 $\pm$ 0.17	0	1	59	0.341
<i>Rhizoplaca subdiscrepans</i>	9.29 $\pm$ 2.06	0.02 $\pm$ 0.02	7.2474	60	<0.001
<i>Umbilicaria americana</i>	23.16 $\pm$ 3.51	4.65 $\pm$ 2.01	7.1083	108	<0.001
Sterile Black Crustose	0.27 $\pm$ 0.19	0.051 $\pm$ 0.03	0.7284	77	0.469
<i>Xanthoria elegans</i>	0.34 $\pm$ 0.23	1.35 $\pm$ 0.32	-4.0594	97	<0.001
<i>Xanthoria sorediata</i>	8.99 $\pm$ 1.90	0.05 $\pm$ 0.04	6.4161	61	<0.001

$p = 0.044$ ) between climbed plots (mean 3.0 species) and unclimbed plots (mean 3.5 species).

Lichen species in ordination space produced by DCA (Fig. 1) separated along axis 1 from foliose and umbilicate, to crustose and crustose-like foliose species. DCA axis 2 separates the fruticose and foliose community to umbilicate dominant cover. DCA eigenvalues for axis 1 (0.8096), axis 2 (0.5296), and axis 3 (0.4063) were high, an indication of a significant separation of different lichen communities over the cliff face. Convex hulls placed around each climbed and unclimbed points share some overlap, but most of the samples are plotted outside of the other treatment's convex hull. Eighty percent concentration ellipses indicate a very narrow overlap between unclimbed and climbed plot's community compositions, with only three unclimbed plots and four climbed plots within the overlap. The DCA indicates a com-

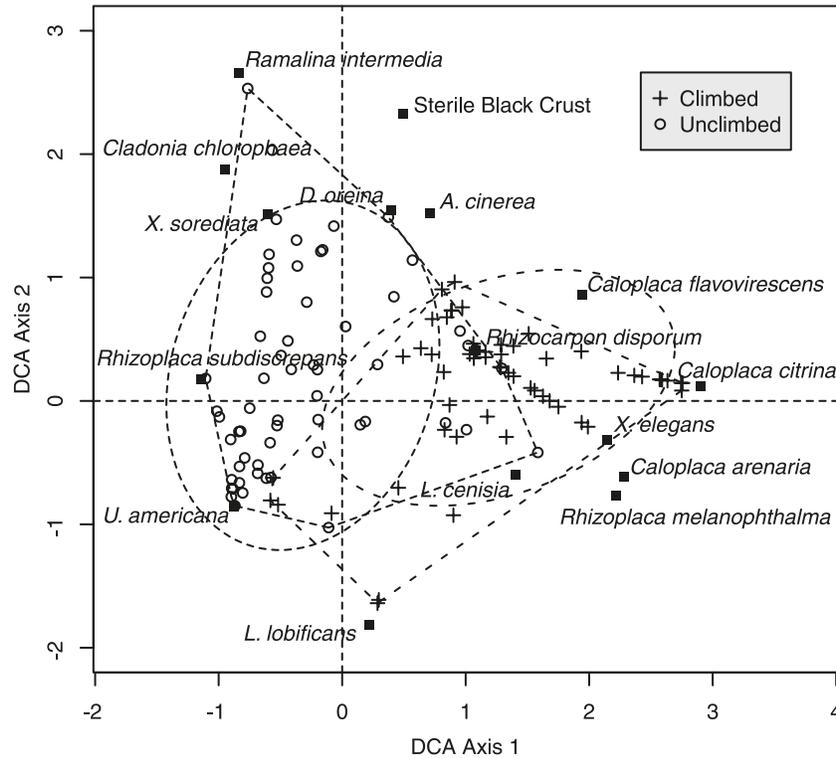
munity dominated by foliose, fruticose, and umbilicate lichens in unclimbed sites and a community dominated by crustose species and "crustose like" foliose species in climbed plots.

Linear regression modeling (Table 3) of cover was able to attribute 26.5% of the variation within all plots to bedding and climbing treatment. Both coefficients in the regression have a negative effect on cover.

Linear regression modeling (Table 3) for richness was able to attribute 35% of the variation between all plots to two environmental response variables (height and north) and climbing treatment. Height and north both have a positive coefficient to richness, and climbing has a negative coefficient to richness.

CCA eigenvalues indicate the environmental response variables and climbing treatment capture a portion of the varia-

**Fig. 1.** Plot of detrended correspondence analysis (DCA) of the cliff-face lichen community found in 120 plots. Half of the plots were located in unclimbed locations and half were located in areas known for climbing. Eighty percent confidence ellipses are placed around each group. Convex hulls are placed around both groups. DCA eigenvalues for axis 1 (0.8096) and axis 2 (0.5296).



**Table 3.** Linear regression results for lichen cover and richness models.

Response variable	df	F	R <sup>2</sup> (adj)	p	Plot characteristics	Partial r <sup>2</sup>	Sign	p
Cover	117	22	0.265	<0.001	Bedding	0.04	-	0.006*
					Climbing	0.22	-	<0.001**
Richness	116	22	0.35	<0.001	Height	0.26	+	<0.001**
					North	0.13	+	0.046
					Climbing	0.03	-	0.017*

**Note:** Significance after Bonferroni correction  $\alpha = 0.05/2 = 0.025^*$ ,  $0.01/2 = 0.005^{**}$ .

tion in the lichen community. The CCA eigenvalues were as follows: for axis 1 (0.481, 45.89% of constrained inertia explained), axis 2 (0.323, 30.84% of constrained inertia explained), and axis 3 (0.13, 12.46% of constrained inertia explained). The total inertia is 5.063 with constrained making up 23.05%. The eigenvalues still suggest, when compared with the DCA values, that there are other possible environmental response variables, or improved modes of measurement of our response variables, that have not been quantified. This could lead to an improved explanation of variation when CCA eigenvalues are compared with DCA eigenvalues.

The climbing vector in the CCA (Fig. 2) is well aligned to the CCA axis 1 and is the longest vector, indicating it as the most influential variable. With this strong alignment to CCA axis 1 it is responsible for a significant amount of the separation that is seen along CCA axis 1, which is a shift to a crustose and crustose-like lichen community from a foliose and fruticose community. North and east are also well aligned to CCA axis 1 with east direction having a greater influence

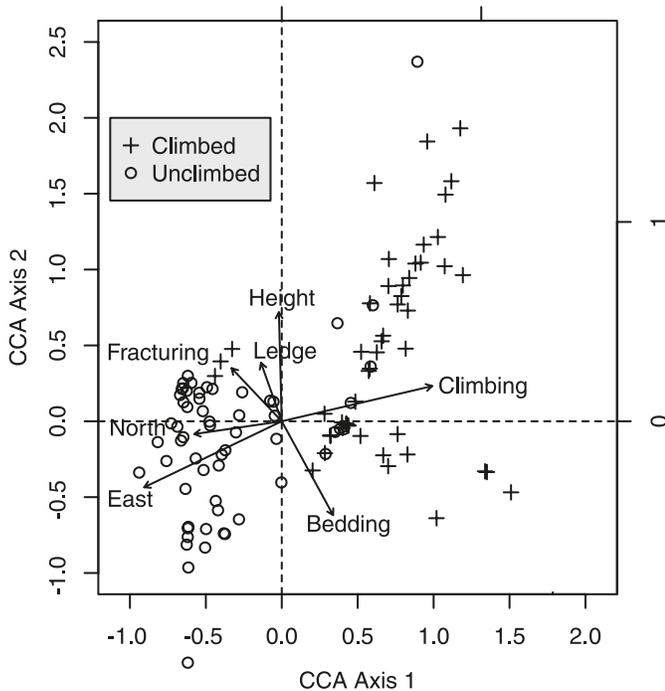
than north. Height and bedding are both fairly aligned to CCA axis 2 and strong vectors. The fracturing vector is not well aligned to either axis. There is a separation along CCA axis 1 into the two distinct groups of unclimbed and climbed plots. Unclimbed plots are not greatly separated along CCA axis 2, but climbed plots are well separated along CCA axis 2.

### Discussion

Microtopographic characteristics (environmental response variables) can be responsible for changes in vascular plant and bryophyte communities on cliffs, which have been identified as a greater influence than the occurrence of rock climbing (Kuntz and Larson 2006b). This single cliff-face study has limited the possible effects from geographic variation and the generality of the study.

The first step in data analysis found significant differences between unclimbed and climbed plots for the lichen response variables. Lichen richness was reduced in plots where climbing

**Fig. 2.** Plot of canonical correspondence analysis (CCA) of the cliff-face lichen community found in 120 plots. Half of the plots were located in unclimbed locations and half were located in areas known for climbing. Vectors are plotted indicating the direction and magnitude of the intensity of each variable measured on the separation of the community. The CCA eigenvalues for axis 1 (0.481) and axis 2 (0.323).



occurs, which is in agreement to many past studies (Nuzzo 1996; McMillan and Larson 2002; Müller et al. 2004; Rusterholz et al. 2004; Baur et al. 2007). Fifteen different species of lichen were identified in unclimbed plots, with a mean of 0.5 more species per plot than climbed plots. Three species were only found in unclimbed plots and one was only found in climbed plots.

Lichen cover was reduced in plots where climbing occurs, which is also similar to many past studies (Nuzzo 1996; Farris 1998; Rusterholz et al. 2004; Baur et al. 2007). Unclimbed plots had a mean cover of 54% and climbed plots only 25%. This reduction of over 50% from climbed to unclimbed plots was significant. Seven of the 16 species identified were significantly different in cover between the climbed plots and the unclimbed plots.

Linear regression models indicated that climbing has a partial influence on the cover and richness of lichens between climbed and unclimbed plots. The dummy variable of climbing for the models of richness and cover was significant,  $p < 0.001$  for cover and  $p = 0.017$  for richness.

The linear model with cover as the dependent variable was able to account for 26.5% of the variation with two variables, bedding and climbing both of which have negative coefficients. Bedding has a partial  $r^2$  of 0.04, so there is little improvement from a model that included only climbing occurrence (partial  $r^2$  of 0.22). The richness model explained 35% of the variation but climbing's partial  $r^2$  was low at 0.03, suggesting height and north were the more important variables. Climbing occurrence in the model resulted in a

reduction of the number of lichen species present. The linear models both indicate that climbing is having a negative impact on the lichen community.

DCA ordination shows a separation of the cliff community along the first two axes. The community group separations are also paralleled by a separation in climbing treatment plots. Unclimbed plots cluster to the left and climbed locations are clustered to the right. This was a good indication that the plots surveyed with climbing were not a subset of the total community as seen in a previous study (Kuntz and Larson 2006a), but that the climbed sites are a distinctly different community. The climbed plots are located in a region of the community separation that is dominated by crustose or crustose-like species. A shift along DCA axis 1 indicates that plots that are located on climbed routes are dominated by lichen species that grow closely attached to the rock and should be more resilient to disturbance.

CCA ordination, which was the final method applied to help in determining if climbing occurrence on this sandstone cliff causes a change in the lichen community, indicates that climbing influence is one of the most dominant factors for the differentiation observed between lichen communities on climbed and unclimbed plots. It is valuable to note that the inertia explained by the constrained axes is 23%.

The species separation along CCA axis 1 is very well aligned with the climbing vector, as well as the components of aspect, the north component having a stronger alignment. This axis was responsible for about 46% of the variation explained by the constrained axes. Separation along CCA axis 2 is not associated with climbed or unclimbed plots, but is a separation within each of those climbing treatments, which appears to be explained by a few environmental response variables. Bedding and height are the main factors well aligned with CCA axis 2. The CCA analysis indicated that climbing is well aligned with the separation that is seen for species composition on plots.

## Conclusions

The results indicate that climbing is affecting this cliff-face lichen community. Its effects are mainly responsible for a change from a foliose and fruticose community found on unclimbed sites (including umbilicates), to a cliff face that is dominated by the very resilient crustose and crustose-like species. Thus, the results agree with Baur et al. (2007), Nuzzo (1996), and Farris (1998). Furthermore, Kuntz and Larson's (2006b) conclusions that environmental response variables, in their work referred to as microtopographic features, do play a role in defining community groups on cliff faces, is also supported by the results.

Very few studies of rock climbing impacts on cliff-face vegetation communities focus on substrate type as a factor. Results of this study tend to indicate that outcomes may differ based on substrate type, region, initial community composition, or other unknown factors. The sandstone substrate, which is easily erodible, simply rubs away during climbing activity and with it removes many of the fragile lichen species. As well, the techniques climbers have adopted to prepare the routes for climbing, which include the use of wire brushes, will need to be limited in the future to help in the preservation of the cliff-face vegetation community.

All this leads us to conclude that sandstone is a substrate with a potential to be impacted from recreational rock climbing. Further research should be conducted in regions where different rock types occur. Impacts of varying climbing techniques should also be investigated to allow land managers a better understanding of the potential impacts of recreational rock climbing on cliff-face vegetation communities.

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