Effects of Rock Climbing on the Vegetation of the Niagara Escarpment in Southern Ontario, Canada

MICHELE A. McMILLAN AND DOUGLAS W. LARSON*

Department of Botany, University of Guelph, Guelph, Ontario, N1G 2W1, Canada

Abstract: *The cliffs of the Niagara Escarpment support unique and diverse plant communities. Although recreational rock climbing has become extremely popular in North America over the past two decades, little is known about the effect of this sport on the natural biota. We examined the ecological effects of rock climbing on vascular plant, bryophyte, and lichen communities along the Niagara Escarpment in southern Ontario. We made comparisons among randomly selected climbed and unclimbed rock outcrops by sampling from three positions: plateau (or cliff edge), cliff face, and talus (or cliff base). Density, percent cover, species richness, and species diversity of vascular plants were lower on climbed outcrops than on unclimbed outcrops. In addition, the proportion of alien plants was three times greater in climbed areas than in unclimbed areas. The frequency and richness of bryophyte species were also significantly lower in climbed areas. The frequency of lichens was the same on climbed and unclimbed cliffs, but species richness was significantly lower in climbed areas, and community composition differed between climbed and unclimbed areas. Our results suggest that rock climbing has significant negative effects on all aspects of the vegetative community on cliffs. Therefore, we recommend that conservation plans be modified to include specific policies regarding recreational rock climbing for lands containing exposed cliffs. For example, we suggest that the establishment of new climbing routes be banned in protected areas along the Niagara Escarpment.*

Efectos del Escalado de Rocas Sobre la Vegetación del Escarpado del Niagara en el Sur de Ontario, Canadá

Resumen: *Los acantilados del Escarpado del Niagara sostienen una comunidad de plantas única y diversa. A pesar de que el escalado recreativo de rocas se ha convertido en una actividad extremadamente popular en Norte América en las últimas dos décadas, poco se conoce del efecto de este deporte sobre la biota natural. Examinamos los efectos ecológicos del escalado de rocas sobre las plantas vasculares, las briofitas y las comunidades de líquenes a lo largo del Escarpado del Niagara, al sur de Ontario. Hicimos comparaciones entre sitios escalados y no escalados seleccionados al azar mediante el muestreo de tres posiciones: planicie (o borde del acantilado), cara del acantilado y talud (base del acantilado). La densidad, el porcentaje de cobertura, la riqueza de especies y la diversidad de especies de plantas vasculares fueron menores en sitios escalados que en sitios no, escalados. Además, la proporción de plantas invasoras fue tres veces mayor en las áreas escaladas que en las no escaladas. La frecuencia y la riqueza de especies de briofitas también fue significativamente menor en áreas escaladas. La frecuencia de líquenes fue la misma en sitios escalados y en sitios no escalados, pero la riqueza de especies fue significativamente más baja en áreas escaladas y la composición de la comunidad difirió entre áreas escaladas y no escaladas. Nuestros resultados sugieren que la escalada de rocas tiene efectos negativos significativos en todos los aspectos de la comunidad vegetal de los acantilados. Por lo tanto, recomendamos la modificación de los planes de conservación para que se incluyan políticas específicas relacionadas con el escalado recreativo de rocas para terrenos que contengan acantilados expuestos. Por ejemplo, sugerimos la prohibición del establecimiento de nuevas rutas de escalado para proteger áreas a lo largo del Escarpado del Niagara.*

**Address correspondence to D. W. Larson; email dwlarson@uoguelph.ca*
Paper submitted September 5, 2000; revised manuscript accepted April 11, 2001.

Introduction

One of the major goals of conservation biology is to conduct scientific research that will aid in the preservation of natural landscapes. Of particular concern to scientists and environmentalists are natural areas that have remained relatively undisturbed for long periods of time. These areas often serve as habitats for a variety of plant and animal species that are not found in more disturbed areas. Accordingly, these lands are often set aside as protected areas. These areas, although protected from urbanization and development, are often subject to high levels of disturbance from recreational activities. Thus, land managers must struggle to find an acceptable balance between biological and social management objectives. To do this effectively, land managers require quantitative data about the effects of recreational activities on the surrounding biota.

The effects of rock climbing have received relatively little attention in the scientific literature, despite the rising popularity of this sport over the past two decades (Valis 1991; Herter 1996). Four studies indicate that rock climbing has a negative effect on vascular plant density and/or species richness (Nuzzo 1995; Herter 1996; Kelly & Larson 1997; Camp & Knight 1998). Two others have documented no appreciable effects on the vascular plant community (Nuzzo 1996; Farris 1998). One researcher identified a significant decline in lichen cover and density with climbing (Nuzzo 1996), whereas another found lichen cover and frequency to decrease with climbing activity at some sites but to remain neutral or even increase at other sites (Farris 1998). The scarcity of literature and the contradictory nature of the results has led to heated debates between land managers and climbers, with both sides requesting further scientific study (Baker 1999; Jodice et al. 1999; Krajick 1999; Young 1999). Consequently, we examined the effects of rock climbing on vascular plants, bryophytes, and lichens on heavily climbed dolomitic limestone cliffs in Ontario.

Methods

Study Site

We sampled along the Niagara Escarpment approximately 30 km southwest of Toronto, Ontario, Canada, from June through August 1998, on public land managed by the Halton Region Conservation authority and private land owned by Milton Limestone. The cliffs are composed of dolomitic limestone formed during the Silurian period (Niagara Escarpment Commission 1979). The majority of Ontario's recreational rock climbing occurs on these cliffs because of their proximity to Toronto and Hamilton. Rock climbing has occurred in the area for up to 50 years (Valis 1991). A thin band of second-growth deciduous forest surrounds this portion of the escarpment.

We examined the effect of rock climbing by comparing the vegetation sampled from "climbed" areas (documented climbing routes) and "unclimbed" areas (no documented routes or detectable use by climbers) (Bracken et al. 1991; Oates and Bracken 1997). Climbed cliffs were sampled from Buffalo Crag (90 graded routes), Rattlesnake Point (142 graded routes), Mt. Nemo (236 graded routes), and Kelso (54 graded routes) conservation areas (Bracken et al. 1991; Oates & Bracken 1997). Unclimbed cliffs were sampled from Mt. Nemo and Crawford Lake conservation areas and from a natural cliff on the property of Milton Limestone Quarry. Rock climbing is not permitted on the cliffs in Crawford Lake Conservation Area or on the Milton Limestone property.

Climbed and unclimbed areas were remarkably similar in terms of their topographies. All cliffs sampled were composed of Silurian dolostone, ranged from 11 to 30 m in height, and had similar numbers of cracks and ledges. All cliffs occurred at an elevation of approximately 300 m above sea level and were within 15 km of one another. The sampled cliffs did not contain water seeps or overhangs greater than 1 m. The same method of site selection was used by Kelly and Larson (1997).

Sampling Design

Sampling was conducted on 50, 1 m wide vertical belt transects: 25 climbed transects chosen randomly from a pool of 101 climbing routes and 25 unclimbed transects chosen randomly from a pool of 106 possible transects. Climbed transects were restricted to previously established routes with difficulty levels between 5.7 and 5.9 (intermediate skill level) and a star rating in the climber's guide book (Bracken et al. 1991). Routes with a star rating are considered of better quality than those without and therefore tend to be climbed more regularly. A section of cliff was determined to be unclimbed if no climbing routes were described for the area (Bracken et al. 1991; Oates & Bracken 1997) and if the area showed no obvious signs of recent climbing activity. Unclimbed transects were restricted to sections of the cliff 7 m in width that appeared physically suitable for climbing, and then only if two experienced climbers and the first author agreed that the transect would receive a difficulty rating of between 5.7 and 5.9 if rated. Climbed and unclimbed transects were rejected if they were <10 m in height or contained a roof or overhang of >1 m, continuous water seeps, or loose rocks.

Three 1×2 m quadrats were established within each of the 50 transects, for a total of 150 quadrats. The first quadrat position, termed "plateau," was located on the top of the cliff, directly adjacent to the cliff face. The second, termed "cliff face," was located in the vertical center of the cliff face. The final quadrat, termed "talus," was located in the area directly adjacent to the cliff at the bottom. Occasionally, climbing routes did not progress in a straight line from the cliff base to the plateau. In this case, the quadrats were shifted right or left, according to the description of the route in the climbing manual.

The plateau, cliff face, and talus were each exposed to disturbance from climbers. Climbers set up their ropes on the plateau when "top-roping." For this climbing technique, climbing ropes are anchored to trees and boulders on the top of the cliff. The plateau also receives disturbance from hikers. Hiking paths occurred on the plateau behind 100% of the climbed transects and 60% of the unclimbed transects. The cliff base is where the belayer—the person who holds the ropes for his or her climbing partner—stands. In addition, the cliff base is where many climbers rest between ascents and where packs and gear are stored. Because the talus is made up of many loose rocks and boulders, it is extremely difficult to hike in the area.

Each quadrat was sampled as follows. The quadrat was divided into 50, 20×20 cm subquadrats. For density, the number of rooted shoots of each species of vascular plant was recorded for each subquadrat. For percent cover, the number of subquadrats containing a species was recorded. The determination of the number of rooted shoots for grasses and sedges was not conducted because of the extremely high densities of these species. Instead, the presence or absence of each grass and sedge species was determined for each subquadrat. If a species' name was unknown, a sample was collected for identification at a later date. Herbarium specimens are housed in the University of Guelph Herbarium in Guelph, Ontario. We identified vascular plants using the nomenclature of Gleason and Cronquist (1991), Cody and Britton (1989), and Voss (1972, 1985, 1996). The origin of each species (native vs. alien) was determined based on the classifications of Newmaster et al. (1998).

Because identification of most bryophyte and lichen species was not possible in the field, we differentiated bryophytes and lichens into visually distinct types by examining specimens with a magnifying glass. A sample of each bryophyte and lichen was collected and subsequently identified under magnification in the laboratory. We used a chisel and hammer to collect small pieces of rock containing endolithic or crustose lichen samples from as close to the quadrat as possible, without disturbing finger and toe holds on climbing routes. The presence or absence of each bryophyte and lichen species was determined for each subquadrat. We identified bryophytes using the nomenclature of Ireland (1982), Ley and Crowe (1999), and Crum (1983). Lichen identifications were determined based on the nomenclature of Brodo (1988) and Wong and Brodo (1992). More difficult specimens were sent to the Canadian Museum of Nature for identification. Bryophyte and lichen specimens are housed in the Department of Botany at the University of Guelph.

Detailed sketches were made of each quadrat to determine the ratio of exposed rock to soil. Density was calculated as the total number of rooted shoots within the boundaries of the 2-m^2 quadrat. Cover was determined as the percentage of subquadrats containing at least one member of the taxonomic group. Richness was calculated as the number of species per quadrat. Species diversity was calculated with the Shannon-Wiener diversity index, $H' = \Sigma^{s}_{i=1} (p_i)(\log_e p_i)$, where H' is the index of diversity, s is the number of species, and p is the proportion of total sample belonging to the ith species (Krebs 1999).

Statistical Analyses

We used a split-plot experimental design (Steel & Torrie 1980; Kuehl 1994) with "climbing intensity" as the whole-plot factor and "quadrat location" as the split-plot factor. Climbing intensity had two levels, climbed and unclimbed, whereas quadrat location had three levels, plateau, cliff face, and talus. To minimize the effect of factors other than climbing intensity and quadrat position on the outcome of the statistical analyses, we used a number of variables as covariates: date of sampling, cliff height, percent canopy cover, and compass direction of the cliff face. The compass direction of the cliff face was divided into a north direction {cosine[(compass reading)·π]} and an east direction {sine[(compass reading)·π]}, because the use of an untransformed compass reading would determine 1° and 359° to be very different from one another, when in actuality they are both almost due north.

All univariate analyses were conducted on normalized data. We examined main effects using F statistics from analysis of variance (ANOVA) tables produced by SAS computer software using PROC MIXED (Anonymous 1995). We examined simple effects using Tukey's procedure because this procedure examines all simple effects simultaneously with a combined error rate (Steel & Torrie 1980; Anonymous 1995). Chi-square tests were used to determine changes in the frequency of individual species, and values were adjusted with Yates's correction for continuity when there was only a single degree of freedom in the test (Steel & Torrie 1980). The Bonferroni correction was used for multiple comparisons (Kuehl 1994).

Results

Occurrence of Vascular Plants

The density of vascular plant species was significantly lower in climbed quadrats than in unclimbed quadrats on the plateau ($p < 0.0001$), cliff face ($p < 0.0005$), and talus ($p < 0.01$) (Fig. 1). Vascular plant cover was also lower in each of the three habitat types, but the difference was statistically significant only for the plateau

(33 ± 4% vs. 59 ± 6%, $p < 0.01$) and talus (41 ± 5% vs. 66 ± 5%, $p < 0.05$) habitats. There was no significant difference in cover between climbed and unclimbed cliff-face quadrats (0 ± 4% vs. 12 ± 4%, $p = 0.28$). On the cliff face, vascular plants were restricted to small cracks and ledges with soil. Consequently, plants occurred in an aggregated distribution on both climbed and unclimbed cliff faces. The density of vascular plants differed significantly among the three habitat types ($p < 0.0005$). The lowest plant densities were on the cliff face, with an average of only one individual per climbed quadrat and six individuals per unclimbed quadrat. The unclimbed talus habitat supported the highest density of vascular plants, with an average of 185 rooted shoots per quadrat.

We found 130 vascular plant species in the area sampled. Although ANOVA indicated that species richness and diversity were both negatively affected by rock climbing ($p < 0.0005$), the effect of climbing was not uniform across habitat type. There were significantly fewer species in climbed quadrats than unclimbed quadrats on the plateau ($p < 0.005$) and cliff face ($p < 0.005$) (Fig. 2). Species richness was very similar, however, between climbed and unclimbed talus quadrats ($p = 1.0$). The Shannon-Wiener diversity index indicated the same trend. Species diversity was lower in climbed plateau (1.1 ± 0.13 vs. 1.8 ± 0.14, $p < 0.005$) and cliff-face quadrats (0.034 ± 0.15 vs. 0.88 ± 0.13, $p < 0.001$) than in their unclimbed counterparts. However, climbed and unclimbed talus quadrats were equally diverse (1.7 ± 0.13 vs. 1.5 ± 0.13, $p = 0.93$).

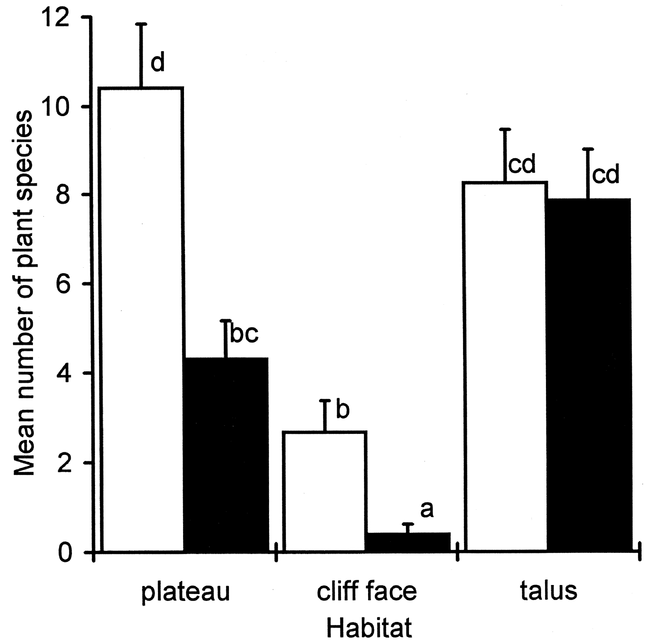

Figure 2. Mean number of vascular plant species present in each quadrat type sampled from the Niagara Escarpment, Ontario, Canada. Open bars represent unclimbed quadrats; solid bars represent climbed quadrats. Bars that share a letter code are not significantly different from one another at α = 0.05.

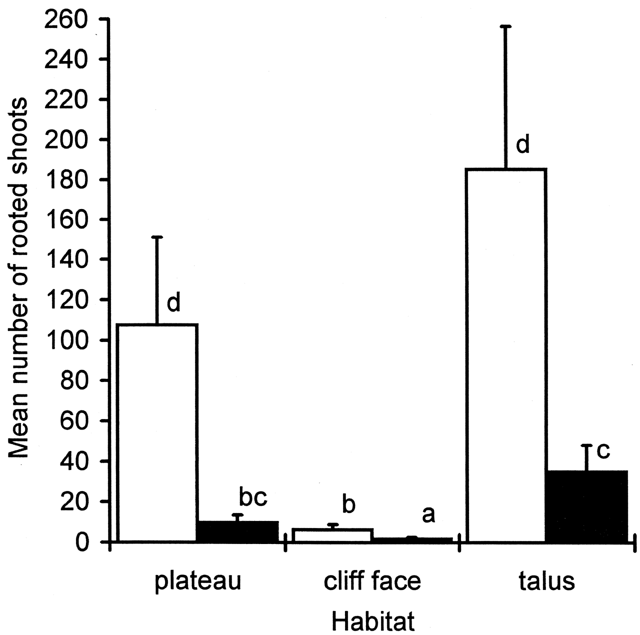

Figure 1. Mean vascular plant density for each quadrat type sampled from the Niagara Escarpment, Ontario, Canada. Open bars represent unclimbed quadrats; solid bars represent climbed quadrats. Bars that share a letter code are not significantly different from one another at α = 0.05.

The results from the canonical correspondence analysis indicate that both habitat type and climbing intensity strongly influence the community composition of vascular plants (Fig. 3). Quadrats were divided into six remarkably distinct groups in the ordination diagram. Quadrats were separated by habitat type along axis 1 and by climbing intensity along axis 2.

The proportion of alien plants was three times higher in climbed quadrats than in unclimbed quadrats ($p < 0.0001$). On average, 81 ± 5% of the plants in climbed quadrats were alien species, whereas only 27 ± 7% of the plants in unclimbed quadrats were alien species. Climbed plateau quadrats contained a significantly higher proportion of alien species than their unclimbed counterparts (49 ± 1% vs. 5 ± 3%, $p < 0.01$), as did climbed talus quadrats (98 ± 2% vs. 75 ± 10%, $p < 0.05$). This difference was not significant between climbed and unclimbed cliff-face quadrats (68 ± 16% vs. 24 ± 11%, $p = 0.41$).

Vascular species that were found significantly more often in unclimbed quadrats included *Acer saccharum*, *Dryopteris marginalis*, *Geranium robertianum*, *Maianthemum canadense*, and *Polypodium virginianum* (Table 1). All these species, with the exception of *G. robertianum*, which is a naturalized alien, are native to

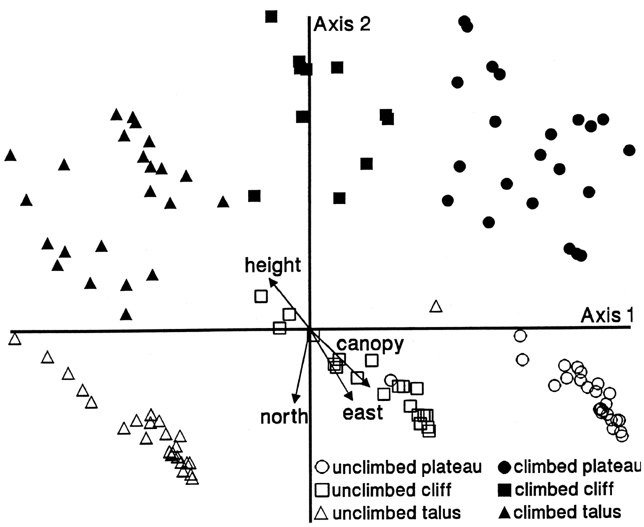

Figure 3. Ordination diagram produced by canonical correspondence analysis of the vascular plant species present in each quadrat sampled from the Niagara Escarpment, Ontario, Canada (λ^1, 0.64; λ^2,0.58). The eigenvalues (λ) associated with each axis indicate the strength of that axis in the separation of data points. Quadrats closer together in the ordination space are more similar to one another in terms of community composition than quadrats that are farther apart. Vectors indicate the direction in which each of the environmental variables separate the data points. The length of the vector indicates the relative importance of the variable in its influence over community composition.

southern Ontario (Newmaster et al. 1998). Vascular plant species found more often in climbed quadrats included *Plantago major* and *Poa compressa*. *P. compressa* is a native plant, whereas *P. major* is alien to the area.

Species most commonly associated with the plateau habitat were *Acer saccharum*, *Dryopteris marginalis*, *Maianthemum canadense*, *Polygonatum pubescens*, *Polypodium virginianum*, *Prunus virginiana*, *Solidago caesia*, *Solidago canadensis*, *Thuja occidentalis*, and *Veronica officinalis* (Table 2). Species most commonly found on the talus were *Cynoglossum officinale*, *Erysimum cheiranthoides*, *Eupatorium rugosum*, *Geranium robertianum*, *Impatiens pallida*, *Leonurus cardiaca*, *Nepeta cataria*, and *Solanum dulcamara*. No plant species were found most often on the cliff face.

Occurrence of Bryophytes

We found 31 bryophyte species in the sampling area, but their overall frequency was quite low. Bryophytes were present in 33 of the 75 unclimbed quadrats but in only 6 of the 75 climbed quadrats. Bryophyte cover was significantly lower in climbed quadrats than in unclimbed quadrats (0.20 ± 0.11% vs. 1.10 ± 0.36%, $p <$ 0.05). Climbed quadrats also supported significantly fewer bryophyte species than unclimbed quadrats (0.02 ± 0.01 vs. 0.07 ± 0.03, $p < 0.05$). Bryophyte cover was higher in talus quadrats (1.03 ± 0.32%) than in cliff-face (0.36 ± 0.15%) and plateau quadrats (0.36 ± 0.15%) ($p < 0.01$). Similarly, bryophyte richness was higher in talus quadrats (0.08 ± 0.03) than in cliff-face (0.02 ± 0.01) and plateau quadrats (0.02 ± 0.01) ($p < 0.05$).

Occurrence of Lichens

We found lichen species in 91% of climbed quadrats and 79% of unclimbed quadrats. A total of 26 species and 8 unidentifiable types were distinguished. The latter of these species could not be identified due to their sterility or small size. It is possible that any of the 8 unidentifiable lichen types may constitute more than one species of lichen. Consequently, the reported values for lichen species richness may be underestimated.

The lichen species we found were almost exclusively on exposed rock. Lichens were rarely found on wood or soil. Our results indicate that there was significantly more exposed rock (less soil) in climbed plateau (67 ± 4% vs. 11 ± 5%, $p < 0.0001$) and talus quadrats (74 ± 4% vs. 40 ± 4%, $p < 0.0001$) than in their unclimbed counterparts. The amount of exposed rock was similar, however, between climbed and unclimbed cliff-face quadrats (98 ± 5% vs. 93 ± 4%, $p = 0.98$).

Lichen cover was remarkably similar between climbed and unclimbed quadrats in each habitat (Fig. 4), but there were fewer lichen species in climbed quadrats than unclimbed quadrats (2.24 ± 0.21 vs. 5.35 ± 0.46, $p <$ 0.0001). Lichen species richness was 60% lower in climbed plateau quadrats ($p < 0.001$), 51% lower in climbed cliff face quadrats ($p = 0.07$), and 62% lower in climbed talus quadrats ($p < 0.0005$) than in their unclimbed counterparts (Fig. 5).

In terms of lichen community composition, the ordination diagram of the canonical correspondence analysis showed a separation of climbed from unclimbed quadrats along axis 1 and a separation of plateau from cliff-face and talus quadrats along axis 2 (Fig. 6).

Species found more often in climbed quadrats included *Caloplaca flavovirescens* and *Caloplaca* sp. (Table 1). Species found more often in unclimbed quadrats included *Acrocordia conoidea*, *Lepraria* cf. *lobificans*, and *Lepraria* sp. Only two lichen species were found significantly more often in one habitat over the others. *Caloplaca citrina* and *Lecanora perpruinosa* were both most common in cliff-face quadrats (Table 2).

Discussion

The cliffs of the Niagara Escarpment support the most ancient forest community east of the Rocky Mountains

Table 1. Frequencies for each species of vascular plant, bryophyte, and lichen present in at least 15% more quadrats of one climbing intensity over the other.[a]

Group	Species	Frequency (%)		χ^{2b}
		climbed	*unclimbed*	
Vascular plants	*Acer saccharum*	0	16	10.96*
	Dryopteris marginalis	0	21	15.74**
	Eupatorium rugosum	5	23	7.97
	Geranium robertianum	23	48	9.45*
	Maianthemum canadense	0	17	12.13**
	Plantago major	15	0	9.81*
	Poa compressa	37	8	16.77***
	Polypodium virginianum	1	28	19.23***
	Taraxacum officinale	43	20	7.93
Bryophytes	*Anomodon attenuatus*	3	27	15.39**
	Anomodon rostratus	0	17	12.13**
	Brachythecium oxycladon	1	16	8.42
Lichens	*Acrocordia conoidea*	13	49	20.95****
	Bacidia granosa	5	21	6.98
	Caloplaca citrina	64	47	3.88
	Caloplaca flavovirescens	29	7	11.56*
	Caloplaca sp.	39	7	20.12***
	Lecidella stigmatea	28	8	8.85
	Lepraria cf. *lobificans*	3	43	31.99****
	Lepraria sp. (not *L. lobificans*)	0	17	12.13**

[a]*Calculated as the percentage of quadrats in which each species was present. Calculations are based on 150 quadrats sampled from the Niagara Escarpment, Ontario, Canada. Bonferroni correction was used to correct for multiple comparisons.*
[b]*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$.

Table 2. Frequencies for each species of vascular plant, bryophyte, and lichen present in one habitat at least 15% more often than in the other two habitats.[a]

Group	Species	Frequency (%)			χ^{2b}
		plateau	*cliff face*	*talus*	
Vascular plants	*Acer saccharum*	22	0	2	20.11***
	Cynoglossum officinale	2	4	30	20.37***
	Dryopteris marginalis	26	0	6	19.45**
	Erysimum cheiranthoides	4	2	22	14.34*
	Eupatorium rugosum	8	4	30	16.28**
	Geranium robertianum	16	18	72	44.17****
	Impatiens pallida	0	0	24	26.09****
	Lactuca serriola	18	12	36	9.09
	Leonurus cardiaca	6	8	40	24.66****
	Maianthemum canadense	26	0	0	28.47****
	Nepeta cataria	10	10	44	22.96***
	Polygonatum pubescens	24	0	0	26.09****
	Polypodium virginianum	36	4	4	27.27****
	Prunus virginiana	22	0	0	23.74***
	Solanum dulcamara	2	12	50	38.22****
	Solidago caesia	24	0	0	22.40***
	Solidago canadensis	22	2	4	14.34*
	Thuja occidentalis	40	10	4	25.20****
	Veronica officinalis	20	2	0	17.85**
Bryophytes	none	—	—	—	—
Lichens	*Bacidia granosa*	2	26	8	6.00
	Caloplaca citrina	20	82	64	41.16****
	Caloplaca sp.	14	38	16	10.12
	Lecanora perpruinosa	2	36	6	27.59****

[a]*Calculated as the percentage of quadrats in which each species was present. Calculations are based on 150 quadrats sampled from the Niagara Escarpment, Ontario, Canada. Bonferroni correction was used to correct for multiple comparisons.*
[b]*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$.

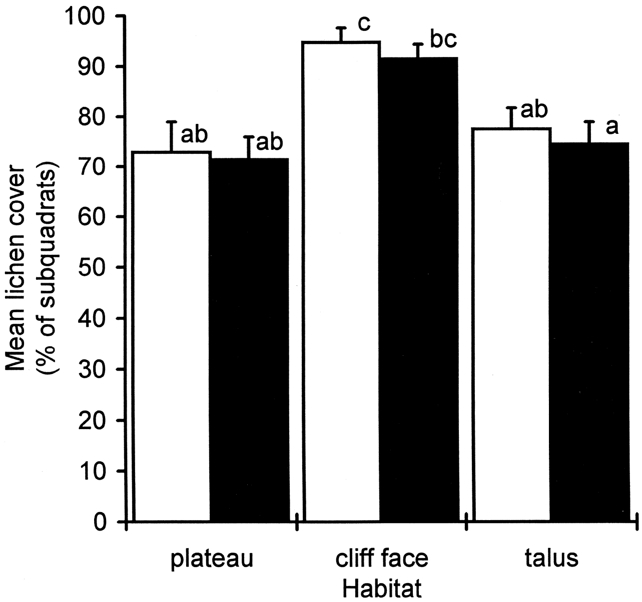

Figure 4. Mean percentage of subquadrats containing exposed rock that also contained lichen species (Niagara Escarpment, Ontario, Canada). Open bars represent unclimbed quadrats; solid bars represent climbed quadrats. Bars that share a letter code are not significantly different from one another at $\alpha = 0.05$.

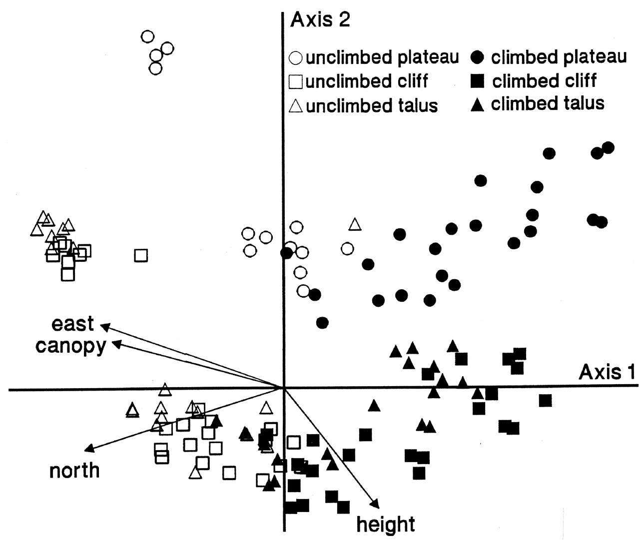

Figure 6. Ordination diagram produced by canonical correspondence analysis of the lichen species present in each quadrat sampled from the Niagara Escarpment, Ontario, Canada. λ^1, 0.41; λ^2, 0.22. Environmental variables (shown as vectors) are canopy, canopy cover over quadrat; east, relative eastness; north, relative northness; and height, cliff height. The length of all vectors has been doubled.

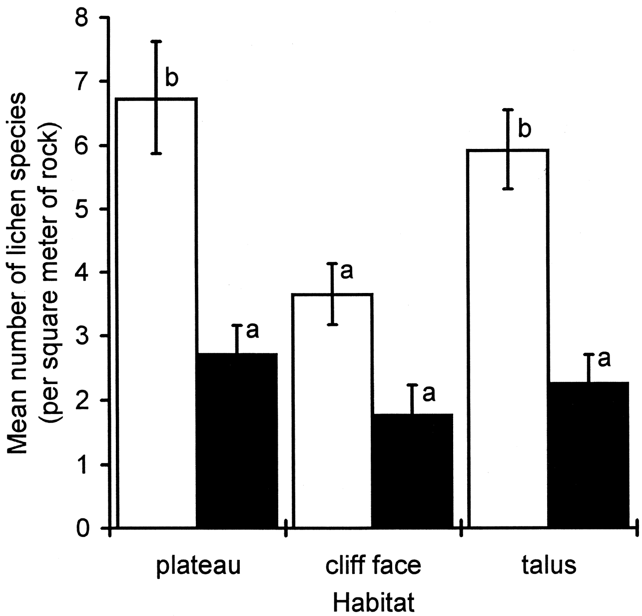

Figure 5. Mean number of lichen species on exposed rock within each quadrat type from the Niagara Escarpment, Ontario, Canada. Open bars represent unclimbed quadrats; solid bars represent climbed quadrats. Bars that share a letter code are not significantly different from one another at $\alpha = 0.05$.

in North America (Larson & Kelly 1991), and there is evidence to suggest that other cliffs around the world also support old-growth forests (Larson et al. 1999). Until recently, the inaccessibility of cliffs has protected them from direct anthropogenic disturbance. Accordingly, few management plans include a mandate for the protection of cliff biota (Kelly & Larson 1997; Krajick 1999; Meirelles et al. 1999). Our results suggest that rock climbing causes considerable damage to the vegetative community as a whole. Vascular plants, bryophytes, and lichens all responded negatively to rock-climbing pressure.

We observed differences between climbed and unclimbed quadrats in each of the three habitat types. Although hiking paths occurred on the plateau behind 100% of the climbed transects and 60% of the unclimbed transects, we believe that hiking disturbance was a minor factor in our study. The hiking trails were nearly always >3 m from the cliff edge, whereas sampling was restricted to the first 2 m of the plateau. Hikers do not always stay on the path, however, and so may be responsible for some of the damage found on the plateau in both climbed and unclimbed quadrats (Larson 1990; Taylor et al. 1993; Parikesit et al. 1995). The talus in this area is composed mainly of loose rocks and boulders; it is therefore extremely difficult to hike along the base of the cliffs in southern Ontario. In general, it is also difficult to access the talus from the paths on the plateau.

During the course of this research, we rarely observed hikers on the talus unless they were on their way to or from a climbing route. Although it is possible that hikers caused a small portion of the disturbance we observed on the talus, climbing is most likely the major source of disturbance in this area. Ascending the cliff faces we sampled requires the use of technical climbing gear. Consequently, the cliff face in this area is subject to direct disturbance from climbers only.

Vascular plant density and cover were lower in climbed areas than in unclimbed areas. Similarly, Herter (1996) and Camp and Knight (1998) noted a decline in overall plant density with climbing. We also observed a decrease in plant species richness and diversity in climbed areas, as did Camp and Knight (1998). Our results suggest that rock climbing also has a dramatic influence over the community composition of plant species on cliffs. The ordination of the canonical correspondence analysis indicated that the vascular plant community was unique for each of the three habitats and that the community composition differed between climbed and unclimbed plots for each habitat. Differences in the community composition of vascular plants between climbed and unclimbed quadrats were influenced by the presence of more alien species in climbed areas. Rock climbing increases the likelihood of alien invasions by increasing the number of available microsites (by reducing plant density) and by introducing alien propagules into the area (from shoes, clothing, and equipment). The invasion of natural habitats by alien species is currently considered one of the major threats to natural wilderness areas. Thus, the change from native to alien species must be considered when the severity of human disturbance on cliffs is determined.

No species of vascular plants we found is considered rare in Ontario (Newmaster et al. 1998), but the plateau, cliff faces, and talus slopes of the Niagara Escarpment all support unique plant communities that occur only on limestone rock. Also, the cliffs in this region support living *Thuja occidentalis* (eastern white cedar) trees that are up to 900 years old (Larson et al. 2000). Both the unique assemblages of species present on the cliffs and the age of the tree stands should be considered in the formation of new management policies for the Niagara Escarpment.

Bryophytes and rock climbing were nearly mutually exclusive in this study. Bryophytes were present in 44% of unclimbed quadrats but in only 8% of climbed quadrats. Bryophyte cover and richness were both significantly higher in unclimbed areas than in climbed areas. Farris (1998) also reported lower (but not statistically significant) means of bryophyte cover in climbed than unclimbed cliff-face quadrats. It appears that the talus habitat provides more suitable conditions for bryophyte growth than plateau or cliff-face habitats. Both percent cover and species richness were highest for unclimbed talus quadrats, which may be due to the increase in organic debris found in talus soils (Cox & Larson 1993). Because bryophyte species were present in such a small percentage of climbed quadrats, it was not possible to determine whether there were differences in bryophyte species composition between climbed and unclimbed sites.

Although there was no detectable difference in lichen cover between climbed and unclimbed quadrats, species richness was reduced in climbed areas and species composition differed between climbed and unclimbed areas. Among the species found most often in climbed quadrats were those from the crustose genera *Caloplaca*, which can be touched, rubbed, or even scratched with little visible consequence. These species could persist even in the most heavily climbed areas. Conversely, species found most often within unclimbed quadrats included species of the folios genus *Lepraria.* Members of this genus are extremely delicate and crumble from the rock with the slightest touch. *Acrocordia conoidea* was far more common in unclimbed quadrats. This species is of particular importance from a conservationist perspective because it is considered "rare" in Ontario, so rare that it is not yet included in the identification manual for the area (Wong & Brodo 1992). Another rare species, *Caloplaca citrina*, was found most often in climbed quadrats. Although they are often overlooked in biodiversity studies, lichens fulfill a significant role in many communities. Lichens are primary producers that represent an important food source for a variety of insects and gastropods. Some invertebrate consumers show tendencies to feed on certain lichen species over others (Fröberg et al. 1993; Baur et al. 1994, 1995). Lichens are extremely slow growing and may take decades to return to a natural condition after the cessation of a disturbance (Belnap 1993; Begon et al. 1996). Consequently, the reduction of lichen richness and the changes in species composition in climbed areas may have long-term effects not only on the lichen community but also on the invertebrate community.

Conservation and Management Implications

Our study provides strong evidence to suggest that rock climbing causes considerable damage to vascular plants, bryophytes, and lichens on the Niagara Escarpment in southern Ontario. Management plans for areas along the escarpment should therefore be modified to include specific policies regarding recreational rock climbing.

Some highly disturbed environments can recover rapidly with a temporary removal of the disturbance (Cole 1994). Closure of areas with heavy recreational use is not advised, however, because visitors tend to respond to such closures by moving into previously undisturbed or less disturbed habitats, thus increasing the areal extent of damage (Jim 1989; Cole 1993, 1994). The effect of rock climbing occurs within relatively few years of climbing activity (Herter 1996) and persists for longer than 2 years after the disturbance is removed (Nuzzo 1996). Thus, the proliferation of climbing routes in currently unclimbed areas in southern Ontario has the potential to cause widespread and long-lasting negative effects. We therefore discourage the closure of currently climbed areas in southern Ontario. Land managers should instead prohibit the establishment of new climbing routes in both climbed and unclimbed areas. This may limit the areal extent of recreational rock climbing in southern Ontario without significantly changing the recreational experience for rock climbers.

Recreationists are far more likely to abide by management plans when they are aware of the ecological rationale behind the restrictions (Jim 1989; Jacobson & Marynowski 1997; Camp & Knight 1998; Vorkinn 1998; Baker 1999; Young 1999). For this reason, we recommend that land managers and conservation authorities provide rock-climbing associations and schools with information on the effect of climbing on endemic cliff biota, including the rationale behind rules and regulations concerning climbing.

We recommend a long-term monitoring study to determine the rate of recovery of the cliff ecosystem after the removal of climbing pressure. Nuzzo (1996) concluded that 2 years was not long enough for vegetation to recover after cessation of rock climbing activity. No other studies have been conducted to determine the length of time required for cliffs to return to a natural condition after the removal of climbing pressure.

Acknowledgments

Funding for this project was generously provided by the Natural Sciences and Engineering Research Council of Canada, Mountain Equipment Co-op, the Lattornell Graduate Student Travel Fund, and the Access Fund. Special thanks go to X. Benjamin, I. Brodo, J. Buck, P. Clarke, J. Crowe, A. Cullen, M. deGruchy, C. Fietsch, S. Girard, K. Gormley, P. Kelly, C. A. Lacroix, G. Lecanu, J. Lundholm, G. Mackie, U. Matthes, A. Millward, A. Nassuth, S. Newman, R. Pal, R. Reader, J. Stewart, S. Thevenet, and P. Wong for their help in the field and laboratory. We also thank the Halton Region Conservation Authority and Milton Limestone Ltd. for allowing us to sample on their properties. M. Farris, R. Knight, E. Main, G. Meffe, and G. Walker provided helpful advice and comments on this manuscript.

Literature Cited

Anonymous. 1995. SAS system for Windows. Version 6.11. SAS Institute, Cary, North Carolina.

Baker, B. 1999. Controversy over use of rock-climbing anchors may be missing the mark. BioScience **49:**529.

Baur, A., B. Baur, and L. Fröberg. 1994. Herbivory on calcicolous lichens: different food preferences and growth rates in two co-existing land snails. Oecologia **98:**313–319.

Baur, B., L. Fröberg, and A. Baur. 1995. Species diversity and grazing damage in a calcicolous lichen community on top of stone walls in Öland, Sweden. Annales Botanici Fennici **32:**239–250.

Begon, M., J. L. Harper, and C. R. Townsend. 1996. Ecology: individuals, populations and communities. Blackwell Science, Oxford, United Kingdom.

Belnap, J. 1993. Recovery rates of cryptobiotic crusts: inoculant use assessment methods. Great Basin Naturalist **53:**89–95.

Bracken, M., J. Barnes, and C. Oates. 1991. The escarpment: a climbers guide. Borealis Press, Toronto.

Brodo, I. M. 1988. Lichens of the Ottawa Region. 2nd edition. Ottawa Field-Naturalist's Club and the National Museum of Natural Sciences, Ottawa.

Camp, R. J., and R. L. Knight. 1998. Effects of rock climbing on cliff plant communities at Joshua Tree National Park, California. Conservation Biology **12:**1302–1306.

Cody, W. J., and D. M. Britton. 1989. Ferns and fern allies of Canada. Research Branch Agriculture Canada, Ottawa.

Cole, D. N. 1993. Wilderness recreation management. Journal of Forestry **91:**22–24.

Cole, D. N. 1994. Backcountry impact management: lessons from research. Trends **31:**10–14.

Cox, J. E., and D. W. Larson. 1993. Environmental relations of the bryophytic and vascular components of a talus slope plant community. Journal of Vegetation Science **4:**553–560.

Crum, H. 1983. Mosses of the great lakes forest. University Herbarium, University of Michigan, Ann Arbor.

Farris, M. A. 1998. The effects of rock climbing on the vegetation of three Minnesota cliff systems. Canadian Journal of Botany **76:**1981–1990.

Fröberg, L., A. Baur, and B. Baur. 1993. Differential herbivore damage to calcicolous lichens by snails. Lichenologist **25:**83–95.

Gleason, H. A., and A. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. 2nd edition. The New York Botanical Garden, The Bronx.

Herter, W. 1996. Die Xerothermvegetation des Oberen Donautals—Gefaerhrdung der Vegetation durchMensch und Wild sowie Schutz—und Erhaltungsvorschlaege. Veroeffentlichungen des projekts "Angewandte Oekologie" PAoe 10. Landesanstalt für Umweltschutz Baden-Württemberg, Karlsruhe, Germany.

Ireland, R. D. 1982. Moss flora of the maritime provinces. National Museums of Canada, Ottawa.

Jacobson, S. K., and S. B. Marynowski. 1997. Public attitudes and knowledge about ecosystem management on Department of Defense land in Florida. Conservation Biology **11:**770–781.

Jim, C. Y. 1989. Visitor management in recreation areas. Environmental Conservation **16:**19–32.

Jodice, P., K. Pyke, and S. Davidson. 1999. Climbing and cliff ecology. Science **284:**434.

Kelly, P. E., and D. W. Larson. 1997. Effects of rock climbing on populations of presettlement eastern white cedar (*Thuja occidentalis*) on cliffs of the Niagara Escarpment, Canada. Conservation Biology **11:**1125–1132.

Krajick, K. 1999. Scientists—and climbers—discover cliff ecosystems. Science **283:**1623–1625.

Krebs, C. J. 1999. Ecological methodology. Addison-Welsey, Menlo Park, California.

Kuehl, R. O. 1994. Statistical principles of research design and analysis. Wadsworth Publishing, Belmont, California.

Larson, D. W. 1990. Effects of disturbance on old-growth *Thuja occidentalis* at cliff edges. Canadian Journal of Botany **68:**1147–1155.

Larson, D. W., and P. E. Kelly. 1991. The extent of old-growth *Thuja* *occidentalis* on cliffs of the Niagara Escarpment. Canadian Journal of Botany **69:**1628–1636.

Larson, D. W., U. Matthes, J. A. Gerrath, J. M. Gerrath, J. C. Nekola, G. L. Walker, S. Porembski, A. Charlton, and N. W. K. Larson. 1999. Ancient stunted trees on cliffs. Nature **398:**382–383.

Larson, D. W., U. Matthes, and P. E. Kelly. 2000. Cliff ecology: pattern and process in cliff ecosystems. Cambridge University Press, Cambridge, United Kingdom.

Ley, L. M., and J. M. Crowe. 1999. An enthusiasts guide to the liverworts and hornworts of Ontario. Lakehead University, Thunderbay, Ontario, Canada.

Meirelles, S. T., V. R. Pivello, and C. A. Joly. 1999. The vegetation of granite rock outcrops in Rio de Janeiro, Brazil, and the need for its protection. Environmental Conservation **26:**10–20.

Newmaster, S. G., A. Lehela, P. W. C. Uhlig, S. McMurray, and M. J. Oldham. 1998. Ontario plant list. Forest research information paper 123. Ontario Forest Research Institute, Sault Ste. Marie, Ontario, Canada.

Niagara Escarpment Commission. 1979. Geology: the Niagara Escarpment. Niagara Escarpment Commission, Georgetown, Ontario, Canada.

Nuzzo, V. A. 1995. Effects of rock climbing on cliff Goldenrod (*Solidago sciaphila* Steele) in Northwest Illinois. American Midland Naturalist **133:**229–241.

Nuzzo, V. A. 1996. Structure of cliff vegetation on exposed cliffs and the effect of rock climbing. Canadian Journal of Botany **74:**607–617.

Oates, C., and M. Bracken. 1997. A sport climbers guide to Ontario limestone. Borealis Press, Toronto.

Parikesit, P., D. W. Larson, and U. Matthes-Sears. 1995. Impacts of trails on cliff-edge forest structure. Canadian Journal of Botany **73:**943–953.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach. 2nd edition. McGraw-Hill, New York.

Taylor, K. C., R. J. Reader, and D. W. Larson. 1993. Scale-dependent inconsistencies in the effects of trampling on a forest understory community. Environmental Management **17:**239–248.

Valis, T. 1991. Escarpment climbing history. Pages 3–6 in M. Bracken, J. Barnes, and C. Oates, editors. The escarpment: a climbers guide. Borealis Press, Toronto.

Vorkinn, M. 1998. Visitor response to management regulations: a study among recreationists in southern Norway. Environmental Management **22:**737–746.

Voss, E. G. 1972. Michigan flora. I. Gymnosperms and monocots. Cranbrook Institute of Science and University of Michigan Herbarium, Bloomfield Hills.

Voss, E. G. 1985. Michigan flora. II. Dicots. Bulletin 59. Cranbrook Institute of Science and University of Michigan Herbarium, Ann Arbor.

Voss, E. G. 1996. Michigan flora. III. Dicots concluded. Bulletin 59. Cranbrook Institute of Science and University of Michigan Herbarium, Ann Arbor.

Wong, P. Y., and I. M. Brodo. 1992. The lichens of southern Ontario, Canada. Canadian Museum of Nature, Ottawa.

Young, W. 1999. Climbing threatened by lichens: smart scientists needed to combat anti-climbing hysteria. Climbing **189:**44–45.