WORKING PAPER 55

Impact of Partial Cutting on Lichen Diversity in Lodgepole Pine Forests on the Chilcotin Plateau of British Columbia

2001

British Columbia

Ministry of Forests Research Program

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Citation:
Miège, D.J., T. Goward, M.J. Waterhouse, and H.M. Armleder. 2001. Impact of partial cutting on lichen diversity in lodgepole pine forests on the Chilcotin Plateau in British Columbia. Res. Br., B.C. Min. For., Victoria, B.C. Work. Pap. 55/2001.

url: http://www.for.gov.bc.ca/hfd/pubs/Docs/Wp/Wp55.htm

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ABSTRACT

The lodgepole pine (*Pinus contorta*) ecosystems of the west Chilcotin Plateau of British Columbia are important northern caribou habitat. This lichen diversity study is part of a larger research program in these forests, designed to develop and test silvicultural systems that maintain caribou winter range yet allow some level of timber harvesting. The research trial included the following treatments: unlogged control; group selection based on 30% area removal and stem-only harvesting; irregular group shelterwood based on 50% area removal with stem-only harvesting; and irregular group shelter-wood based on 50% area removal via whole-tree harvesting. In 1995, prior to logging, the lichen assessment plots were established and measured. In 1998, they were remeasured, 2.5 years after logging. Results showed slight decreases in stand-level lichen richness ($F = 4.51$, $P = 0.02$), diversity ($F = 3.65$, $P = 0.04$), and abundance ($F = 5.73$, $P = 0.01$) in all the partial cutting treatments compared to the uncut controls. Differences between partial cutting treatments were not detected, possibly because of limitations in the study design. Correlation analyses found significant negative relationships between the amount harvested in each plot and richness ($r = -0.34$, $P = 0.03$), diversity ($r = -0.33$, $P = 0.04$) and abundance ($r = -0.32$, $P = 0.05$); and significant positive correlations between the amount harvested and percent cover of slash ($r = 0.79$, $P = 0.0001$) and direct beam solar radiation ($r = 0.64$, $P = 0.0001$).

ACKNOWLEDGEMENTS

We would like to thank Ken MacKenzie, Kristi Iverson, and Ray Coupé for providing initial orientation to the study area and subsequent assistance in the field during the 1995 field season. Also, we thank Dan Burgess for his astute field observations and early contributions to the text. Furthermore, we would like to thank Ordell Steen, Doug Steventon, Jim Young, John Youds, and Amanda Linnell Nemec for reviewing the paper.

The innovative timber harvesting tested in this study was made possible through the support and co-operation of Riverside Forest Products Limited, the B.C. Ministry of Forests Chilcotin Forest District, and Clusko Logging Enterprises Limited.

This project was funded by Forest Renewal British Columbia, and by the B.C. Ministry of Forests under Experimental Project 1208.

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1 INTRODUCTION

Lichens are widely recognized as the major winter forage of woodland caribou (*Rangifer tarandus caribou*) throughout their range (Edwards and Ritcey 1960; Edwards et al. 1960; Scotter 1962, 1967; Ahti and Hepburn 1967; Cichowski 1989). Specific feeding habits differ, however, from one region to another. In mountainous areas of heavy snowfall in southeastern and east-central British Columbia, caribou eat arboreal (tree-dwelling) lichens almost exclusively during the winter. By contrast, in regions of lighter snowfall (e.g., west-central and northern British Columbia), caribou are able to use terrestrial (ground-dwelling) lichens in addition to arboreal lichens. Research in the Itcha – Ilgachuz mountain area in west-central British Columbia has shown that terrestrial lichens are an important food of woodland caribou during winter months (Cichowski 1989).

Logging can have a drastic effect on available arboreal lichen biomass (Stevenson 1979, 1985, 1988, 1990; Stevenson and Enns 1992; Rominger et al. 1994). Much effort has been directed at understanding the effects of silvicultural practices on arboreal lichen biomass in the Engelmann Spruce – Subalpine Fir (ESSF) and Interior Cedar – Hemlock (ICH) forest zones (Stevenson et al. 1994). By contrast, the effects of logging on lichen biomass in even-aged lodgepole pine (*Pinus contorta*) stands of the Sub-Boreal Pine – Spruce (SBPS) and Montane Spruce (MS) zones are much less well documented. In those stands, the terrestrial lichen flora can often cover 50–60% the forest floor.

Typical clearcut harvesting treatments do not retain lichen cover. Miège et al. (2001) reported a 64% decrease in lichen cover in the open portions of a 70% removal treatment unit within a pilot block in the study area. In Alberta, Woodard[1] completed a study on lichen recovery in blocks harvested by clear-cutting, and concluded that cutblocks even 30 years old still only had 50% of the cover of preferred woodland caribou forage species. In another related study in the Itcha – Ilgachuz area, Miège and Goward[2] observed that 8- to 13-year-old clearcuts had, on average, only 12% of the cover of caribou-preferred lichen species present in uncut forests.

Concerns for the long-term sustainability of caribou in regions affected by logging have initiated several complementary research studies on the Chilcotin Plateau. Collectively, these studies examine the feasibility of various silvicultural systems that employ partial cutting for maintaining a healthy population of northern caribou while still allowing some level of timber removal. One pilot test within the study area, for example, described low lichen diversity and abundance following a harvest with 70% volume removal, but suggested that cuts with less volume removed, careful management of slash, and adequate shading from residual trees might maintain caribou forage lichens (Miège et al. 2001). Another study is under way to quantitatively assess the response of known forage lichens to partial cutting (Waterhouse 1998).

Based on the knowledge gained from the pilot trial (Miège et al. 2001), two silvicultural systems were developed and applied using two alternative

1 Woodard, P.M. 1995. The effects of harvesting on lichen regeneration rates and plant diversity in west-central Alberta. Alberta Environmental Protection, Land and Forests Services, Edmonton, Alta. Unpubl. rep.
2 Miège, D. and T. Goward. 1999. Macrolichens of lodgepole pine forests within northern caribou range in central British Columbia. B.C. Ministry of Forests, Cariboo Forest Region, Williams Lake, B.C. Unpubl. rep.

harvesting techniques. The group selection system, designed for arboreal lichen sites, was based on 33% area removal (in 15–20 m diameter openings) every 80 years. For areas where terrestrial lichens predominate, an irregular group shelterwood was developed. The opening size is larger than used for arboreal lichen sites (25–30 m), but 50% of the area is cut and the remainder of the stand will be cut in 70 years. Both the opening size and percent of harvesting will affect the amount of solar radiation reaching the terrestrial lichen community. The amount of direct beam solar radiation is thought to have a primary influence on the health and survival of lichens.

Whole-tree harvesting and stem-only harvesting were used in this study. Whole-tree harvesting may cause more physical damage to the lichens as the trees are dragged to roadside processing areas to be limbed and cut to length. The advantage of this technique, from the lichen standpoint, is that it removes slash from the site. With stem-only harvesting, the trees are limbed and cut-to-length on site and the slash is piled. Only the bole of the tree is pulled to the landing, therefore causing less ground disturbance.

In this study, our main objective was to test for changes in lichen richness as a result of the partial cutting treatments. Secondary objectives included exploring differences in lichen diversity, mortality, and abundance among three logging treatments and unlogged controls, and relating differences to slash loading and direct beam solar radiation.

2 METHODS

2.1 Study Area

The study area is located on the Fraser Plateau in west-central British Columbia at 52°30′ N, 124°36′ W. Bordering the Itcha Mountain range approximately 46 km northwest of Puntzi Lake, it lies both to the east and west of Satah Mountain, and has gentle elevation gains from 1280 to 1675 m (Figure 1). The study area includes five replicated research blocks. Blocks 1 and 2 are located within the Sub-Boreal Pine – Spruce very dry, cold (SBPSxc) biogeoclimatic subzone (Steen and Coupé 1997). Blocks 3, 4, and 5 are located in the Montane Spruce very dry, very cold (MSxv) subzone.

The dominant tree species on all sites is lodgepole pine, with stand ages between 100 and 275 years. Stem densities in these forests range from 354 to 1747 stems per hectare, with a corresponding net merchantable volume between 66 and 270 m^2/ha. Spruce (*Picea glauca* or *Picea glauca* × *engelmannii*) is very uncommon in the SBPS blocks, but becomes more common in blocks 4 and 5 in the MS subzone. The shrub layer in both subzones is characterized by *Juniperus communis* and *Shepherdia canadensis*, although shrubs are generally more abundant in the MSxv than in the SBPSxc. The herb layer is dominated by dwarf shrubs: *Arctostaphylos uva-ursi* in the SBPSxc and *Vaccinium scoparium* and *Empetrum nigrum* in the MSxv. The moss and lichen layer is dominated by mosses in the MSxv and by lichens in the SBPSxc. The principal ground lichens in both subzones are species of *Cladina*, *Cladonia*, *Peltigera*, and *Stereocaulon*.

All lichen assessment plots were established on well-drained and moderately well-drained soils, with predominantly sandy loam texture. The moisture regime is mesic and the topography is mostly flat or gently rolling, although some plots in block 5 are located on slopes as steep as 32%.

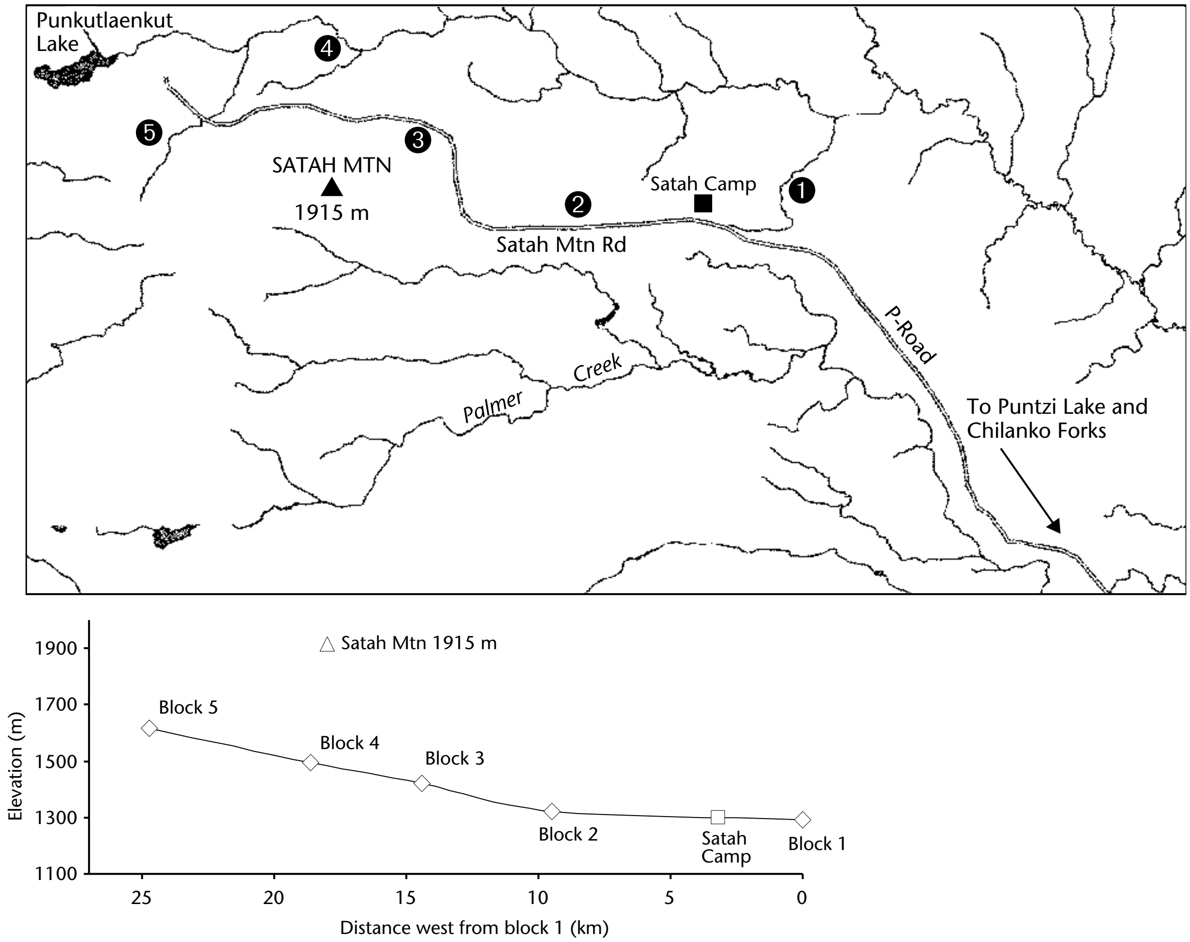


FIGURE 1 *Overview map of the Itcha – Ilgachuz study area (top), with elevational trends shown in cross section (below). Y-axis is vertically exaggerated.*

2.2 Silvicultural Systems and Timber Harvesting Treatments

Each of the five replicated blocks in the study area was divided into four treatment units of approximately 15–30 ha. One treatment unit is an uncut control; the three other treatments differ by silvicultural system and method of partial cutting.

There are two silvicultural systems that are being tested: irregular group shelterwood and group selection. The irregular group shelterwood targets 50% area removal every 70 years, and is planned for areas with high terrestrial lichen abundance. The purpose is to shelter lichens from excessive solar radiation. Two methods of harvesting are associated with the irregular group shelterwood: stem only and whole tree. The group selection system is based on 33% area removal with a cutting cycle of 80 years. This system is designed to retain both terrestrial and arboreal lichens. In each treatment unit, the actual harvest area (%) and diameter of the cut openings (m) were measured from maps produced with the Global Positioning System.

Treatment 1 (T1) is an irregular group shelterwood that employed stem-only harvesting. The mean cut area was 40% (n = 5, SD = 9%) and openings are 26.2 m in diameter (SD = 7.5 m). Trees were felled and piled with a zero tail-swing feller-buncher, processed, limbed, and cut to length on site by a separate dangle-head processor, and then moved to the roadside by a six-wheeled, rubber-tired forwarder. Most of the slash was deposited in piles rather than spread over the openings.

Treatment 2 (T2) is an irregular group shelterwood that used whole-tree harvesting. The actual area removed was, on average, lower than planned, with a mean of 38% (n = 5, SD = 7%) and an average opening size of 22.9 m (SD = 5.6 m) in diameter. In T2, however, the felled trees were grapple-skidded to the roadside before processing. A strip of the harvesting unit was clearcut parallel to the road to accommodate the processing (mean area = 4% of entire treatment unit, n = 4, SD = 2%). A processing area was not used in block 2 because of very light volume removal. Processing areas were heavily traversed by machinery, and piled slash at the roadside was burned the year after harvest.

Treatment 3 (T3) is a group selection silvicultural system. Here, the mean harvest area was 28% (n = 5, SD = 4%). Like T1, trees were processed on site before being forwarded to the roadside. The mean opening diameter was 14.5 m (SD = 3.3 m).

A comparison of T1 and T2 allowed us to examine the impacts on lichens of two different logging methods, and comparisons of those with T3 allowed us to study the effects of a lighter amount of timber removal coupled with smaller opening size.

Harvesting occurred on all blocks between January and April of 1996 on a snowpack of 50–100 cm. A small part of block 4 was processed and forwarded in February 1997 on a 35-cm snowpack.

2.3 Placement of Permanent Plots

To assess the lichen, two circular 30 m diameter plots were established and surveyed in each treatment unit of all blocks, for a total of 40 plots (i.e., two plots per treatment unit × four treatment units per block × five blocks). Plots of this size are judged effective at capturing species richness, though they are less accurate for the estimating of cover (McCune and Lesica 1992).

All plots were centred on randomly selected grid points within each treatment unit (grid points were 50 m apart) that had been established for a complementary project (Waterhouse 1998). The plots were placed on zonal site series for their associated biogeoclimatic subzones (Steen and Coupé 1997). Grid points were rejected if they fell on non-zonal site series, or on areas where trees were recently killed by mountain pine beetle (because opening of the stand by the beetles may have caused the structure of the lichen community to change).

2.4 Plot Assessment and Analyses

Records were made of lichens present on several substrates. At each plot, five trees were sampled for arboreal lichens to a height of 2.5 m. Selected trees had an average lichen loading and were located closest to the centre of the plot. When possible, lichen identifications were made in the field. Several confirmation voucher specimens were collected, and unknown specimens were also collected for later identification. We did not record the presence of crust lichens. In a few cases, taxonomically difficult species needed to be grouped under one name (e.g., *Bryoria "fuscescens"* includes *B. simplicior* and *B. lanestris*, and *Stereocaulon "tomentosum"* includes *S. alpinum* and *S. grande*[3]).

In addition to recording lichen presence, we also applied a modified version of the five-point frequency and abundance scale described by Goward and Arsenault (1997). The value is assigned following an examination of all surfaces

3 Nomenclature follows Esslinger and Egan (1995).

of all substrates present in the plot. Percent cover classes were reserved for species having moderate to high abundance, while class based on the actual number of colonies present was used for species of lower abundance. To better assess terrestrial lichen cover, we modified the scale with the addition of a "3.5" class, intended to represent cover of 6–20%. (We used this class only for terrestrial lichens.) The classes in the modified system were as follows:

- 1 = one or two lichen colonies per 2 linear metres on trees, snags, and shrubs, or per 16 m^2 on the ground
- 2 = three to five colonies per 2 linear metres, or per 16 m^2 on the ground
- 3 = six colonies per 2 linear metres, or up to 5% cover
- 3.5 = 6–20% cover
- 4 = 2–50% cover
- 5 = 51% or greater cover

In the case of fruticose species, a colony was defined as a cluster (e.g., *Cladonia*) or weft (e.g., *Bryoria*) of thalli morphologically homogeneous throughout. In the case of lichens belonging to other life forms (crustose, squamulose, and foliose), a colony was defined as being functionally equivalent to a single thallus, whether small, medium, or large.

Individual lichen species were assessed for mortality levels. Lichen status was based primarily on our assessment of pigment loss and/or discoloration of the thallus, which follows methods used by Benedict (1990). The mortality rate increments of 25 and 50% were used for ease of estimation, and 25% mortality in lichens was thought to be biologically significant—that is, having implications for caribou.

Twelve "functional" substrate types were assessed for lichen abundance: 1) *Pinus* branches; 2) *Pinus* boles; 3) *Picea* branches; 4) *Picea* boles; 5) upturned roots; 6) decaying stumps; 7) downed logs; 8) moss-covered downed logs; 9) rocks; 10) moss-covered rocks; 11) forest floor; and 12) shrubs. The selected substrate categories were designed to ensure that all surfaces were checked, and thus that maximum ecological variability was measured. More detailed analysis of the substrate data is treated by Miège and Goward.[4]

We adopted the term "functional substrate types" to reflect those occasions when one substrate class supports a lichen flora more typical of another substrate class. For example, the "upturned root" category was used to capture the diversity of lichens that can occur when a tree falls over and leaves a large soil and root mound at its base. In the study area, we often found upturned roots away from which the soil had fallen, and in a decorticate condition. Such root mounds function more like a rotting stump and were recorded as such. In analyzing the data for diversity index and lichen community, we used the maximum value ascribed to a lichen species within the plot, regardless of the substrate on which it was recorded. This value denotes the ecological suitability of the site for that particular lichen—or, said another way, it best describes the lichen's abundance under optimum substrate availability (Goward and Arsenualt 1997).

Our methods were similar to the "whole-plot ocular" method of McCune and Lesica (1992). However, their substrate categories are more broadly based

4 Miège, D. and T. Goward. 1999. Macrolichens of lodgepole pine forests within northern caribou range in central British Columbia. B.C. Ministry of Forests, Cariboo Forest Region, Williams Lake, B.C. Unpubl. rep.

(i.e., consolidated to tree branches, tree boles, and ground), and they used percent cover estimates (in 17 classes) for all species. We believe that our six-point frequency and abundance scale allows a greater resolution for the numerous lichen species that typically occur at covers of less than 1%, while still providing a relatively quick description of lichen abundance for each plot.

Total percent cover of terrestrial lichens was estimated following Luttmerding et al. (1990). (Given that the lichen covers are ocular estimates over 30 m diameter plots, some caution is warranted in assessing the results.) Mesoslope position was also described according to Luttmerding et al. (1990).

When we established our plots in 1995, there was no way of predicting which trees would be removed during logging. The type of logging that was done removed trees along skid trails or in small patches. We therefore knew that some of our plots could fall entirely within a residual forest, or entirely within a small patch cut. The possibility also existed that some plots could end up straddling cut and uncut sites. Consequently, to quantify the degree to which the tree canopy and forest floor substrate had been altered for each plot, we recorded three additional environmental parameters during the 1998 data collection period: 1) the portion that had been logged; 2) the amount of each plot covered by logging slash; and 3) the resulting stand openness. The logged portion was estimated roughly by comparing the area of the plot with cut stumps to the area with standing trees. The slash and logged estimates were expressed as a visually estimated cover percent of the entire plot. Finally, stand openness was assessed using fisheye photography of the canopy.

Forest canopy fisheye photographs depict the shape of canopy gaps or configurations of residual stands (a 7.5-mm fisheye lens creates a circular image encompassing a 180° field of view). These images were digitized and later analyzed by computer to produce a quantitative index of solar radiation reaching the forest floor throughout the growing season. The value of the index is expressed as a percentage of the amount of radiation incident on a surface without any effect of topography or forest canopy. Given that lichens are reported to be sensitive to unrestricted insolation (e.g., Eriksson 1975), we also chose to report direct beam solar radiation rather than diffuse beam radiation. The software used was GLI/C, developed by Canham (1995). The calculations are specific to the latitude of the site and the length of the growing season (Canham 1988).

We calculated a Shannon Diversity Index for each plot. This involved first calculating a relative abundance (p) for each species in the plot. We used the following formula, where n is the representative frequency or abundance class of the individual species, and N is the sum of all the representative class values for the plot:

EQUATION 1 *Relative abundance*

$$p = \frac{n}{N}$$

Next, the Shannon Diversity Index (H') was calculated by using the following equation:

EQUATION 2 *Shannon Diversity Index*

$$H' = -\sum_{i=1}^{s} p_i \times \ln p$$

(s = species richness)

2.5 Experimental Design and Statistical Methods

The experimental design is a one-way randomized block. Within each of the five replicate blocks are four treatment units. The four treatments (unlogged control, 50% stem-only harvesting, 50% whole-tree harvesting, and 30% stem-only harvesting) were randomly assigned to the treatment units within each block. Within each treatment unit, there are two plots (subsamples) used to sample the lichen community and associated physical characteristics.

One-way analysis of variance and a priori contrasts were used to test the null hypothesis that there were no significant differences between the treatments. In all cases, the type III mean square from the block-by-treatment interaction (df = 12) was used instead of the default error term of the model to test for treatment effects.

Ward's cluster analysis (Sneath and Sokal 1973; McCune and Mefford 1997) of the pre-treatment data (1995) indicated that there are two distinct lichen communities in the study area (Appendix 1). The analysis used the relative abundance values (i.e., 1, 2, 3, 3.5, 4, 5) to calculate the Euclidean distances. Blocks 1 to 3, it was found, are characterized by an abundance of ground-dwelling *Cladonia* species, while blocks 4 and 5 have abundant epiphytic *Bryoria* species. Based on occurrence, 71% of the species were found to be in common between the two communities. The species not in common tend to occur infrequently and at lower abundance. These observations led us to do additional analyses of variance for the species richness variable since the combination of species present may respond differently to the harvesting treatments. For the other variables of interest (species diversity index, percent cover of terrestrial lichen, direct beam solar radiation, and percent cover of slash), we did not expect differing treatment responses because of the location of the blocks.

The a priori contrast hypotheses for species richness, species diversity, and abundance were:

1. Is the unlogged control different from the harvested treatments?
2. Is the 50% stem-only harvesting different from the 50% whole-tree harvesting?
3. Is the 30% stem-only harvesting different from the 50% stem-only harvesting?

The a priori contrast hypotheses for direct beam solar radiation were:

1. Is the unlogged control different from the harvested treatments?
2. Are the 50% removal treatments different from the 30% removal treatment?

The a priori contrast hypotheses for slash were:

1. Is the unlogged control different from the 50% whole-tree harvesting treatment?
2. Is the whole-tree harvesting treatment different from the stem-only harvesting treatments?
3. Is the 30% stem-only harvesting different from the 50% stem-only harvesting?

Pearson's correlation coefficients and associated probability levels were calculated between lichen and habitat variables. Results of all statistical tests were considered significant at $\alpha = 0.05$.

An annotated list of lichens found in the study plots is given in Appendix 2. A summary table for lichen data is in Appendix 3, and physical characteristics of the plots are listed in Appendix 4.

3 RESULTS

3.1 Lichen Diversity

Ninety-one macrolichen (i.e., non-crustose) species were recorded for the study area. One species, an undescribed *Hypocenomyce*, is new to science. The total number of lichen species recorded strictly within the research plots was 75.

3.1.1 Species richness Initially, we examined lichen diversity by comparing the total number of lichen species found (species richness) within each treatment type. The overall ANOVA model was significant ($P < .05$) for 1998, but non-significant in 1995 (Table 1). The number of species was slightly lower in the treatments compared to the control ($P < .01$) (Table 2) in 1998.

The apparent species shift between blocks 1 to 3 and blocks 4 and 5 suggests that the types of species present may respond differently to the treatments. When the two communities were analyzed separately, the ANOVA models were non-significant ($P > 0.05$). However, the a priori contrast comparing the control to the three treatments was significant for blocks 1 to 3 (Table 2) in 1998.

In 1995, species richness for T3 in blocks 4 and 5 there was relatively low. The post-logging richness values recorded in 1998 compare more favourably with those calculated for the rest of the study area (Table 1). The most likely reason for this is that the observers missed species, present only in trace amounts, in 1995.

3.1.2 Species diversity index The Shannon Diversity Index (H') represents both the number of species present and their abundance. The overall ANOVA model was significant ($P < .05$) for 1998 (Table 3). The a priori contrast for 1998, comparing the control to the three treatments, indicates that the species diversity index was lower in the treatments ($F = 7.62$, df = 1, $P = .02$) (Table 4).

3.2 Lichen Abundance

Terrestrial lichen abundance (all species) was compared based on percent cover. The overall ANOVA model was significant ($P < .05$) for 1998 (Table 5). The a priori contrast comparing the control to the three treatments in 1998 indicates that, as for species diversity, the lichen cover was lower in the treatments ($F = 15.61$, df = 1, $P = .01$) (Table 6).

3.3 Lichen Mortality

During our 1998 post-logging lichen survey, we observed several plots in which a number of lichens appeared to have been damaged by increased exposure to the sunlight. Also, most of the detectable lichen mortality occurred against the north edge of canopy openings, where shade from the southern edge trees is at a minimum. Most strongly affected were various species of *Peltigera*, as well as *Cladonia ecmocyna*.

TABLE 1 *Mean lichen species richness for each treatment and ANOVA results in 1995 and 1998 in the Itcha – Ilgachuz study area. Results are considered significant at α = .05 and are in bold.*

Block	Year	Mean lichen species richness				Sum of squares	F	P
		C	T1	T2	T3			
1–5	1995	33.3	30.3	31.4	30.9	50.48	0.96	0.44
	1998	34.0	30.2	29.2	31.9	132.68	4.51	**0.02**
		(n = 10)	(n = 10)	(n = 10)	(n = 10)		(df 3,12)	
1–3	1995	34.33	31.5	31.7	34.0	40.45	0.62	0.63
	1998	35.2	30.5	29. 2	32.3	40.49	2.55	0.15
		(n = 6)	(n = 6)	(n = 6)	(n = 6)		(df 3,6)	
4–5	1995	31.8	28.5	31.0	26.3	75.25	5.19	0.10
	1998	32.3	29.8	29.3	31.3	22.75	2.12	0.27
		(n = 4)	(n = 4)	(n = 4)	(n = 4)		(df 3,3)	

TABLE 2 *A priori contrasts for 1995 and 1998 lichen species richness in the Itcha – Ilgachuz study area. Results are considered significant at α = .05 and are in bold. SOH – stem-only harvesting; WTH – whole-tree harvesting.*

Block	Year	Contrast	df	Sum of squares	F	P
1–5	1995	Control vs treatments	1	44.4	2.52	0.14
		50% SOH vs 50% WTH	1	6.05	0.34	0.59
		50% SOH vs 30% SOH	1	1.80	0.10	0.75
1–5	1998	Control vs treatments	1	95.4	9.73	**0.01**
		50% SOH vs 50% WTH	1	5.00	0.51	0.49
		50% SOH vs 30% SOH	1	14.45	1.47	0.25
1–3	1995	Control vs treatments	1	17.01	0.78	0.41
		50% SOH vs 50% WTH	1	0.08	0	0.95
		50% SOH vs 30% SOH	1	18.75	0.86	0.39
1–3	1998	Control vs. treatments	1	91.13	5.73	**0.05**
		50% SOH vs 50% WTH	1	5.33	0.34	0.58
		50% SOH vs 30% SOH	1	10.08	0.63	0.46
4–5	1995	Control vs treatments	1	30.08	6.22	0.09
		50% SOH vs 50% WTH	1	12.50	2.59	0.21
		50% SOH vs 30% SOH	1	10.13	2.09	0.24
4–5	1998	Control vs treatments	1	14.08	3.93	0.14
		50% SOH vs 50% WTH	1	0.50	0.14	0.73
		50% SOH vs 30% SOH	1	4.50	1.26	0.34

TABLE 3 *Mean lichen diversity by treatment and ANOVA results for 1995 and 1998 in the Itcha – Ilgachuz study area. Results are considered significant at α = .05 and are in bold.*

	Mean lichen diversity						
Year	C (n = 10)	T1 (n = 10)	T2 (n = 10)	T3 (n = 10)	Sum of squares	F (df 3,12)	P
1995	3.39	3.31	3.34	3.32	0.04	0.82	0.51
1998	3.42	3.31	3.28	3.36	0.11	3.65	**0.04**

TABLE 4 *A priori contrasts for 1995 and 1998 lichen species diversity index in the Itcha – Ilgachuz study area. Results are considered significant at α = .05 and are in bold. SOH – stem-only harvesting; WTH – whole-tree harvesting.*

Block	Year	Contrast	df	Sum of squares	F	P
1–5	1995	Control vs treatments	1	0.04	2.18	0.17
		50% SOH vs 50% WTH	1	0.005	0.27	0.61
		50% SOH vs 30% SOH	1	0.0008	0.05	0.83
1–5	1998	Control vs treatments	1	0.08	7.62	**0.02**
		50% SOH vs 50% WTH	1	0.0024	0.02	0.64
		50% SOH vs 30% SOH	1	0.017	1.64	0.22

TABLE 5 *Mean lichen abundance, based on percent cover, for each treatment and ANOVA results for blocks 1 to 5 in 1995 and 1998 in the Itcha – Ilgachuz study area. Results are considered significant at α = .05 and are in bold.*

	Lichen abundance (percent cover)						
Year	C (n = 10)	T1 (n = 10)	T2 (n = 10)	T3 (n = 10)	Sum of squares	F (df 3,12)	P
1995	48.5	43.5	37.5	39.5	707	1.83	0.19
1998	49.8	35.0	28.5	33.5	2519	5.73	**0.01**

TABLE 6 *A priori contrasts for 1995 and 1998 lichen abundance in the Itcha – Ilgachuz study area. Results are considered significant at α = .05 and are in bold. SOH – stem-only harvesting; WTH – whole-tree harvesting.*

Block	Year	Contrast	df	Sum of squares	F	P
1–5	1995	Control vs treatments	1	520.8	4.05	0.07
		50% SOH vs 50% WTH	1	180.0	1.40	0.26
		50% SOH vs 30% SOH	1	80.0	0.62	0.45
1–5	1998	Control vs treatments	1	2288.1	15.61	**0.002**
		50% SOH vs 50% WTH	1	211.3	1.44	0.25
		50% SOH vs 30% SOH	1	11.25	0.08	0.79

The number of lichen species exhibiting more than 25% mortality is compared to the percentage of direct beam solar radiation in Figures 2 and 3. Both figures display apparent thresholds of about 50% direct beam solar radiation after which lichen mortality occurs. That is, there is not a gradual increase in the number of affected lichen species over the range of light readings. It is interesting to note that in blocks 4 and 5, lichen mortality (in excess of 25%) was recorded at a minimum of about 57% direct beam solar radiation, while in blocks 1 to 3, this value was about 38% (Figures 2 and 3).

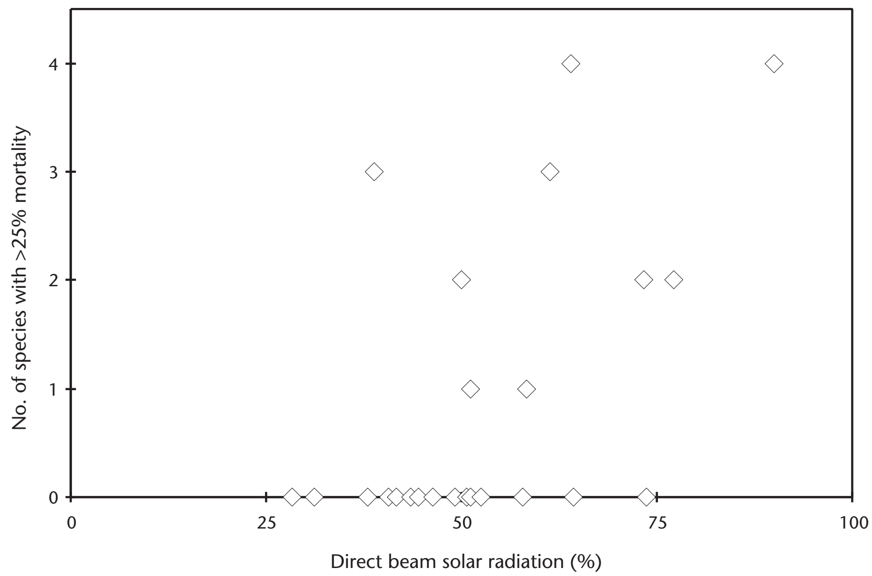


FIGURE 2 *Comparison of solar radiation to lichen mortality in the Itcha – Ilgachuz study area, blocks 1, 2, and 3.*

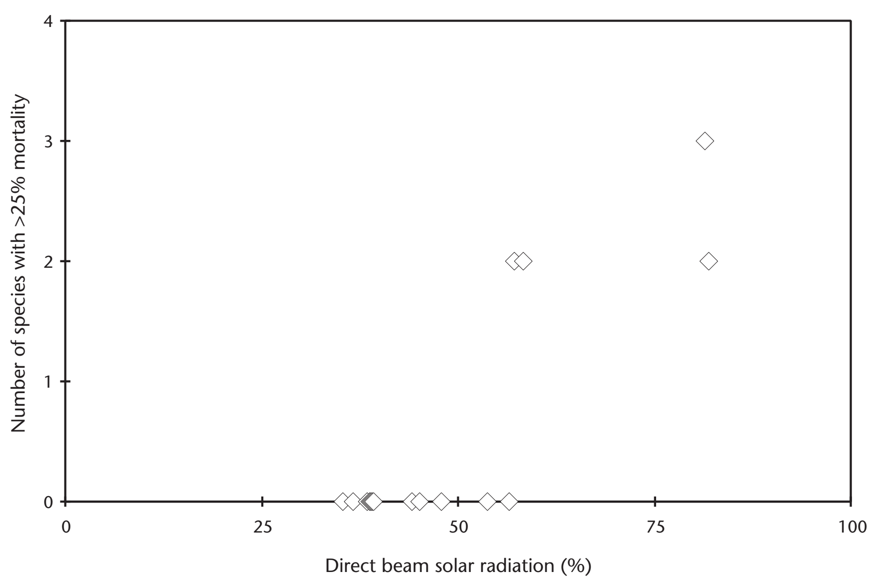


FIGURE 3 *Comparison of direct beam solar radiation to lichen mortality in the Itcha – Ilgachuz study area, blocks 4 and 5.*

3.4 Relationships of Solar Radiation and Slash to Lichen Community Variables

The average direct beam solar radiation and slash load values for each treatment type are presented in Table 7. The ANOVA models were significant ($P < 0.05$) for both slash and light (Table 7). An a priori contrast showed that the control had significantly less direct beam solar radiation than the three treatments (Table 8). Furthermore, there was significantly more slash in the lichen assessment plots in stem-only harvesting treatments with on-site processing, compared to plots with whole-tree harvesting (Table 8).

There are significant ($\alpha = 0.05$) negative correlations between lichen richness, diversity and abundance, and percent harvest (Table 9). Direct beam solar radiation and percent slash both exhibit very strong positive correlations ($P = 0.0001$) with percent harvest, but neither variable is significantly ($\alpha = 0.05$) correlated with lichen richness, diversity, or abundance (Table 9).

TABLE 7 *Mean direct beam solar radiation and slash for each treatment and ANOVA results for blocks 1 to 5 in 1998 in the Itcha – Ilgachuz study area. Results are considered significant at $\alpha = .05$ and are in bold.*

	Treatment mean						
	C (n = 10)	T1 (n = 10)	T2 (n = 10)	T3 (n = 10)	Sum of squares	F (df 3,12)	P
Solar radiation (% of total)	40.9	52.8	63.0	50.3	2483	3.89	**0.04**
Slash (% cover)	0	16.0	7.0	16.5	1872	9.58	**0.01**

TABLE 8 *A priori contrasts for 1998 direct beam solar radiation and slash in the Itcha – Ilgachuz study area. Results are considered significant at $\alpha = .05$ and are in bold. SOH – stem-only harvesting; WTH – whole-tree harvesting.*

Block	Year	Variable	Contrast	df	Sum of squares	F	P
1–5	1998	Solar radiation	Control vs treatments	1	1567	7.37	**0.02**
1–5	1998	Solar radiation	30% SOH vs 50% SOH and WTH	1	392	1.85	0.20
1–5	1998	Slash	Control vs 50% WTH	1	245	3.76	0.08
1–5	1998	Slash	30% SOH vs 50% SOH	1	1	0.02	0.89
1–5	1998	Slash	50% WTH vs 30 and 50% SOH	1	570	8.76	**0.01**

TABLE 9 *Correlation matrix of lichen and habitat variables in 1998 in the Itcha – Ilgachuz study area (n = 40 plots). Results are considered significant at $\alpha = .05$ and are in bold.*

	Harvest		Direct beam solar radiation		Slash	
	r	P	r	P	r	P
Richness	-.34	**.03**	-.02	.91	-.19	.23
Diversity	-.33	**.04**	-.006	.97	-.18	.27
Abundance	-.32	**.05**	-.22	.17	-.30	.06
Direct beam solar radiation	.64	**.0001**	–	–	–	–
Slash	.79	**.0001**	.36	**.02**	–	–

4.1 Lichens as Ecosystem Indicator Species

Our study design established an equal number of plots in each of the five replicated blocks. The blocks, however, are not ecological equivalents. Rather, they span two distinct biogeoclimatic zones. Because of the relatively flat topography of the area and only modest gains in elevation, there is a broad transition area from one zone to the next. The differentiation between lichen communities defined for this study (blocks 1, 2, and 3 versus blocks 4 and 5) roughly corresponds to the break between the SBPSxc and MSxv subzones. However, block 3 is classified as MS using traditional biogeoclimatic indicators (Steen and Coupé 1997), although it is clearly grouped with the SBPS blocks based on lichen community structure. This suggests that a careful assessment of lichen flora can assist considerably in defining ecosystems, particularly in areas with high lichen diversity and cover (see Miège and Goward[5] for further discussion).

Blocks 1, 2, and 3 can be described as having very diverse and abundant ground lichens. This is less the case for blocks 4 and 5, where the arboreal lichens make up a considerable portion of the total lichen diversity and biomass.[6] The data illustrate the uniqueness of the SBPSxc and MSxv subzones in terms of both the diversity and abundance of terrestrial lichens found there.

4.2 Measurement of the Impact of Partial Cutting on Forest Canopy

One of the initial challenges we faced with gathering the post-logging lichen data was devising a method by which we could quantify the level of canopy disturbance at any given plot. Hemispherical photography of the forest canopy has a distinct advantage over more traditional approaches to measuring canopy cover. At northern latitudes, the other techniques fail to account for the fact that the sun is not directly overhead, but lower on the horizon. The computer program used to analyze the hemispherical photos incorporates the latitude of the study area to calculate sun angles over the growing season. This can be especially important in small forest gap situations where the zenith angle may result in little direct sunlight actually reaching the forest floor (e.g., Canham et al. 1990).

In some situations, hemispherical photography might also be a better measure of logging impact than is an estimate of percent harvest. For example, in plots where most of the harvesting has occurred to the south, the forest canopy that would normally intercept the sun's rays has been removed. The plot itself may have very little harvesting within the boundaries, but it will still have a high degree of direct beam solar radiation. Conversely, another plot could be completely harvested, but if it lies just north of a dense stand of trees, it will not receive much direct solar radiation. To some extent, measurements from hemispherical photographs can also provide surrogate measures for other microclimatic factors such as extended snow lie and soil temperature.

Nevertheless, in this study, lichen abundance still showed a stronger correlation with percent harvest than with solar radiation, which indicates that other factors are also likely involved, though they are not captured from a measurement of canopy openness. These factors include, for example, direct physical damage, slash loading, and loss of substrate.

5 Ibid.
6 Ibid.

4.3 Impact of Logging on Lichen Abundance

To assess how logging had affected lichen abundance, we compared two harvesting techniques: stem-only harvesting (T1) and whole-tree harvesting (T2). The silvicultural system and amount of harvesting in each treatment type were the same. Relative to stem-only harvesting, whole-tree harvesting potentially causes more direct physical damage to terrestrial lichens, as a result of the skidding of trees. However, this kind of damage was held to a minimum by winter logging on a suitable snowpack (dense and deeper than 30 cm) and by careful use of machinery. Consequently, the main differences that resulted between the two techniques were that whole-tree harvesting required a processing area and stem-only harvesting left slash in the openings.

Because arboreal lichens are removed when trees are removed, a treatment involving 30% harvested can be expected to incur an immediate reduction in arboreal lichen biomass of at least 30%. Added to this can be the losses resulting from any damage to the branches of the residual trees. The methodology used in this particular study did not permit detailed measurements of epiphytic lichen biomass. However, stand-level changes in lichen diversity could be measured, and these findings are discussed in section 4.4.

Sudden, drastic increases in solar radiation (such as those that occur after trees are removed) can be particularly detrimental to lichen species poorly adapted to the drying effects of the sun. It has been shown that lichen thalli may dry out within just a few hours in dry weather (Smith 1962). Bliss and Hadley (1964) examined respiration and photosynthesis rates of *Cladina rangiferina*, *Cetraria nivalis*, and *C. islandica*—caribou forage lichens that are also found in the Itcha – Ilgachuz study area. They discovered that respiration and photosynthesis rates were at their maximum only when lichen thalli were near saturation. At 77–83% of full saturation, photosynthesis rates dropped to 0–13% and respiration to 33–75% of the rates at saturation (Bliss and Hadley 1964). Therefore, with canopy removal, we expected an accelerated drying effect on the lichen thallus and, consequently, decreased efficiency in basic life functions. Our own observations have shown that plots with elevated light levels tend to contain more species exhibiting signs of mortality than do plots with lower light levels.

As important as solar radiation is for them, lichens are also poorly adapted to survival with no light and a lack of ventilation, as would be the case when they are fully covered by slash. Although we did not observe a significant correlation between slash loading and lichen abundance, we know that where slash has covered lichens, those individuals have not survived. Eriksson (1975) identified the presence of slash as being the most obvious immediate way in which logging affected caribou grazing.

In summary, we concluded that elevated slash deposits and increased solar radiation as a result of logging are two factors that are likely to contribute to at least a localized reduction in lichen abundance. We emphasize, however, that many areas within the treatment units show little or no reduction in lichens. Most of the detectable lichen mortality occurred against the north edge of canopy openings, where shade from the southern edge trees is at a minimum.

4.4 Impact of Logging on Lichen Diversity

In blocks 1 to 3, species richness was lower in the treatments than in the control, but this was not true for blocks 4 and 5, where species richness did not differ significantly between the treatments and control. This can likely be attributed to two main factors. First, given that the terrestrial lichen community in blocks 1 to 3 is more diverse and abundant than in blocks 4 and 5, community changes in that stratum might simply be more obvious overall than is the case for blocks 4 and 5. Second, the MSxv in which blocks 4 and 5 lie is moister than the SBPSxc (where blocks 1 and 2 are located). This may help alleviate some of the thallus desiccation associated with increased solar radiation.

We concluded that lichen species diversity does decline after partial cutting, but only slightly. For example, treatment T2 in blocks 1 to 3 had 17% fewer species than did the control in 1998. However, we had already detected 8% fewer species there during our pre-treatment survey. In some cases (e.g., T3 for blocks 4 and 5), the logged units averaged only 3% fewer species than the control. As the post-logging survey was completed within three summers after logging, it is possible that the lichen community may still be in a state of transition (i.e., it could still decline). However, Miège et al. (2001) reported dramatic changes to lichen communities within 4 months in a plot with 70% volume removal (and small group retention) in the same area. Therefore, we expect that any further impacts will likely be small, assuming that other processes, such as an increase in vascular plant cover, do not occur.

4.5 Limitations of This Study

This study was originally designed to compare the number of species present in the various treatments before and after harvesting. To capture all lichen species, 30 m diameter plots were used. Because of the labour-intensive sampling involved, however, only two plots were established per treatment unit. Such a low number of plots does not provide accurate or precise enough data to enable the treatments to be separated using analysis of variance. This lack of power could be improved by increasing the sample size. Also, the plots intercepted varying amounts of forest and opening within each treatment unit, and these amounts were not necessarily directly related to the actual percent harvested. To deal with this effect, correlation analysis was used to try to quantify some of the relationships between lichen and habitat variables regardless of treatment. Future studies should consider plot placement wholly in or out of cut areas.

Over such a large plot, observer bias and error in estimating percent lichen cover are also unavoidable. In our study, the same observer was present in both years (1995 and 1998), potentially reducing bias. Also important to note is that the percent cover estimate includes lichens that are dead and sickly. This amount, which could be quite substantial in areas of high insolation, would result in overestimation of cover.

The calculation of the species diversity index was based on the assigned class for abundance rather than on percent cover. These broad classes reduce the resolution of the index, and thus only large differences would be detectable using analysis of variance. Estimates of percent cover by species would improve the resolution of the index, but they would also be extremely time-consuming and subject to the errors associated with ocular estimates.

Finally, we recognize that the inability of the study to detect differences between harvesting treatments might have resulted from the target area removals not being met. The difference between the irregular group shelterwoods and group selection was 10–12% instead of 17%. However, the opening sizes were distinctly different and probably have a stronger effect on the lichens.

Our study revealed that partial cutting treatments with 30 or 50% of the area harvested in openings of 15–26 m in diameter did result in localized decreases in lichen abundance, likely associated with the presence of logging slash and increased solar radiation. The health of some lichen species used by caribou appeared to be affected on sites in which canopy removal was sufficient to cause excessive drying of the lichen thallus. Although some lichen colonies died, each of the affected plots supported thriving colonies of the same species on sites with somewhat more shade throughout the day.

Based on these findings, we believe that lichen mortality and decreases in lichen cover can be mitigated through the adoption of small harvested openings and the careful placement of logging slash:

- Lichen mortality was greatest along the north edge of openings, where there is the least amount of shading. If openings were sufficiently small to permit some shading along the north edge, some lichen mortality might be avoided.

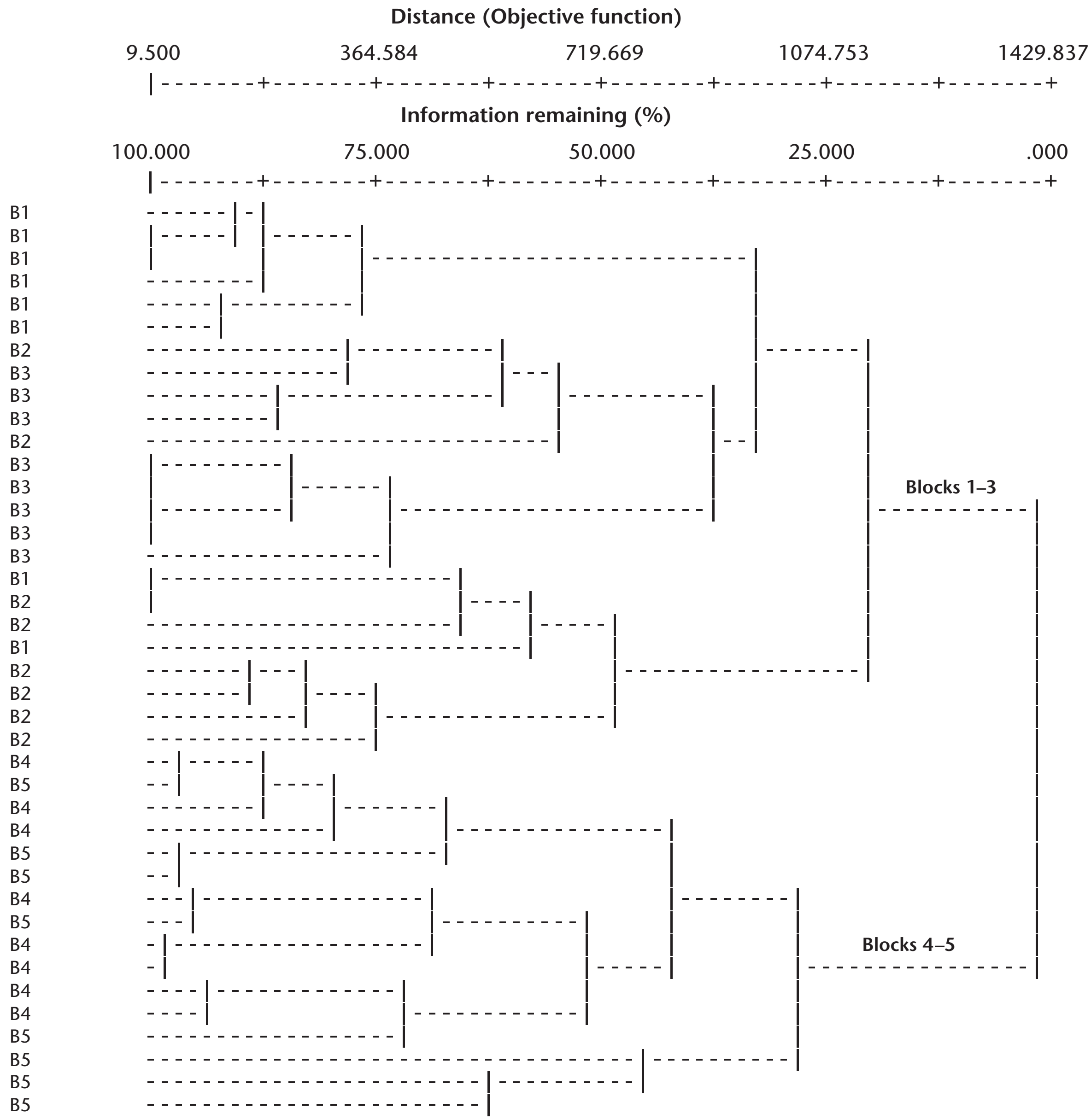
- Given that lichens do not persist when buried under slash, this suggests that placing aggregated piles of slash along the sunniest edges (north and east) of the canopy openings will minimize the overall impact to lichen abundance. In addition, slash should be piled in a manner that minimizes its contact with terrestrial lichens and that does not present a physical obstruction to caribou.

The partial cutting tested appears to have a slight detrimental effect on lichen diversity. Differences in diversity were noted between logging treatments and the unharvested controls. However, we did not detect differences between the logging treatments, which may reflect limitations of the study design.

On a sufficient snowpack (> 30 cm), it would appear that either grapple-skidding with roadside processing (whole-tree harvesting), or on-site processing and forwarding (stem-only harvesting) are two methods by which trees may be harvested while still maintaining terrestrial lichens. Stem-only harvesting results in about 16% of the treatment area being lost to slash; with whole-tree harvesting, that amount drops to approximately 7%. However, it is necessary with whole-tree harvesting to consider the roadside portion of the unit that is used for processing—which, for the study area, was typically near 4%. Thus, cumulative losses in whole-tree harvesting treatments could approach 11%, and with a less-than-adequate snowpack that figure could be much higher.

APPENDIX 1 Ward's cluster analysis for research blocks in 1995 using relative abundance values to calculate Euclidean distance (Software = PC-ORD, Version 3.01)

Percent chaining = 2.32



Each lichen species recorded in the study area was categorized into the most appropriate of six functional groups. The groups are based primarily on substrate, but are also specific to the requirements of the study (i.e., caribou forage lichen groups). Our list of lichens used by caribou was generated from observations and analyses by several authors (Edwards et al. 1960; Ahti and Hepburn 1967; Holleman and Luick 1977; Moser et al. 1979; Cichowski 1989; Ahti 1962[7]; Woodard 1995[8]). Other species (e.g., *Stereocaulon tomentosum*, *Cladonia multiformis*, and *C. uncialis*) are also considered important to caribou, based on similarities in morphology and chemistry to the referenced species.

Nomenclature follows Esslinger and Egan (1995). Synonyms, which may still be in use, are listed following the accepted name. The first number after the lichen name records the number of plots in which that species was observed (total plots = 40) in 1995. The next line ("Frequency in blocks 1–5") describes how those plots were distributed relative to the research blocks (how many plots in which the lichen was seen for each block, up to a maximum of eight).

The descriptive frequency estimates (rare, infrequent, frequent, common) are intended to denote local status and provincial status, respectively. For foliose species, the estimates for provincial status are based on Goward et al. (1994). The provincial status of fruticose genera is based on Goward (1999). Finally, common substrates are listed for each species.

Arboreal forage lichens

Alectoria sarmentosa (Ach.) Ach. ssp. *sarmentosa*.
Total plot records: 10
Frequency in blocks 1–5: 1, 1, 1, 4, 3
Infrequent, Common
Arboreal, rare on stumps, more common at higher elevations

Bryoria fremontii (Tuck.) Brodo & D. Hawksw.
Total plot records: 29
Frequency in blocks 1–5: 6, 3, 4, 8, 8
Frequent, Common
Arboreal

Bryoria fuscescens (Gyelnik) Brodo & D. Hawksw s. lat.
Total plot records: 40
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Frequent, Common
Arboreal, infrequent on stumps and elevated logs
Taxonomic Note: The *B. fuscescens* group (*B. fuscescens*, *B. glabra*, *B. lanestris*, and *B. simplicior*) posed considerable difficulties in field identification, and for this reason have been grouped under *B. fuscescens*. However, based on laboratory study of the material collected during the course of field work, *B. fuscescens* is likely the most abundant of these species, followed by *B. simplicior* and *B. lanestris*. By contrast, *B. glabra* may not actually occur at all in this region of British Columbia, though a few thalli were noted (but not collected) that closely approach it.

Bryoria lanestris (Ach.) Brodo & D. Hawksw.
Note: See comments under *B. fuscescens*.
Common in British Columbia
Arboreal

Bryoria simplicior (Vainio) Brodo & D. Hawksw.
Note: See comments under *B. fuscescens*.
Frequent in British Columbia
Arboreal

Other arboreal lichens

Hypogymnia austerodes (Nyl.) Räsänen.
Total plot records: 5
Frequency in blocks 1–5: 1, 3, 0, 0, 1
Infrequent, Common
Arboreal, infrequent on stumps

7 Ahti, T. 1962. Ecological investigations on lichens in Wells Gray provincial park, with special reference to their importance to mountain caribou. University of Helsinki, Department of Botany, Helsinki, Finland. Unpubl. rep.
8 Woodard, P.M. 1995. The effects of harvesting on lichen regeneration rates and plant diversity in west-central Alberta. Alberta Environmental Protection, Land and Forests Services, Edmonton, Alta. Unpubl. rep.

Hypogymnia imshaugii Krog.
Total plot records: 1
Frequency in blocks 1–5: 0, 1, 0, 0, 0
Rare, Common
Arboreal

Hypogymnia occidentalis Pike.
Total plot records: 2
Frequency in blocks 1–5: 0, 1, 0, 1, 0
Rare, Frequent
Arboreal, but one specimen found on a stump in block 2

Hypogymnia physodes (L.) Nyl.
Total plot records: 7
Frequency in blocks 1–5: 2, 2, 0, 2, 1
Infrequent, Common
Arboreal, one specimen found on an elevated log in block 1

Kaernefeltia merrillii (Du Reitz) Thell & Goward.
[Syn. *Tuckermannopsis merrillii* (Du Reitz) Hale]
Total plot records: 34
Frequency in blocks 1–5: 5, 7, 8, 7, 7
Frequent, Common
Arboreal
Name based on Goward et al. (1994)

Letharia columbiana (Nutt.) J.W. Thomson.
Total plot records: 2
Frequency in blocks 1–5: 0, 0, 0, 0, 2
Rare, Frequent
Arboreal
This record apparently represents the northernmost locality for this species. Within the study area, *L. columbiana* was restricted entirely to upper elevations.

Letharia vulpina (L.) Hue.
Total plot records: 32
Frequency in blocks 1–5: 5, 4, 8, 8, 7
Frequent, Common
Arboreal, occasionally on stumps

Melanelia subelegantula (Essl.) Essl.
Total plot records: 1
Frequency in blocks 1–5: 0, 1, 0, 0, 0
Rare, Frequent
Arboreal

Nodobryoria abbreviata (Müll. Arg.) Common & Brodo.
[Syn. *Bryoria abbreviata* (Müll. Arg.) Brodo & D. Hawksw]
Total plot records: 5
Frequency in blocks 1–5: 0, 0, 0, 0, 5
Rare, Frequent
Arboreal

Parmelia sulcata Taylor.
Total plot records: 8
Frequency in blocks 1–5: 2, 1, 2, 2, 1
Infrequent, Common
Arboreal

Platismatia glauca (L.) Culb. & C. Culb.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 1, 0
Rare, Common
Found only on a stump in the study area, but is usually arboreal

Tuckermannopsis chlorophylla (Willd.) Hale.
[Syn. *Cetraria chlorophylla* (Willd. in Humb.) Vainio]
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 1, 0
Rare, Common
Arboreal

Tuckermannopsis orbata (Nyl.) M.J. Lai.
[Syn. *Cetraria orbata* (Nyl.) Fink]
Total plot records: 1
Frequency in blocks 1–5: 0, 1, 0, 0, 0
Rare, Common
Arboreal (*Picea* branch)

Usnea lapponica Vainio.
Total plot records: 3
Frequency in blocks 1–5: 0, 1, 2, 0, 0
Rare, Common
Arboreal
Taxonomic note: The identification is tentative, owing to the depauperate nature of the available material. *Usnea* is clearly at the limits of its ecological range within the study area.

Usnea scabrata Nyl. Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 1, 0
Rare, Frequent
Arboreal

Vulpicida canadensis (Räsänen) J. E. Mattsson & M.J. Lai.
[Syn *Cetraria canadensis* (Räsänen) Räsänen]
Total plot records: 18
Frequency in blocks 1–5: 1, 4, 6, 3, 4
Frequent, Common
Arboreal, rare on logs

Vulpicida pinastri (Scop.) J.-E. Mattsson & M.J. Lai.
[Syn *Cetraria pinastri* (Scop.) Gray]
Total plot records: 31
Frequency in blocks 1–5: 8, 4, 8, 6, 5
Common, Common
Shrubs, arboreal, logs, infrequent on upturned roots and stumps

Tree bole lichens

Parmeliopsis ambigua (Wulfen) Nyl.
Total plot records: 40
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Common, Common
Arboreal, logs, stumps, upturned roots

Parmeliopsis hyperopta (Ach.) Arnold.
Total plot records: 40
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Common, Common
Arboreal, logs, stumps, upturned roots
Generally occurs lower on the trunk than *P. ambigua*

Forest floor forage lichens

Cetraria ericetorum Opiz ssp. *reticulata* (Räsänen) Kärnefelt.
Total plot records: 40
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Common, Frequent
Usually forest floor, also on logs, stumps

Cetraria islandica (L.) Ach. ssp. *islandica*.
Total plot records: 4
Frequency in blocks 1–5: 1, 1, 1, 0, 1
Rare, Frequent
Forest floor, stumps, shrubs, mossy logs

Cladina arbuscula (Wallr.) Hale & Culb. ssp. *beringiana* (Ahti) N.S. Golubk.
Total plot records: 36
Frequency in blocks 1–5: 8, 7, 8, 7, 6
Frequent, Frequent
Forest floor, rare on logs
Taxonomic note: *C. arbuscula* and *C. mitis* can be difficult to distinguish in the field; identification accuracy is approximately 85%

Cladina mitis (Sandst.) Hustich.
[Syn: *Cladonia arbuscula* ssp. *mitis*]
Total plot records: 32
Frequency in blocks 1–5: 5, 7, 6, 8, 6
Frequent, Frequent
Forest floor
Taxonomic note: See comment under *C. arbuscula*

Cladina rangiferina (L.) Nyl.
Total plot records: 35
Frequency in blocks 1–5: 8, 7, 8, 8, 4
Frequent, Common
Forest floor
Taxonomic note: One specimen of *C. rangiferina* was morphologically similar to *Cladina stellaris*, but was identified in the laboratory by chemical analysis

Cladonia cornuta (L.) Hoffm. ssp. *cornuta*.
Total plot records: 39
Frequency in blocks 1–5: 7, 8, 8, 8, 8
Common, Frequent
Forest floor, also frequent on logs, mossy logs, stumps, mossy rocks, upturned roots

Cladonia ecmocyna Leighton ssp. *intermedia* (Robbins) Ahti.
Total plot records: 39
Frequency in blocks 1–5: 7, 8, 8, 8, 8
Common, Common
Forest floor, frequent on logs and mossy rocks

Cladonia gracilis (L.) Willd. ssp. *turbinata* (Ach.) Ahti.
Total plot records: 40
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Common, Common
Forest floor, logs, stumps

Cladonia uncialis (L.) F.H. Wigg.
Total plot records: 8
Frequency in blocks 1–5: 1, 5, 1, 0, 1
Infrequent, Common
Forest floor

Flavocetraria cucullata (Bellardi) Kärnefelt & Thell.
[Syn. *Cetraria cucullata* (Bellardi) Ach.]
Total plot records: 1
Frequency in blocks 1–5: 1, 0, 0, 0, 0
Rare, Common
Forest floor

Flavocetraria nivalis (L.) Kärnefelt & Thell.
[Syn. *Cetraria nivalis* (L.) Ach.]
Total plot records: 2
Frequency in blocks 1–5: 1, 0, 1, 0, 0
Rare, Common
Forest floor

Stereocaulon alpinum Laurer *ex* Funck.
Infrequent, Frequent
Forest floor
Taxonomic note: See comments under *S. tomentosum*

Stereocaulon condensatum Hoffm.
Total plot records: 2
Frequency in blocks 1–5: 0, 1, 0, 0, 1
Rare, Rare
Forest floor
Found only over soil on xeric microsites

Stereocaulon paschale (L.) Hoffm.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 1, 0
Rare, Common
Forest floor

Stereocaulon tomentosum Fr.
Total plot records: 52
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Common, Common
Forest floor, rocks, infrequent on upturned roots and logs
Note: Depauperate and sterile *S. tomentosum* can be difficult to distinguish from other similar members of its genus. We may have included *S. alpinum*, though that species appears to be uncommon in this area of British Columbia.

Other forest floor lichens

(Some of these may also be used for forage, but are likely of lesser importance.)

Cetraria aculeata (Schreber) Fr.
[Syn. *Coelocaulon aculeatum* (Schreber) Link]
Total plot records: 1
Frequency in blocks 1–5: 0, 1, 0, 0, 0
Rare, Common
Forest floor

Cladonia borealis Stenroos.
Total plot records: 24
Frequency in blocks 1–5: 8, 7, 4, 2, 3
Frequent, Common
Forest floor, logs, stumps, upturned roots

Cladonia cariosa (Ach.) Sprengel.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 0, 1
Rare, Common
Forest floor

Cladonia cervicornis (Ach.) Flotow ssp. *verticillata* (Hoffm.) Ahti.
Total plot records: 25
Frequency in blocks 1–5: 6, 6, 8, 1, 4
Frequent, Frequent
Forest floor, infrequent on stumps and upturned roots

Cladonia crispata (Ach.) Flotow var. *crispata*.
Total plot records: 27
Frequency in blocks 1–5: 7, 4, 5, 6, 5
Frequent, Frequent
Forest floor, logs, infrequent on mossy rocks

Cladonia cyanipes (Sommerf.) Nyl.
Total plot records: 9
Frequency in blocks 1–5: 6, 3, 0, 0, 0
Infrequent, Rare
Forest floor

Cladonia decorticata (Flörke) Sprengel.
Total plot records: 2
Frequency in blocks 1–5: 0, 2, 0, 0, 0
Rare, Infrequent
Forest floor

Cladonia macrophyllodes Nyl.
Total plot records: 4
Frequency in blocks 1–5: 0, 0, 2, 1, 1
Rare, Frequent
Forest floor

Cladonia multiformis G. Merr.
Total plot records: 3
Frequency in blocks 1–5: 1, 0, 0, 0, 2
Rare, Frequent
Forest floor
This species, and *C. phyllophora*, both grow tall enough that they are likely often used as forage by caribou

Cladonia phyllophora Hoffm.
Total plot records: 34
Frequency in blocks 1–5: 8, 7, 8, 6, 5
Frequent, Common
Forest floor
Taxonomic note: See comments under *C. stricta*, and *C. multiformis*

Cladonia pyxidata (L.) Hoffm.
Total plot records: 23
Frequency in blocks 1–5: 6, 8, 5, 1, 3
Frequent, Common
Forest floor, logs, stumps

Cladonia stricta (Nyl.) Nyl.
Taxonomic note: *C. stricta* is morphologically similar to *C. phyllophora*, but it has narrower cups. This species was identified from material that had been collected as *C. phllophora*. Records of *C. phyllophora* therefore likely include some records of *C. stricta*.

Cladonia subulata (L.) F.H. Wigg.
Total plot records: 6
Frequency in blocks 1–5: 2, 2, 1, 0, 1
Infrequent, Frequent
Forest floor, upturned roots

Lobaria linita (Ach.) Rabenh.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 1, 0, 0
Rare, Frequent
Forest floor

Nephroma expallidum (Nyl.) Nyl.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 0, 1
Rare, Infrequent
Forest floor

Peltigera aphthosa (L.) Willd.
Total plot records: 37
Frequency in blocks 1–5: 8, 6, 8, 7, 8
Frequent, Common
Forest floor, mossy rocks, and upturned roots
In very open or dry sites, *P. aphthosa* occurs only in well-shaded microsites and small depressions

Peltigera canina (L.) Willd.
Total plot records: 15
Frequency in blocks 1–5: 6, 2, 5, 1, 0
Infrequent, Common
Forest floor

Peltigera didactyla (With.) Laundon var. *didactyla*.
Rare, Common
Forest floor
Taxonomic note: See comments under *P. didactyla* var. *extenuata*

Peltigera didactyla var. *extenuata* (Nyl.) Goffinet & Hastings.
Total plot records: 8
Frequency in blocks 1–5: 2, 3, 0, 0, 3
Infrequent, Frequent
Forest floor, occasionally on upturned roots

Peltigera kristinssonii Vitik.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 0, 1
Rare, Infrequent
Forest floor

Peltigera lepidophora (Vainio) Bitter.
Total plot records: 6
Frequency in blocks 1–5: 2, 4, 0, 0, 0
Infrequent, Infrequent
Forest floor

Peltigera leucophlebia (Nyl.) Gyelnik.
Total plot records: 17
Frequency in blocks 1–5: 5, 0, 6, 3, 3
Frequent, Frequent
Forest floor, upturned roots, infrequent on mossy rock

Peltigera malacea (Ach.) Funck.
Total plot records: 36
Frequency in blocks 1–5: 8, 7, 8, 8, 5
Frequent, Frequent
Forest floor, mossy rock, upturned roots

Peltigera ponojensis Gyelnik.
Total plot records: 2
Frequency in blocks 1–5: 0, 1, 0, 0, 1
Rare, Frequent
Forest floor

Peltigera praetextata (Sommerf.) Zopf.
Total plot records: 2
Frequency in blocks 1–5: 0, 0, 0, 1, 1
Rare, Infrequent
Forest floor, upturned roots

Peltigera rufescens (Weiss) Humb.
Total plot records: 21
Frequency in blocks 1–5: 6, 7, 5, 1, 2
Frequent, Frequent
Forest floor

Peltigera venosa (L.) Hoffm.
Total plot records: 3
Frequency in blocks 1–5: 0, 1, 1, 1, 0
Rare, Frequent
Forest floor, upturned roots

Psoroma hypnorum (Vahl) S. Gray.
Total plot records: 10
Frequency in blocks 1–5: 2, 2, 3, 2, 1
Infrequent, Frequent
Forest floor, upturned roots, mossy rock

Solorina crocea (L.) Ach.
Total plot records: 8
Frequency in blocks 1–5: 0, 0, 2, 1, 5
Infrequent, Frequent
Forest floor, upturned roots

Lichens of decaying wood

Cladonia bacilliformis (Nyl.) Glück.
Total plot records: 34
Frequency in blocks 1–5: 8, 8, 8, 4, 6
Frequent, Frequent
Logs, stumps, rare on forest floor

Cladonia botrytes (K. Hagen) Willd.
Total plot records: 11
Frequency in blocks 1–5: 4, 5, 1, 0, 1
Infrequent, Frequent
Logs, also common on forest floor

Cladonia carneola (Fr.) Fr.
Total plot records: 39
Frequency in blocks 1–5: 7, 8, 8, 8, 8
Common, Common
Logs, forest floor, stumps, frequent at base of *Pinus*

Cladonia cenotea (Ach.) Schaerer.
Total plot records: 33
Frequency in blocks 1–5: 7, 5, 7, 6, 8
Common, Common
Logs, also common on forest floor, stumps, upturned roots

Cladonia chlorophaea (Sommerf.) Sprengel.
Total plot records: 27
Frequency in blocks 1–5: 5, 4, 6, 6, 6
Frequent, Common
Logs, forest floor, infrequent on upturned roots and at base of *Pinus*
Taxonomic note: Chemical testing involving thin-layer chromatography is necessary to

confirm identification. It is uncertain whether the local material should be assigned to *C. chlorophaea* s. str., or to one or more of several closely chemically related taxa.

Cladonia deformis (L.) Hoffm.
Total plot records: 40
Frequency in blocks 1–5: 8, 8, 8, 8, 8
Common, Frequent
Logs, forest floor, stumps, upturned roots, mossy rock, infrequent at base of *Pinus*

Cladonia fimbriata (L.) Fr.
Total plot records: 33
Frequency in blocks 1–5: 8, 7, 8, 5, 5
Common, Frequent
Logs, forest floor, infrequent on stumps and upturned roots

Cladonia macilenta (Genth) Schaerer.
[Syn *Cladonia bacillaris* Nyl.]
Total plot records: 2
Frequency in blocks 1–5: 0, 0, 2, 0, 0
Rare, Common
Decorticated logs
Note: The possibility exists that this species was inadvertently included with *C. ochrochlora* in some plots. It may therefore be more common than indicated in the plot data.

Cladonia norvegica Tønsberg & Holien.
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 0, 0, 1
Infrequent, Frequent
Logs

Cladonia ochrochlora Flörke.
Total plot records: 28
Frequency in blocks 1–5: 6, 4, 5, 6, 7
Frequent, Common
Logs, stumps, upturned roots, rare on mossy rock and base of *Pinus*
Taxonomic note: See *C. macilenta*

Cladonia sulphurina (Michaux) Fr.
Total plot records: 36
Frequency in blocks 1–5: 7, 8, 8, 6, 7
Common, Common
Logs, forest floor, upturned roots, infrequent on base of *Pinus*

Hypocenomyce scalaris (Ach.) M. Choisy.
[Syn. *Psora scalaris* (Ach. ex Lilj.) Hook.]
Total plot records: 18
Frequency in blocks 1–5: 0, 4, 6, 3, 5
Frequent, Frequent
Charred stumps, charred logs

Hypocenomyce "sp.1."
Total plot records: 1
Frequency in blocks 1–5: 0, 0, 1, 0, 0
Rare, previously unknown in British Columbia
Charred stump
This is an undescribed species (Einar Timdal, University of Oslo, pers. comm., 1995)

APPENDIX 3 Lichen data collected from field plots in 1995 and 1998

Plot ID[a]	Species richness 1995	Species richness 1998	Species diversity 1995[b]	Species diversity 1998[b]	Lichen cover 1995 (%)	Lichen cover 1998 (%)
B1 C-I3	37	33	3.47	3.38	75	80
B1 C-L3	36	32	3.46	3.36	55	60
B1 T1-E1	35	35	3.46	3.45	35	40
B1 T1-E3	34	35	3.41	3.45	55	30
B1 T2-C2	29	30	3.26	3.28	55	25
B1 T2-J4	27	28	3.21	3.23	35	35
B1 T3-C4	32	35	3.36	3.48	60	40
B1 T3-F2	32	32	3.35	3.37	45	40
B2 C-B4	34	39	3.41	3.54	65	75
B2 C-D6	32	38	3.36	3.55	25	33
B2 T1-C3	28	31	3.25	3.32	30	30
B2 T1-E8	33	30	3.38	3.31	80	45
B2 T2-C6	37	30	3.49	3.32	15	15
B2 T2-D5	32	31	3.34	3.36	40	35
B2 T3-F5	30	27	3.31	3.22	40	40
B2 T3-G4	34	36	3.43	3.48	20	20
B3 C-D4	35	36	3.47	3.48	75	65
B3 C-F7	32	33	3.40	3.42	80	70
B3 T1-A1	31	27	3.33	3.19	80	80
B3 T1-A2	28	25	3.23	3.12	50	50
B3 T2-B7	31	25	3.36	3.15	60	30
B3 T2-E7	34	31	3.43	3.34	75	50
B3 T3-D9	39	33	3.56	3.41	75	60
B3 T3-E9	37	31	3.52	3.32	60	40
B4 C-A6	30	31	3.31	3.34	30	30
B4 C-D4	34	33	3.41	3.40	10	10
B4 T1-H1	27	29	3.20	3.29	15	15
B4 T1-H2	29	27	3.24	3.23	15	10
B4 T2-H2	30	30	3.28	3.31	40	35
B4 T2-I1	29	29	3.26	3.28	10	10
B4 T3-A4	25	29	3.11	3.26	35	35
B4 T3-B1	23	34	3.04	3.41	15	10
B5 C-C6	26	26	3.12	3.17	10	10
B5 C-D2	37	39	3.50	3.55	60	65
B5 T1-B8	28	30	3.26	3.29	30	25
B5 T1-D4	30	33	3.31	3.40	45	25
B5 T2-D2	39	32	3.56	3.39	35	30
B5 T2-E3	26	26	3.18	3.17	10	20
B5 T3-F5	30	31	3.32	3.33	35	40
B5 T3-F7	27	31	3.20	3.35	10	10

a Plot ID as follows: block, treatment, plot number.
b Shannon Diversity Index.

Plot ID[a]	Mesoslope position	Ventilation 1995[b]	Ventilation 1998[b]	Canopy cover 1995 (%)	Direct beam solar radiation 1998 (%)	Harvest (%)	Slash (%)
B1-C-13	Level	MH	M	28	38.0	0	0
B1-C-L3	Level	MH	M	44	28.3	0	0
B1-T1-E1	Level	MH	H	0	51.2	20	10
B1-T1-E3	Level	MH	MH	100	43.5	5	5
B1-T2-C2	Level	MH	H	84	61.3	45	5
B1-T2-J4	Level	MH	H	28	73.3	20	5
B1-T3-C4	Level	MH	MH	32	49.1	40	25
B1-T3-F2	Middle	MH	MH	96	57.9	45	20
B2-C-B4	Level	H	H	0	52.5	0	0
B2-C-D6	Level	MH	M	80	46.3	0	0
B2-T1-C3	Crest	H	H	0	77.1	55	35
B2-T1-E8	Level	H	H	20	51.1	40	15
B2-T2-C6	Level	MH	M	0	58.3	10	5
B2-T2-D5	Level	H	MH	100	64.4	10	5
B2-T3-F5	Level	MH	MH	84	50.7	20	10
B2-T3-G4	Level	H	H	40	73.6	25	5
B3-C-D4	Level	M	M	64	44.4	0	0
B3-C-F7	Level	MH	M	76	40.7	0	0
B3-T1-A1	Level	M	M	72	41.7	0	0
B3-T1-A2	Level	M	MH	96	31.2	35	20
B3-T2-B7	Level	M	H	20	63.9	55	10
B3-T2-E7	Level	M	H	24	90.1	50	10
B3-T3-D9	Level	MH	MH	100	38.8	25	15
B3-T3-E9	Level	M	MH	8	50.0	40	30
B4-C-A6	Level	M	M	4	38.9	0	0
B4-C-D4	Crest	M	M	56	39.1	0	0
B4-T1-H1	Level	M	H	0	38.4	10	5
B4-T1-H2	Middle	M	H	0	58.3	60	25
B4-T2-H2	Crest	M	M	32	45.1	5	5
B4-T2-I1	Level	LM	M	56	35.3	0	5
B4-T3-A4	Middle	M	M	24	38.8	5	10
B4-T3-B1	Middle	LM	M	4	56.5	25	20
B5-C-C6	Toe	MH	M	44	36.7	0	0
B5-C-D2	Middle	H	H	0	44.2	0	0
B5-T1-B8	Middle	MH	H	0	81.9	65	25
B5-T1-D4	Level	MH	H	68	53.7	40	20
B5-T2-D2	Upper	H	H	0	81.5	35	10
B5-T2-E3	Depression	MH	H	24	57.2	60	10
B5-T3-E7	Middle	MH	H	0	39.3	5	5
B5-T3-F7	Toe	MH	H	4	47.8	40	25

a Plot ID as follows: block, treatment, plot number.
b Ventilation: LM = low to moderate; M = moderate; MH = moderate to high; H = high.

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