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Terrestrial lichen response to partial cutting in lodgepole pine forests on caribou winter range in west-central British Columbia

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Abstract: In west-central British Columbia, terrestrial lichens located in older, lodgepole pine (*Pinus contorta*) forests are important winter forage for woodland caribou (*Rangifer tarandus caribou*). Clearcut harvesting effectively removes winter forage habitat for decades, so management approaches based on partial cutting were designed to maintain continuous lichen-bearing habitat for caribou. This study tested a group selection system, based on removal of 33% of the forest every 80 years in small openings (15 m diameter), and two irregular shelterwood treatments (whole-tree and stem-only harvesting methods) where 50% of the stand area is cut every 70 years in 20 to 30 m diameter openings. The abundance of common terrestrial lichens among the partial cutting and no-harvest treatments was compared across five replicate blocks, pre-harvest (1995) and post-harvest (1998, 2000 and 2004). The initial loss of preferred forage lichens (*Cladonia*, *Cladina*, *Cetraria* and *Stereocaulon*) was similar among harvesting treatments, but there was greater reduction in these lichens in the openings than in the residual forest. After eight years, forage lichens in the group selection treatment recovered to pre-harvest amounts, while lichen in the shelterwood treatments steadily increased from 49 to 57% in 1998 to about 70% of pre-harvest amounts in 2004. Although not part of the randomized block design, there was substantially less lichen in three adjacent clearcut blocks than in the partial cuts. Regression analysis pre- and post-harvest indicated that increased cover of trees, shrubs, herbs, woody debris and logging slash corresponded with decreased forage lichen abundance. In the short-term, forestry activities that minimize inputs of woody debris, control herb and shrub development, and moderate the changes in light and temperatures associated with canopy removal will lessen the impact on lichen. Implementation of stand level prescriptions is only one aspect of caribou habitat management. A comprehensive approach should consider all factors and their interactions to maintain a viable population of woodland caribou in west-central British Columbia.

Key words: British Columbia; caribou; forest management; lichen; *Rangifer tarandus caribou*; silvicultural systems; winter range.

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Introduction

The northern woodland caribou ecotype (*Rangifer tarandus caribou*) (Heard & Vagt, 1998) in the Chilcotin region of west-central British Columbia (B.C.) is estimated at 2175 animals (Youds *et al.*, 2002). This population is designated as 'Threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and qualifies for protection and recovery under the Canadian *Species at Risk Act* (SARA).

The historic range of northern caribou in the Central Interior has become increasingly restricted due to past forest development, access issues, private land ownership and other development (Youds *et al.*, 2002). In other jurisdictions, development has been linked to declines in caribou populations (Edmonds, 1988; Cumming & Beange, 1993; Smith *et al.*, 2000). In order to manage development, the Northern Caribou Strategy component of the Cariboo-Chilcotin Land Use Plan (CCLUP) (Youds *et al.*, 2002) delineated the current caribou range (about 1.5 million hectares) into no-forest-harvesting areas and parks (31%), conventional clearcut forest harvesting areas (52%), conventional clearcuts within a natural seral distribution zone (4%), and "modified" (partial cut) harvest areas (13%). The research trial described in this paper was initiated in 1994 to test silvicultural systems that could be used in the "modified" harvest area zone (> 180 000 ha) to maintain caribou habitat while allowing for timber extraction.

A key habitat component affected by forest harvesting is lichen, which is the major winter forage of woodland caribou throughout their range (Edwards *et al.*, 1960; Scotter, 1967; Ahti & Hepburn, 1967). The northern caribou ecotype in British Columbia craters for terrestrial lichens and sometimes grazes arboreal lichens in the winter (Wood, 1996; Johnson *et al.*, 2004). In west-central B.C., fecal fragment analysis indicated that both terrestrial and arboreal lichens are important forage during winter, comprising 68% of the caribou's diet and occurring in about equal proportions (Cichowski, 1989), although field observations indicated that terrestrial lichens are preferred.

In west-central British Columbia, during winter the two largest herds of caribou are found primarily in low-elevation lodgepole pine forests that are older than 80 years (Cichowski, 1989). Caribou preferentially select older stands on poorer growing sites because they have greater lichen abundance (Cichowski, 1989) than immature stands. Two habitat selection studies in Alberta showed that caribou preferred pine stands older than 75 years because they had sufficient quantities of forage lichens (Edmonds & Bloomfield, 1984; Shepard *et al.*, 2007).

The common practice of clearcut harvesting of lodgepole pine on an 80 year rotation (Daintith *et al.*, 2005), reduces the amount of terrestrial lichens substantially in west-central B.C. (Enns, 1992; Goward *et al.*, 1998; Miège *et al.*, 2001a) and elsewhere (Eriksson, 1975; Woodard, 1995; Harris, 1996; Webb, 1998; Coxson & Marsh, 2001), at least in the short term. Retrospective studies on fire origin stands (Braulisauer *et al.*, 1996; Hooper & Pitt, 1996; Goward *et al.*, 1998; Coxson & Marsh, 2001) and on older clearcuts (Woodard, 1995; Harris, 1996, Racey *et al.*, 1996; Webb, 1998) indicate that recovery could take several decades. The degree of damage due to harvesting is influenced by season of harvest (summer or winter), harvesting method (stem-only or whole-tree), and whether or not harvesting is followed by site preparation (Kranrod, 1996). The decline of lichen can be attributed to sudden exposure to new environmental conditions (Kershaw, 1985), as well as physical damage, ground disturbance and debris loading (Eriksson, 1975; Kranrod, 1996; Webb, 1998; Miège *et al.*, 2001a). Other than the preliminary work done by Miège *et al.* (2001a), there is no published literature on the immediate impact of partial cutting on terrestrial lichens or their rate of recovery.

Large areas with sufficient, accessible forage are necessary so caribou can live at relatively low densities in order to successfully evade predators (Bergerud *et al.*, 1984; Seip, 1991). Widespread application of clearcutting reduces the amount of usable caribou habitat, effectively shrinking their range. The goal of this project is to examine silvicultural systems and forest harvesting techniques that could retain terrestrial and arboreal lichen continuously in space and time.

Lodgepole pine forests in west-central British Columbia are provincially unique (Meidinger & Pojar, 1991). The cold, dry climate and undeveloped soils have resulted in the open canopy stands with pine regeneration often in the understory, and these stands persist, barring fire or insect attack, more than 300 years without climaxing to more shade-tolerant species. The structure of the stands led to the possibility of using silvicultural systems that employ partial cutting. Two silvicultural systems (irregular group shelterwood and group selection) and two harvesting techniques (whole-tree and stem-only) were selected for this study, which tests the hypothesis that the abundance of terrestrial lichens is not adversely affected by the degree of partial cutting or harvesting system associated with the first entry of each silvicultural system. Data were collected pre-harvest (1995) and several times post-harvest (1998, 2000 and 2004) in partial cut and no-harvest treatments in five replicate blocks.

Study area

The study area was located about 110 km northwest of Alexis Creek, B.C. on a gently rolling, high-elevation plateau (52°28´N, 124°43´E) and is located in the winter range of the Itcha-Ilgachuz caribou herd. The five study blocks in the trial were established in the very dry, cold Sub-Boreal Pine–Spruce (SBPSxc) and very dry, very cold Montane Spruce (MSxv) biogeoclimatic subzones (Steen & Coupé, 1997). In both

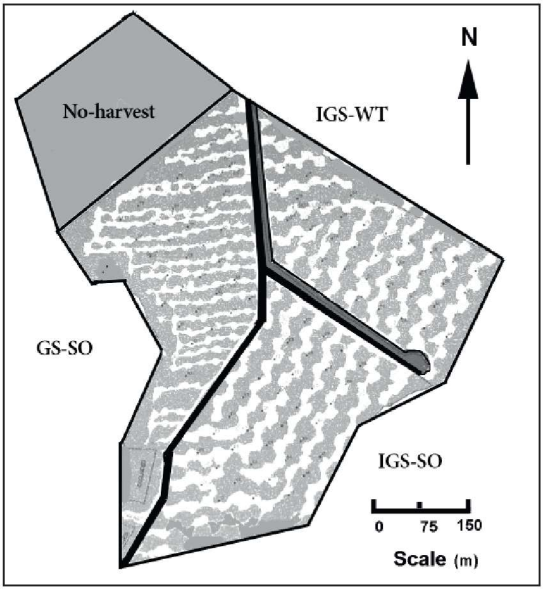

Fig. 1. Layout of block 5 showing the treatments: irregular group shelterwood – stem-only harvesting (IGS-SO), irregular group shelterwood – whole-tree harvesting (IGS-WT), group selection – stem-only harvesting (GS), and no-harvest.

subzones, lodgepole pine is the dominant tree species and undergrowth is low growing. Kinnikinnick (*Arctostaphylos uva-ursi*) and pinegrass (*Calamagrostis rubescens*) in the SBPSxc are replaced by crowberry (*Empetrum nigrum*), twinflower (*Linnaea borealis*), grouseberry (*Vaccinium scoparium*), and feathermosses (mostly *Pleurozium schreberi* and *Dicranum* spp). A rich variety of lichens, especially *Cladonia* spp., occur in both subzones. In all blocks, herbs such as northwestern sedge (*Carex concinnoides*) and bunchberry (*Cornus canadensis*) occurred in low abundance (1 to 2%). Soopalallie (*Sheperdia canadensis*) grows in small patches throughout the study area, while common juniper (*Juniperus communis*) was the most abundant shrub in the SBPSxc.

The five study sites are spread along a 30-km gradient that rises in elevation from 1280 m in the east (SBPSxc) to 1670 m in the west (MSxv) and are described in more detail in Waterhouse *et al.* (2010). Sagar *et al.* (2005) describes the changes in air temperature, soil temperature and rainfall across the elevation gradient in clearcuts and partial cuts.

The forests at the blocks were initiated after stand-destroying wildfires 220–300 years ago. Stands in the SBPSxc are much more open than those in the MSxv due to drier site conditions and past mortality from mountain pine beetle (*Dendroctonus ponderosae*). Based on 1995 cruise data, the maximum tree height was 17 m and gross volume was 110 m^3/ha in the SBPSxc, whereas maximum tree height was 20 m with gross volume of 270 m^3/ha in the MSxv sites. Tree densities (trees greater than 12.5 cm diameter at 1.3 m) ranged from about 800 stems per hectare in the SBPSxc to 1400 stems per hectare in the MSxv. A mountain pine beetle infestation in the early 1980s killed 7 to 21% of the canopy trees, and the latest mountain pine beetle infestation killed about 4% of canopy trees by 2003, and 16% by 2004.

Methods

Experimental design

A complete randomized block design was chosen for the study. Five blocks were selected from current blocks laid out for operational harvesting. Each block was between 60 and 113 ha, and was divided into four equal-sized treatment units of approximately 15 to 28 ha. The three partial-cutting treatments and no-harvest treatment were randomly assigned to the treatment units in each block (Fig. 1). Data were collected pre-harvest in 1995, then post-harvest in 1998, 2000 and 2004. In 2001, three clearcuts (>34 ha) adjacent to the trial blocks (1, 3 and 5) were added for descriptive purposes. Data were collected in these blocks in 2001 and 2005.

Silvicultural systems and harvesting description

Two silvicultural systems in combination with two harvesting methods were tested: irregular group shelterwood (IGS) with stem-only (SO) harvesting, IGS with whole-tree (WT) harvesting, and group selection (GS) with SO harvesting. The two irregular group shelterwood systems were designed to harvest 50% of the stand area every 70 years in openings ranging from 20 to 30 m in diameter. These systems were developed to provide partial shade for terrestrial lichen sites in the harvested openings. With stem-only harvesting, debris from topping and de-limbing was left in the harvested openings to maintain long-term site productivity (Wei *et al.*, 2000), but was aggregated to minimize the impact on terrestrial lichens and to create open space for planting trees. With whole-tree harvesting debris from topping and de-limbing is piled and burned at the roadside. The third silvicultural system, a GS system in combination with stem-only harvesting, was designed to harvest approximately one-third of the stand in 15-m wide openings every 80 years. This system was developed for sites with abundant arboreal lichen. All treatments were cut with a feller-buncher in the winter of 1996 (January to April) on a 30-cm snowpack.

In the stem-only system, a processor worked in the stand and a forwarder was used to move tree boles to the road; in the whole-tree system, a grapple-skidder pulled trees to a roadside area for processing. A post-harvest Global Positioning Survey of the blocks found that the average area cut was 39% in the IGS and 28% in the GS and that the opening sizes were within the targeted range (Waterhouse *et al.*, 2010). An additional 3-7% of the IGS-WT treatment was clearcut to make a processing and burning area. The clearcuts were harvested using the whole-tree method at the following times: block 1 (winter 1996), block 3 (summer 1994) and block 5 (summer 1996).

Data collection

Pre-harvest (summer 1995), across the 20 treatment units (5 blocks x 4 treatments) a total of 900 plots were installed and measured. A grid, based on 50-m interval spacing, was used to permanently locate 36–50 plots within 50 m of the boundaries of each treatment unit. Forty plots were installed in each clearcut. At each plot, a rebar pin was set flush to the ground. Next, a 0.8-m radius aluminum hoop (2.0 m^2) with an inlaid equilateral triangle was placed on the ground in order to locate a second pin. The pins were used to position the sample hoop at each assessment.

A line intercept method was used to quantify substrates, lichens and mosses. The intercept (130 cm) was measured along the edge of the triangle opposite the first pin to avoid any trampling that may have occurred during plot establishment. The observer used an adjustable T-square to level the hoop and look directly over the area to be measured. The intercept was read twice. On the first pass, the observer recorded the amount and type of substrate. A continuous record was made along the transect, noting each substrate and its' length if it equaled or exceeded 0.5 cm. Substrate was divided into five categories: mineral soil, humus and fine litter (less than 1 cm in diameter), mixed humus and mineral soil, rock, and woody debris (medium class was woody debris greater than 1 cm but less than 7.5 cm in diameter, including branches, twigs and cones; coarse class was greater than 7.5 cm in diameter).

On the second pass, the following lichen and moss species were recorded: boreal feathermoss (*Pleurozium schreberi, Ptilium crista-castrensis,* and *Hylocomium splendens*), *Dicranum* spp., other moss species, *Cladonia gracilis, Cladonia cornuta, Cladonia ecmocyna,* other *Cladonia* species, *Cladina* species, *Peltigera aphthosa*, other *Peltigera* species, *Stereocaulon* species, and *Cetraria* species. A complete list of the arboreal and terrestrial lichen species found in the study area is reported elsewhere (Miège *et al.*, 2001b). Post-harvest, three categories were used to describe lichen health: dead, sickly and healthy. Sickly lichens were severely discolored, partially broken and very dry, while dead lichens were structurally disintegrating, not adhered to the ground surface, and discoloured or bleached. Pre-harvest (1995), all lichens and mosses were assumed to be healthy.

Site conditions assessed for each plot were slope, aspect, position and shape for both meso- and microslope (Luttmerding *et al.*, 1990). Soils were described in terms of moisture regime, drainage, texture, and form and depth of humus layer (Steen & Coupé, 1997). In each 2-m^2 plot, the type and amount of plot disturbance (compression, and displacement from humans, wildlife and harvesting), percent cover of slash from logging and wind fall, and percent cover and modal height of vegetation by layer (shrubs, dwarf shrubs, herbaceous vegetation, and coniferous tree regeneration (<1.3 m tall)) were estimated (Luttmerding *et al.*, 1990). Starting in 2004, percent cover of individual plant species was also measured in the 2-m^2 plots. An estimate of percent cover of trees taller than 1.3 m was obtained using a periscope that vertically projected a grid of points at 12 degrees into the canopy.

Data analyses

All data analyses were performed with SAS, Version 9.1.3 (SAS Institute Inc., 2004). Lichen and moss data were organized into 13 response variables: boreal feathermoss, *Dicranum* spp., moss (all species), *Cladonia gracilis, Cladonia cornuta, Cladonia ecmocyna*, *Cladonia* (all species), *Cladina*, *Peltigera aphthosa*, *Peltigera* (all species), *Stereocaulon*, *Cetraria*, and preferred lichen (*Cladonia*, *Cladina*, *Cetraria*, and *Stereocaulon*). The grouping of preferred species is based on information from several sources (Edmonds & Bloomfield, 1984; Thomas & Hervieux, 1986; Cichowski, 1989; Thomas *et al.,* 1996). Prior to analysis, intercept lengths for each response variable (previously converted to %) were averaged (over plots) for each block and treatment unit.

The preferred group of lichens was analyzed with a two-way (block × treatment) ANOVA of the treatment-unit means, which were approximately normally distributed. Scheffé's multiple range tests were used to compare all pairs of treatments.

For species that were relatively common but had non-normally distributed mean abundances (moss, *Dicranum*, *Peltigera*, *Cladonia,* and *Cladonia ecmocyna*), a non-parametric analysis of variance—Friedman's two-way (block × treatment) test with adjustment for ties (Hollander & Wolfe, 1973)—was used to test for treatment effects. The overall significance of treatment differences and the significance of differences between all pairs of treatments (adjusted to account for multiple comparisons) were determined by referring to Tables 39 and 41 in Odeh *et al.* (1977). Both total abundance (i.e., the combined abundance of healthy, sickly, and dead specimens) and the abundance of healthy specimens alone were analyzed. Variables with many zero values (i.e., species that occurred infrequently or in low abundance) were not analyzed.

The ANOVA and Friedman analysis were repeated for plots located in open areas and for those located in forested areas. In both cases, the corresponding measurements for the no-harvest treatment were included for comparison. Parametric and non-parametric results were considered significant at $\alpha = 0.05$.

Regression analysis of correlations between preferred lichen and predictor variables of interest (i.e., woody debris [medium plus coarse litter] % intercept, logging slash % cover, shrub % cover, dwarf shrub % cover, herb % cover, regeneration % cover, and tree % cover) were conducted for the pre-harvest and each year of post-harvest data. The regression model (based on the theory of normally-distributed data) was fitted to the line-intercept (abundance) data for the group of preferred lichen species because it had relatively few zeroes (i.e., occurred in most plots). The following model was fitted:

$$\sqrt{l} = \mu + \sum_{v=1}^{m} \varphi_v x_v + t_i + b_j + tb_{ij} + \varepsilon_{ij}$$

where l is the length of the line-intercept (a square-root transformation was applied to enhance the normality of the data); μ is a constant (intercept); φ_1, φ_2, …, φ_m are unknown regression coefficients; the selected variables (x_1, x_2, …, x_m) describe the environmental conditions at the transect location; the subscripts i (= 1, 2, 3, 4) and j (= 1, 2, 3, 4, 5) denote treatment and block; { t_i } are dummy variables representing treatment effects not captured by the variables x_1, x_2, …, x_m;{ b_j } and { tb_{ij} } are random block and treatment × block (treatment unit) effects; and ε_{ij} is the residual (random) error. The random effects b_j, tb_{ij}, and ε_{ij} were assumed to be independent, normally distributed random variables with zero means and constant variances.

Backward elimination was used to select predictor variables {x_1, x_2, …, x_m} from the following candidates: shrub cover, dwarf shrub cover, herb cover, regeneration cover, tree cover, woody debris cover

Table 1. Average percent cover on the line intercept followed by frequency of occurrence. Data were collected in 1995 from five blocks along an elevation gradient.

Biogeoclimatic subzone	SBPSxc			MSxv	
Block	1	2	3	4	5
Elevation (m)	1290	1320	1420	1495	1620
% Intercept and plots (*n*)	Avg.% (195)	Avg.% (199)	Avg.% (201)	Avg.% (154)	Avg.% (151)
Boreal feathermosses	0.2 (9)	0.2 (4)	6.1 (92)	29.2 (127)	18.0 (99)
Dicranum spp.	0.3 (33)	0.2 (23)	2.1 (85)	9.4 (140)	9.4 (115)
All moss species	1.6 (104)	0.5 (42)	9.9 (150)	43.8 (153)	30.7 (140)
Peltigera apthosa	2.9 (89)	0.5 (22)	3.4 (91)	1.0 (40)	2.0 (49)
All *Peltigera* spp.	11.6 (176)	5.8 (155)	6.5 (149)	1.5 (60)	2.4 (62)
All *Cetraria* spp.	1.5 (151)	0.8 (100)	0.6 (91)	0.1 (13)	0.2 (26)
Cladonia gracilis	3.1 (153)	2.7 (133)	0.6 (65)	0.2 (22)	0.3 (20)
Cladonia cornuta	0.6 (79)	0.2 (33)	0.3 (36)	0.2 (27)	0.1 (13)
Cladonia ecmocyna	2.0 (129)	0.6 (42)	4.3 (131)	3.3 (94)	6.3 (106)
All *Cladonia* spp.	9.8 (192)	7.5 (180)	9.1 (186)	5.6 (126)	7.7 (117)
All *Cladina* spp.	2.1 (88)	0.6 (34)	0.6 (38)	0.8 (24)	0.5 (10)
All *Stereocaulon* spp.	1.4 (58)	2.7 (64)	0.5 (31)	0.1 (8)	0.3 (9)
All preferred lichens	14.9 (192)	11.6 (190)	10.8 (187)	6.6 (134)	8.8 (126)

and slash cover. The treatment dummy variables { t_i } were added to the list of potential predictors; these variables were included or excluded as a group.

Parameters were estimated by the residual (restricted) maximum likelihood (REML) method (PROC MIXED in SAS). A pseudo R^2 for the regressors and random effects (Downer & Benfield, 1999) was calculated for each model, and a likelihood ratio test was used to assess the overall significance of the regressors. Regression results were considered significant at $\alpha = 0.05$.

Results

Pre-harvest (1995)

Lichens were fairly abundant across the trial blocks; however, some species and species groupings changed with biogeoclimatic subzone (Table 1). The group of species that is considered preferred by caribou (*Cladonia*, *Cladina*, *Cetraria* and *Stereocaulon*) ranged from 11 to 15% in the SBPSxc blocks and from 7 to 9 % in the MSxv blocks. Within the preferred lichen group, *Cetraria, Cladonia gracilis, Cladina* and *Stereocaulon* occurred more frequently and had greater abundance in the three lower elevation SBPSxc blocks than in the MSxv blocks. *Cladonia ecmocyna* and other *Cladonia* species made up 86 to 91% of the preferred lichen community in the two highest elevation blocks in the MS. Mosses (mostly boreal feathermoss and *Dicranum* spp.) achieved maximum abundance (31 to 44%) in the MS blocks, moderate abundance in the mid-elevation SBPS block (10%) and low abundance (<2%) in the two lowest elevation SBPS blocks. There were no significant ($P \le 0.05$) differences pre-harvest (1995) among the treatments for preferred lichen or other subsets of lichens and moss species.

Post-harvest treatment effects

The strongest treatment differences in the preferred lichen group occurred in 1998 (2.5 years post-treatment) and 2000 (4.5 years post-treatment). The no-harvest treatment had significantly more healthy

Table 2. Comparison of abundance (% of transect line covered) of preferred lichens among treatments using parametric analysis of variance (df = 3, 12). Least-square means and standard errors shown with different letters are significantly different at $\alpha = 0.05$ based on Scheffé adjusted *P*-value. All health classes include healthy, sickly and dead lichens.

Year			No-harvest	IGS-SO[1]	IGS-WT[2]	GS-SO[3]	F	*P*
1995	All health classes	Whole	11.3 ± 1.8^{a}	10.0 ± 1.8^{a}	11.0 ± 1.8^{a}	9.9 ± 1.8^{a}	0.28	0.84
1998	All health classes	Whole	11.6 ± 1.4^{a}	6.6 ± 1.4^{b}	8.2 ± 1.4^{ab}	6.9 ± 1.4^{b}	6.86	0.0061
2000	All health classes	Whole	12.1 ± 1.5^{a}	7.1 ± 1.5^{b}	8.9 ± 1.5^{ab}	7.9 ± 1.5^{b}	7.95	0.004
2004	All health classes	Whole	12.1 ± 1.5^{a}	8.2 ± 1.5^{b}	9.3 ± 1.5^{ab}	11.2 ± 1.5^{ab}	5.04	0.02
1998	Healthy	Whole	11.1 ± 1.3^{a}	4.9 ± 1.3^{b}	6.3 ± 1.3^{b}	5.2 ± 1.3^{b}	8.98	0.0022
2000	Healthy	Whole	11.4 ± 1.5^{a}	5.3 ± 1.5^{b}	7.4 ± 1.5^{b}	6.7 ± 1.5^{b}	11.76	0.0007
2004	Healthy	Whole	11.3 ± 1.4^{a}	6.8 ± 1.4^{b}	7.8 ± 1.4^{ab}	10.3 ± 1.4^{ab}	4.97	0.02
1998	Healthy	Forest	11.1 ± 1.3^{a}	6.0 ± 1.3^{b}	7.1 ± 1.3^{ab}	5.8 ± 1.3^{b}	6.13	0.009
2000	Healthy	Forest	11.4 ± 1.5^{a}	6.4 ± 1.5^{b}	8.3 ± 1.5^{ab}	7.2 ± 1.5^{b}	7.54	0.004
2004	Healthy	Forest	11.3 ± 1.4^{a}	7.1 ± 1.4^{a}	7.8 ± 1.4^{a}	11.0 ± 1.4^{a}	4.34	0.03
1998	Healthy	Openings[4]	11.1 ± 1.3^{a}	3.5 ± 1.4^{b}	4.0 ± 1.4^{b}	4.0 ± 1.4^{b}	9.77	0.002
2000	Healthy	Openings[4]	11.4 ± 1.5^{a}	3.6 ± 1.4^{b}	4.9 ± 1.4^{b}	5.2 ± 1.4^{b}	16.16	0.0002
2004	Healthy	Openings[4]	11.3 ± 1.4^{a}	6.5 ± 1.5^{b}	7.7 ± 1.5^{ab}	8.5 ± 1.5^{ab}	4.20	0.03

[1] irregular group shelterwood with stem-only harvesting.

[2] irregular group shelterwood with whole-tree harvesting.

[3] group selection with stem-only harvesting.

[4] In the no-harvest treatment, there are no openings created by logging but the treatment unit mean is used for comparison.

preferred lichen than the three other treatments (Table 2). The three treatments had a similar drop (43 to 51%) in lichen abundance. When the forest and opening plots were separated within each treatment, lichen cover was significantly lower in the openings than the no-harvest treatments in both 1998 and 2000. The effect was not as strong when lichen cover was compared between the residual forest and no-harvest treatment. In 1998, the two stem-only treatments were significantly different from the no-harvest treatment, while in 2000, only the IGS-SO treatment remained significantly lower. There was comparatively less lichen in the openings than in the residual forest within each treatment, in both years.

By 2004, the overall treatment effect for healthy, preferred lichens remained significant ($p = 0.02$), but the differences among the treatments changed from the previous assessments. The IGS-SO treatment still had significantly less preferred lichen (6.8%) than the no-harvest treatment (11.3%), but the GS-SO and IGS-WT were no longer significantly different from the no-harvest treatment. The amount of preferred lichen in the GS-SO treatment (10.3%) was similar to the no-harvest treatment (11.3%) and the pre-harvest amount (9.9%). In the IGS-WT treatment, the amount of lichen increased from 6.3% in 1998 to 7.8% in 2004, while in the IGS-SO treatment, the amount of lichen increased from 4.9% in 1998 to 6.8% in 2004 (Table 2). Figure 2 shows the trend in treatment means over time. The overall tests of treatment effect were significant for the subsets of data from the residual forest and openings, but the treatment differences were no longer significant when pairs of treatment means were compared among the forested treatments (Table 2). There were larger gains in lichen abundance in the openings than in the

Table 3. Comparison of openings in the partial cuts and no-harvest treatments using non-parametric analysis of variance (based on Friedman's Chi) for healthy species and groupings of species post-harvest. Rank sum differences marked with an * are statistically different at $\alpha = 0.037$ (experiment wide error rate).

				Difference between treatment rank sums					
Species	Year	Chi	*P*	IGS-SO[a] vs No-harvest	IGS-WT[b] vs No-harvest	GS-SO[c] vs No-harvest	IGS-SO vs IGS-WT	GS-SO vs IGS-SO	GS-SO vs IGS-WT
Dicranum spp.	1998	13.65	<0.001	-15*	-6	-10	9	5	-4
	2000	10.35	<0.009	-13*	-5	-9	8	4	-4
	2004	10.47	<0.009	-13*	-8	-10	5	3	-2
All moss species	1998	9.00	<0.023	-12*	-8	-6	4	6	2
	2000	8.76	0.023	-12*	-5	-5	7	7	0
	2004	9.00	<0.023	-10	0	0	10	10	0
All *Peltigera* spp.	1998	4.20	>0.21	-8	-6	-4	2	4	2
	2000	7.32	0.06	-11*	-6	-5	5	6	1
	2004	4.92	0.210	-7	-8	-3	-1	4	5
Cladonia ecmocyna	1998	10.68	0.005	-12*	-11*	-7	1	5	4
	2000	10.68	0.005	12*	-11*	-7	1	5	4
	2004	7.32	0.055	-10	-9	-7	1	3	2
All *Cladonia* spp.	1998	9.24	<0.023	-11*	-10	-9	1	2	1
	2000	13.56	<0.001	-15*	-8	-7	7	8	1
	2004	4.92	0.210	-8	-7	-3	1	5	4

[a] irregular group shelterwood with stem-only harvesting.

[b] irregular group shelterwood with whole-tree harvesting.

[c] group selection with stem-only harvesting.

Table 4. Percent cover (mean and standard deviation) for species and species groupings per treatment for all blocks in 1995 (pre-harvest) and 2004 (all health classes). Three clearcuts adjacent to the trial blocks were added for comparison using 2005 data.

		Cover (%)				
Species	Year	No-harvest *n* = 229	IGS-SO[a] *n* = 225	IGS-WT[b] *n* = 223	GS-SO[c] *n* = 223	Clearcut *n* = 120
Feathermosses	1995	6.7 ± 16.9	8.7 ± 18.6	12.9 ± 22.8	9.7 ± 21.0	
	2004-05	9.3 ± 19.0	5.2 ± 12.6	8.7 ± 15.3	6.5 ± 15.5	1.6 ± 1.9
Dicranum spp.	1995	3.7 ± 8.5	4.0 ± 8.8	4.0 ± 7.8	3.3 ± 7.0	
	2004-05	4.7 ± 8.7	2.5 ± 5.7	3.3 ± 5.7	2.9 ± 6.5	0.6 ± 0.4
All moss spp.	1995	12.2 ± 20.5	15.0 ± 22.5	19.2 ± 26.8	15.0 ± 23.8	
	2004-05	15.9 ± 22.6	8.7 ± 15.7	13.6 ± 18.3	10.5 ± 18.0	2.3±2.7
Peltigera aphthosa	1995	1.3 ± 3.5	1.7 ± 4.1	3.2 ± 6.1	1.9 ± 4.1	
	2004-05	2.2 ± 5.4	1.3 ± 3.1	2.1 ± 4.6	1.4 ± 3.3	0.1 ± 0.1
All *Peltigera* spp.	1995	5.3 ± 6.8	6.1 ± 7.9	6.5 ± 8.5	5.8 ± 8.5	
	2004-05	7.7 ± 9.6	5.6 ± 7.5	5.0 ± 6.0	5.3 ± 7.0	1.6 ± 2.0
Cetraria spp.	1995	0.7 ± 1.1	0.7 ± 1.3	0.7 ± 1.4	0.6 ± 1.1	
	2004-05	1.1 ± 1.6	0.7 ± 1.2	0.9 ± 1.4	0.9 ± 1.5	0.8 ± 0.7
Cladonia gracilis	1995	1.3 ± 2.4	1.8 ± 3.2	1.1 ± 2.0	1.8 ± 3.5	
	2004-05	0.4 ± 1.2	0.7 ± 1.5	0.3 ± 0.8	0.7 ± 1.6	0.2 ± 0.3
Cladonia cornuta	1995	0.4 ± 0.9	0.3 ± 0.7	0.3 ± 0.7	0.2 ± 0.6	
	2004-05	0.3 ± 0.7	0.2 ± 0.6	0.3 ± 1.5	0.2 ± 0.7	0.1 ± 0.1
Cladonia ecmocyna	1995	2.7 ± 6.0	3.1 ± 5.9	3.6 ± 7.3	3.1 ± 4.5	
	2004-05	3.8 ± 5.5	2.2 ± 3.9	2.9 ± 5.3	3.2 ± 4.6	1.4 ± 1.1
All *Cladonia* spp.	1995	8.6 ± 8.1	8.2 ± 8.2	8.3 ± 8.5	7.5 ± 6.7	
	2004-05	8.7 ± 8.2	6.8 ± 6.9	6.3 ± 6.7	8.6 ± 8.1	3.6 ± 1.9
Cladina spp.	1995	0.8 ± 3.1	0.9 ± 2.6	1.0 ± 2.7	1.2 ± 3.4	
	2004-05	1.2 ± 3.1	0.7 ± 1.7	1.0 ± 2.6	1.2 ± 3.2	0.7 ± 0.6
Stereocaulon spp.	1995	1.6 ± 5.7	0.7 ± 3.8	1.1 ± 3.6	0.9 ± 3.9	
	2004-05	1.5 ± 5.2	0.3 ± 1.7	1.2 ± 3.7	0.9 ± 3.8	0.2 ± 0.2
Preferred lichens	1995	11.6 ± 10.3	10.4 ± 10.8	11.1 ± 10.6	10.1 ± 9.1	
	2004-05	12.4 ± 10.4	8.5 ± 8.0	9.3 ± 8.9	11.6 ± 10.5	5.3 ± 3.0

[a] irregular group shelterwood with stem-only harvesting.
[b] irregular group shelterwood with whole-tree harvesting.
[c] group selection with stem-only harvesting.

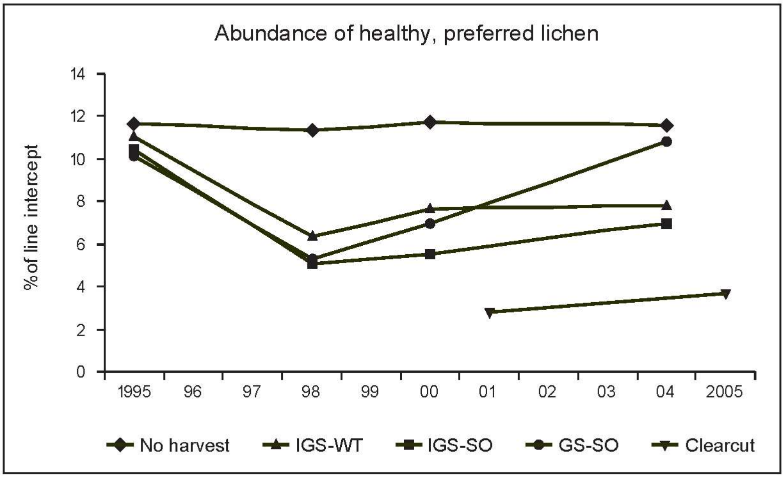

Fig. 2. Mean abundance of healthy, preferred lichen by year and treatment in the main trial (n = 5) and adjacent clearcuts (n = 3). IGS-SO: irregular group shelterwood with stem-only harvesting; IGS-WT: irregular group shelterwood with whole-tree harvesting; GS-SO: group selection with stem-only harvesting

residual forest but there remained significantly more lichen in the no-harvest treatment than in the openings within IGS-SO (Table 2).

There were sufficient data to compare some individual species and groups of species between the no-harvest treatments and the openings in the partial cut treatments (Table 3). Mosses and *Dicranum* spp. were significantly lower in cover in the openings compared to the no-harvest treatment in 1998, 2000 and 2004. *Cladonia* spp. and *Cladonia ecmocyna* were all less abundant in the openings, especially in the IGS treatments, when compared to the no-harvest treatment in 1998 and 2000. All *Peltigera* spp. were only significantly lower in the IGS-SO openings in 2000. The mean and standard deviation by treatment for species and species groupings for 1995 and 2004 are shown in Table 4.

Abundance of lichen and moss in the three adjacent clearcuts

In 2001, the average amount of healthy, preferred lichen in clearcuts was about one quarter of that found in the no-harvest treatments in the adjacent trial blocks and about half of that found in the partial cuts in 2000 (Fig. 2). By 2005, the average amount of healthy, preferred lichen in clearcuts increased from 2.8 to 3.7%. *Cladonia* made up 65% of the preferred lichen group in 2000 and 60% in 2005. All species measured in the clearcuts were present in the no-harvest treatments. In 2005, *Cladonia ecmocyna* was 25% of the preferred lichen sample, followed by *Cetraria* (21%), *Cladina* (18%) and *Stereocaulon* (6%).

Mosses in the mid-elevation block averaged less than 1% compared to 7.4% in the no-harvest treatment (2004), and in the highest elevation block, they averaged 2 to 5% (2001 and 2005, respectively) compared to 39% in the no-harvest treatment (2004).

Variables that could affect abundance

Variables (substrate [humus, mineral soil, rock, and woody debris from natural litter and logging slash], disturbance [human, harvesting, wildlife], and vegetation [shrubs, dwarf shrubs, herbs, tree regeneration and overstorey trees]) that could influence the abundance of lichen and moss species were very similar among treatments pre-harvest (Table 5). Pre-harvest and in the no-harvest treatments over time, humus was the most common substrate (92–95%) with woody debris (coarse and medium litter) and rock up to 3.5% each. Post-harvest in the partial cuts, humus decreased slightly, while woody debris increased 2–6%, depending on the treatment. In addition, woody debris identified as logging slash was input into all the treatments. Maximum values were recorded in 1998 and 2000 (IGS-SO: 12%, GS-SO: – 10% and IGS-WT: 5%) when it was easiest to identify debris from logging origin. Cover of rock, mineral soil and mixed soil remained unchanged. In the three adjacent clearcuts, cover of woody debris in 2001 was 12% and logging slash was 20%. The most disturbance (up to 3%) in the plots occurred in 1995 due to compression by humans installing the plots.

Although partial cutting removed 28 to 39% of the forest, there was not an equivalent decrease in overhead canopy cover. In 1998 to 2004, it averaged 31–39% in the partial cuts compared to 46% in the no-harvest treatment (Table 5). There was 0.3% overhead canopy cover recorded in the clearcuts in 2005. Shrubs ranged from 4 to 8% cover in the partial and clearcut treatments, which was similar to the no-harvest treatments. By 2000 and 2004, dwarf shrubs in the partial cuts had increased by about 2–6% from the pre-harvest amount and in comparison to the no-harvest treatments over time. There was a similar amount of dwarf shrub in the clearcuts and partial cuts (14 to 19%). Herbs in the

Table 5. Mean percent cover of soil and litter substrates, logging slash, disturbance, and vegetation layers by year and treatment.

	No-harvest (n = 229 plots)				IGS-SO[a] (n = 225 plots)				IGS-WT[b] (n = 223 plots)				GS-SO[c] (n = 223 plots)				Clearcut (n=120 plots)	
	1995	1998	2000	2004	1995	1998	2000	2004	1995	1998	2000	2004	1995	1998	2000	2004	2001	2005
Humus	94.0	93.0	92.8	92.3	92.0	89.0	86.7	86.6	95.0	96.0	93.8	92.4	94.0	93.0	90.4	90.4	80.2	78.0
Mineral soil	0.1	0.2	0.3	0.8	1.0	0.1	0.2	0.2	0.0	0.0	0.0	0.5	0.6	0.2	0.2	0.2	2.1	2.2
Mixed soil	0.3	0.3	0.1	0.1	0.3	0.6	0.1	0.2	0.1	0.4	0.1	0.2	0.1	0.2	0.1	0.2	2.9	1.4
Rock	2.9	4.0	3.0	2.9	2.6	2.3	2.3	2.6	1.0	1.2	1.2	1.5	0.7	0.8	0.7	0.7	2.2	3.2
Litter - coarse	1.7	2.0	2.3	1.7	1.9	2.8	6.8	1.8	1.9	2.0	2.0	1.3	3.5	2.8	5.0	3.3	3.1	4.3
Litter - medium	1.4	1.3	1.6	2.3	1.9	3.6	3.9	8.5	1.7	2.5	2.9	4.1	1.8	3.0	3.8	5.2	9.0	10.9
Logging slash	0.0	0.0	0.0	0.0	0.0	12.3	12.4	9.1	0.0	5.0	5.4	2.2	0.0	9.9	9.7	6.1	20.1	14.8
Disturbance	2.4	1.1	0.9	1.3	3.1	1.1	0.8	1.0	1.7	1.0	0.5	1.3	2.8	1.4	0.7	1.2	5.6	0.8
Shrubs	6.4	6.3	7.9	8.5	7.8	5.1	6.5	6.9	5.1	4.0	5.8	6.1	6.0	4.7	7.2	8.0	3.6	4.5
Dwarf shrubs	9.1	7.3	12.5	10.1	12.3	8.4	15.9	14.3	13.0	8.7	16.4	15.1	13.3	10.3	19.0	17.4	15.0	16.9
Herbs	2.1	1.6	3.1	2.0	2.8	2.2	4.8	4.0	2.5	2.6	5.0	4.0	2.3	1.9	4.8	3.1	12.8	17.4
Regeneration	0.3	0.2	0.4	0.5	0.5	0.9	0.7	0.8	0.3	0.3	0.7	0.7	0.7	0.4	0.7	0.7	2.0	3.4
Trees	38.8	44.8	47.2	45.4	39.1	31.2	32.2	30.4	48.8	39.8	43.2	36.5	42.2	37.9	38.2	37.5	0.0	0.3

[a] irregular group shelterwood with stem-only harvesting. [b] irregular group shelterwood with whole-tree harvesting. [c] group selection with stem-only harvesting.

no-harvest treatment and pre-harvest in the partial cuts averaged 2 to 3%, and increased in the partial cuts by 1 to 2% by 2004. Herbs in the clearcuts averaged 17% by 2005, and the most abundant species were northwestern sedge (*Carex concinnoides*) (6%), fireweed (*Epilobium angustifolium*) (2%), spike trisetum (*Trisetum spicatum*) (3%), short-awned ricegrass (*Oryzopsis pungens*) (1%), bunchberry (*Cornus canadensis*) (1%), and foxtail barley (*Hordeum jubatum*) (1%). All these species were 1% or less in the no-harvest treatments and partial cuts.

Regression analysis using plots from the partial cut and no-harvest treatments

Pre-harvest, the abundance of preferred forage lichen was significantly negatively related to cover of woody debris, herbs, dwarf shrubs, shrubs, and trees, while regeneration cover and treatment effects were the only non-significant variables (Table 6). This indicates that the best growing locations in the forest for lichen have minimal woody debris, and few herbs, dwarf shrubs, and shrubs, and spots with less overhead cover from trees. In the post-harvest analyses in 1998, 2000 and 2004, logging slash, woody debris, dwarf shrubs, and herbs continued to be negatively related to the abundance of preferred lichen (Table 6). Trees were not significant factors in 1998, but in the next two assessments cover from overstorey trees was again negatively associated with preferred lichen abundance. Regeneration (small pine trees) remained non-significant. Treatment effects (lower abundance in the partial cuts compared to the no-harvest) were significant in all years for the IGS treatments, but only in 1998 and 2000 in the GS treatment. Overall R^2 values ranged from 0.23 pre-harvest to 0.29 to 0.34 post-harvest.

Discussion

Immediate response to harvesting

There is little available literature on the impact of partial cutting on terrestrial lichens in caribou winter range. However, it has been hypothesized that

Table 6. Significant intercepts and coefficients for linear multiple regression models using healthy, preferred lichen as the dependent variable in 1995, 1998, 2000, and 2004 (n = 899).

	1995		1998		2000		2004	
	Mean ± Std	*P*	Mean ± Std	*P*	Mean ± Std	*P*	Mean ± Std	*P*
Logging slash	n/a		-0.0250 ± 0.0027	<0.0001	-0.0200 ± 0.0038	<0.0001	-0.0180 ± 0.0048	<0.0002
Woody debris	-0.0350 ± 0.0059	<0.0001	-0.0270 ± 0.0054	<0.0001	-0.0150 ± 0.0041	0.0003	-0.0280 ± 0.0047	<0.0001
Shrubs	-0.0130 ± 0.00510	<0.0117	-0.0130 ± 0.0054	0.0138	-		-	
Dwarf shrubs	-0.0160 ± 0.0038	<0.0001	-0.0160 ± 0.0042	0.0002	-0.0150 ± 0.0032	<0.0001	-0.0160 ± 0.0036	<0.0001
Herbs	-0.0540 ± 0.0122	<0.0001	-0.0420 ± 0.0094	<0.0001	-0.0340 ± 0.0062	<0.0001	-0.0400 ± 0.0083	<0.0001
Regeneration	-		-		-		-	
Trees	-0.0030 ± 0.0014	0.0491	-		-0.0020 ± 0.0011	0.0415	-0.0060 ± 0.0014	<0.0001
IGS-SO[a]-no-harvest	-		-0.7460 ± 0.1822	0.0009	-0.7600 ± 0.1463	<0.0001	-0.4280 ± 0.1676	0.0218
IGS-WT[b]-no-harvest	-		-0.6900 ± 0.1800	0.0016	-0.5150 ± 0.1436	0.0028	-0.4460 ± 0.1652	0.0168
GS-SO[c]-no-harvest	-		-0.7480 ± 0.1818	0.0008	-0.5140 ± 0.1464	0.0030	-	
Intercept	3.49 ± 0.24	<0.0001	3.36 ± 0.22	<0.0001	3.48 ± 0.22	<0.0001	3.71 ± 0.24	<0.0001
R^2	0.23	<.0001	0.32	<0.0001	0.34	<0.0001	0.29	<0.0001

[a] irregular group shelterwood with stem-only harvesting. [b] irregular group shelterwood with whole-tree harvesting. [c] group selection with stem-only harvesting.

partial cutting could promote continued terrestrial lichen growth by interrupting the normal succession pattern to feathermoss dominance in the northern part of British Columbia (Sulyma & Coxson, 2001). Snyder (1987) recommended trying selective logging in older pine stands, in west-central Alberta, to increase light to promote lichen abundance. Preliminary work in west-central B.C. suggested small openings would have less impact on lichens than clearcuts (Enns, 1998; Miège *et al.*, 2001a).

Our results showed that both the group selection and irregular group shelterwood systems using stem-only harvesting were associated with a 43 to 51% decline in the amount of preferred terrestrial lichens (particularly *Cladonia*) within 2.5 years of winter harvesting. In the first two post-harvest assessments, the group selection and irregular group shelterwoods were not significantly different from each other. Also, the greatest reductions were in the openings but lichens in the residual forest were also impacted. Morphotypes of lichen growing in subdued light are not well adapted to sudden exposure to stronger light conditions when the forest canopy is removed. Lichens that can grow in full sunlight have darker pigmentation and a much thicker upper cortex to protect their chlorophyll from oxidation (Kershaw, 1985).

The amount of physical damage can influence the mortality of the lichens. Kranrod (1996) in west-central Alberta, in a pre- and post-harvest study, documented an immediate post-harvest reduction in lichen of at least 50% in summer-logged treatments, whereas in winter-logged treatments, there was minimal impact after six months.

A number of studies from across Canada report lower lichen abundance in young clearcuts (Woodard, 1995; Harris, 1996; Webb, 1998; Goward *et al.*, 1998), but they are not supported by pre-treatment data. Similarly, we found that adjacent clearcuts had much less lichen cover (2.8%) than the no-harvest treatments (11.7%), even 5 to 7 years post-harvest.

Recovery over time

Generally, the rate of recovery can be influenced by the amount of lichen fragments available post-harvest (Harris, 1996; Webb, 1998) and the number of colonies that survive harvesting. Comparative studies show that young stands of logging origin have more lichen than those of fire origin because of the availability of fragments and colonies (Webb, 1998; Coxson & Marsh, 2001). Furthermore, winter harvesting leaves more undisturbed colonies from which to reinitiate (Coxson & Marsh, 2001).

We found that the quantity of lichen in the forested and cut portions of the treatments has been recovering since 1998. It has been especially rapid in the small gaps (15 m diameter) associated with the group selection system, where in 2004, the quantity of lichen approximated the pre-treatment level. The shelterwood treatments were at 68% and 71% of their pre-treatment level in 2004 so a longer period of time is required. However, by 2004, the whole-tree harvesting treatment was not statistically different from the no-harvest treatment, possibly indicating a shorter-term impact.

The speedy recovery of lichens in the group selection treatment compared to the shelterwood treatments may be due to the small diameter of the openings and less area cut. The greater coverage by the residual trees in the group selection treatment would more effectively block light and maintain cooler, shadier conditions. This may have particularly facilitated recovery of the lichens classified as sickly in the initial 1998 measurement. Also, woody debris left over from the stem-only harvest may have further ameliorated microclimate conditions to facilitate recolonization. Goward *et al.* (1998) and Enns (1998) both comment on thalli growing in the shelter of logs or tip-up mounds often appear robust, while those in more exposed sites are dead or moribund.

The amount of time required to fully recoup the pre-treatment lichen amounts in the shelterwood treatments is unknown. A simple linear extrapolation of the shelterwood results for the first eight years of our study suggests about 20 years to recover lichen to pre-harvest levels, while clearcuts would require about 30 years. These estimates are consistent with information from retrospective studies on stands originating from clearcutting or fire. Generally, the amount of time to recover lichen appears to depend on the geographic area, intensity of the disturbance, and the lichen species present.

In west-central Alberta, Woodard (1995) and Snyder & Woodard (1992) found total lichen cover (predominantly *Cladonia* and *Peltigera*) equaled that occurring in unlogged stands 20 to 30 years after clearcutting. In Ontario, the dominant species, *Cladina stellaris, Cladina rangiferina* and *Cladina mitis*, were exceedingly abundant in older clearcuts (43 to 46 years, horse-logged and not site prepared) compared to mature stands (Harris, 1996). Racey *et al.* (1996) estimated that logged areas could function as caribou winter habitat after 40 years and that removal of the organic matter was necessary to ensure succession to a jack pine–lichen community rather than to black spruce–feathermoss community. In Sweden, Eriksson (1975) suggested that some areas reforested after clearcutting were "fair" reindeer range in 20 to 30 years.

Studies on pine stands originating from fire in western Canada give some indication that development of lichen mats takes at least 40 years. In the vicinity of the study area, Goward *et al.* (1998) found stands aged 42 to 70 years had abundant preferred lichen (14 to 25% cover). Similarly, Braulisauer (1996) and Hooper & Pitt (1996) described stands aged 67 to 85 years as having a mean cover of 16% of preferred species, which was consistent through stands up to 385 years old, though the proportion of *Cladonia* decreased and *Cladina* increased over time. Further north in British Columbia, *Cladina* dominated the forest floor surface in 50–100 years stands (Coxson & Marsh, 2001). Snyder (1987) reported that in west-central Alberta, similar to west-central B.C., equal quantities of preferred lichen were found in 50- and 200-year-old lodgepole pine stands, but species shifted from *Cladonia* to a mix of *Cladonia*, *Cladina* and *Peltigera*. In north-east Alberta and northwest Saskatchewan (Carroll & Bliss, 1982), the recovery of the lichen mat (dominantly *Cladina*) in jack pine stands (*Pinus banksiana*) is 45 years.

Based on the estimated rate of recovery of lichens and other published results, the final cut planned for the shelterwood silvicultural systems in 70 years should be more than sufficient to recover terrestrial lichen in the context of a mature forest. The group selection system, planned on an 80-year cutting cycle, was designed for sites with substantial arboreal lichen as well as terrestrial lichen. Although the terrestrial lichen has rapidly recovered, it could take a long time to recover arboreal lichen in the gaps. This is due to the time it takes to develop stand attributes, such as defoliated branches, stable environmental conditions and adequate ventilation that are conducive to heavy lichen loading (Goward & Campbell, 2005). With the system fully implemented, at any point in time, more than one third of the forest is over 80 years and one third is over 160 years, so sufficient arboreal lichen should be available to caribou. This is preferable to the clearcut method which directly removes all the arboreal lichen-bearing trees. Indications from local studies (Braulisauer, 1996; Hooper & Pitt, 1996; Goward *et al.*, 1998) are that the forests in the Montane Spruce and especially in the Sub-boreal Pine Spruce zones will maintain a reasonable component of terrestrial lichen throughout the life cycle of the managed forest, unlike some other jurisdictions where pine–lichen stands over time transition to predominantly feathermoss (Racey *et al.*, 1996; Brakenhielm & Liu, 1998; Sulyma & Coxson, 2001; Coxson & Marsh, 2001).

The silvicultural systems also affect other plant species that may compete with preferred lichen species for space and resources, but also may have some forage value for caribou. *Peltigera*, mosses, grasses, sedges, conifer needles, dwarf shrubs and shrubs are found at low levels in caribou diets (Scotter, 1967; Edmonds & Bloomfield, 1984; Thomas & Hervieux, 1986; Cichowski, 1989; Thomas *et al.,* 1996). *Peltigera*, *Stereocaulon*, "winter-green" vascular plants, and green parts of sedges and grasses have higher protein content and are thought to increase the digestibility of *Cladonia*, *Cladina* and *Cetraria* species, which have high carbohydrate value but low protein value (Person *et al.*, 1980; Klein, 1982; Edmonds & Bloomfield, 1984). We found that *Peltigera* species remained common within the partially cut treatments, though mean abundance dropped in the openings. Also, abundance of herbs (mostly grasses and sedges), shrubs, and "winter-green" dwarf shrubs (predominantly *Linnaea borealis*, *Arctostaphylos uva-ursi* and *Empetrum nigrum*) only increased by a few percent in the partial cuts so did not pose an increased competitive threat. Overall, the partial cutting silvicultural systems have provided a range of food sources in close proximity for caribou.

In contrast, clearcuts lost a large amount of preferred lichen and *Peltigera* species, while sedge and grass cover increased by 11%, and cover of shrubs and dwarf shrubs remained similar to the partial cuts. With the absence of lichens from young clearcuts, the other species may be of little use to caribou in the winter. The significantly greater herb response in the clearcuts is noteworthy as it has the potential of making those areas more attractive during summer to deer and moose—the primary prey of wolves. Although fewer caribou use these areas in the snow free seasons, any habitat alteration that could lead to greater wolf numbers is of concern to caribou which are sensitive to increased predation (Seip, 1991; 1992).

Method of harvesting

Whole-tree and stem-only harvesting were selected for this study because both types are used in west-central B.C. There were concerns associated with each method. In the pilot study for our trial, Miège *et al.* (2001a) found that the slash generated through on-site processing covered the lichens, causing mortality. Conversely, whole-tree skidding, even on snow, could cause more physical damage to the lichen mat, and the associated roadside processing area would severely reduce lichen cover.

A direct comparison between the two shelterwood treatments showed no significant differences in preferred lichens between the treatments over the eight-year study period. The amount of physical disturbance (compression and displacement) was minimal in both systems, and opening size and area cut were similar, suggesting similar changes in environmental conditions such as light, occurred in the two treatments. However, by 2004, the whole-tree system, unlike the stem-only system, was no longer significantly different from the no-harvest treatment. Possibly the lower slash input (5%) in the whole-tree treatment (compared to the stem-only system [12%]) was enough to cause the non-significant difference from the no-harvest treatment. However, the impact of the roadside processing area (3 to 7% per treatment unit) associated with whole-tree harvesting was not included in the treatment effect. Kranrod (1996) concluded that stem-only harvesting, when in combination with winter logging and no scarification, retained the most lichen immediately post-harvest because the debris piles moderated the micro-environment within the clearcut.

Key factors that affect lichen abundance

In our regression analysis, factors such as woody debris and vegetation cover that were negatively related to lichen abundance pre-harvest, continued to be significant post-harvest. The direct comparison between harvesting systems (WT and SO) showed no statistical differences. However, harvesting did increase the amount of woody debris, particularly in the SO system. This debris occupies forest floor space, making it unavailable for lichen. Furthermore, in the MSxv and SBPSxc biogeoclimatic subzones, the process of decay is slow, so the debris remains solid and dry for a long time. In moister environments, as described by Racey *et al.* (1996) and Harris (1996), colonization of stumps is rapid, and coverage of slash piles occurred in 40 years (Harris, 1996). When slash is deposited on the ground, it crushes lichen. Low suspended slash can prevent light and precipitation from reaching the lichen, and it creates a poorly ventilated environment that encourages the growth of fungal mats. Conversely, high suspended slash and areas adjacent to slash piles may provide refugia for lichen in the short and long term.

The increased light and moisture in the partial cuts stimulated a small amount of growth of herbs and dwarf shrubs. Whether lichen can colonize the area occupied by these plants as stands redevelop is unknown. Lichen occupancy increased as tree cover decreased, implying that natural gaps with more light are the best locations for lichens. Perhaps after the initial shock of exposure, lichens may grow exceptionally well in gaps until the young stand redevelops.

Management implications and conclusions

The group selection and irregular group shelterwood treatments maintain forage lichen in the residual stand. Recovery of terrestrial lichens in the group selection system occurred within eight years of harvest, and possibly will happen within 20 years in the shelterwood systems. The group selection system is recommended for 20% of the modified harvesting area, which supports the most arboreal lichen in addition to terrestrial lichen. Survival and growth of planted trees in the openings is sufficient for the planned rotation periods (140 or 240 years) (Waterhouse *et al.*, 2010). Natural regeneration is also a viable silvicultural option for openings in the SBPS blocks as they were sufficiently regenerated in seven years (Steen *et al.*, 2007). Also, treefall studies indicate that the stands have remained very stable (Waterhouse & Armleder, 2004).

An estimated 20-year recovery of forage in the shelterwood treatments does not necessarily mean that the residual forested component can be harvested earlier than the planned removal in 70 years. Foremost, lichens growing in the first entry openings will be negatively affected to some degree by the removal of the adjacent forest. Secondarily, prime winter habitat is not only determined by the quantity of forage lichens but the context in which they are available. There may be enough terrestrial lichen in immature stands, but these stands are less desirable (Schaefer and Pruitt, 1991). Also, removal of the forest canopy results in increased winter snow depths relative to the forest, making it more energetically demanding for caribou to access lichens (Schaefer, 1996). Johnson *et al.* (2001) found that when snow conditions (depth and density) limited access to terrestrial lichens, caribou switched to foraging on less abundant arboreal lichens. It may take several decades to recover the snow interception capacity of older stands.

In the cold, dry ecosystems of west-central B.C., aggressive forest harvesting and site preparation methods are not necessary to destroy feathermoss mats and re-initiate succession to lichen communities. Winter logging and no site preparation causes the least immediate damage to pre-harvest lichen mats (Harris, 1996; Kranrod, 1996; Enns, 1998; Webb, 1998; Coxson & Marsh, 2001). A direct comparison found that stem-only or whole-tree harvesting similarly reduced lichen; however, there was more slash deposited in the stem-only system, and regression analysis pre– and post-harvest showed that increases in woody debris and slash were associated with a significant reduction in lichen abundance. Others (Kranrod, 1996; Enns, 1998; Goward *et al.*, 1998) suggest that once woody debris is in place, it helps maintain lichen. There is the added advantage of leaving woody debris for long-term site productivity (Wei *et al.*, 2000).

High tree mortality caused by mountain pine beetle has complicated this trial. Beetle attack was first recorded in 2003, and by 2008, the pine beetles had killed about 60% of the mature trees on the trial blocks. Some implications to the lichen community, and subsequently to northern caribou, are discussed by Armleder & Waterhouse (2008).

Partial cutting remains an effective management tool to manage caribou habitat in west-central B.C. where timber harvesting is a management reality. However, large areas with no development are also part of the overall strategy for maintaining caribou.

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