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Original Research

Recovery of Terrestrial Lichens Following Wildfire in the Boreal Shield of Saskatchewan: Early Seral Forage Availability for Woodland Caribou (*Rangifer tarandus caribou*)

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Abstract

In boreal forests, wildfire is a dominant ecological process that affects the distribution and abundance of terrestrial lichens, the principal winter food for Woodland Caribou (*Rangifer tarandus caribou*). Fires commonly destroy the lichen mat, and there is a succession in the cover and composition of terrestrial lichens since time of burn. Currently, management agencies in Canada operate with a threshold of 40 years before habitat is considered suitable for Woodland Caribou following a wildfire. This study used two independent datasets to analyze short-term and long-term progression of terrestrial forage lichen cover following wildfire in the Boreal Shield of northern Saskatchewan, and compared these data with similar studies in other caribou ranges. Terrestrial forage lichens were found to recover 20-50 years faster in Jack Pine (*Pinus banksiana*) stands than has been reported from previous studies from the boreal forest and tundra habitats, and average cover peaked at 21-30 years after fire in Jack Pine stands. After this peak, lichen cover decreased and remained relatively low between 41-90 years. A secondary increase in cover occurred between 101-150 years. *Cladina mitis/arbuscula* was the dominant species, and was, of the three preferred forage species analyzed, the one that recovered most quickly after fire whereas *C. stellaris* and *C. rangiferina* appeared later. Forage lichen cover was lower in spruce (*Picea* spp.) stands than in Jack Pine stands. Based on forage lichen cover alone, we conclude that Jack Pine stands as young as 21-30 years may provide a more suitable supply of forage cover for Woodland Caribou than do intermediate aged stands between 50 to 90 years old; however, optimal habitat may

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not occur until approximately 100 years after fire. Our results help explain how Woodland Caribou have persisted for several thousand years in the Boreal Shield of Saskatchewan, an environment with high fire frequency and extent, as a matrix of relatively young and old mature habitats may be more suitable for caribou than vast areas of intermediate aged habitats. These findings may have important management implications for Boreal Woodland Caribou. Based on forage supply, this bi-modal pattern of lichen recovery observed in the Boreal Shield of Saskatchewan suggests that it may be more appropriate to include two phases of caribou habitat availability in models, rather than applying a single threshold after which habitat is deemed suitable.

Key Words: Boreal Shield, Caribou Management, *Cladina*, *Cladonia*, Fire, Jack Pine, Lichen Recovery, *Pinus banksiana*, *Rangifer tarandus*, Saskatchewan.

INTRODUCTION

Woodland Caribou (*Rangifer tarandus caribou*) are found throughout Canada's boreal forest, and have been declining both in distribution and population size at the southern extent of their range (McLoughlin *et al.* 2003; Environment Canada 2008; Latham *et al.* 2011; Environment Canada 2012). This species is listed as threatened in Canada (COSEWIC 2002), and Vulnerable (S3) in Saskatchewan (SKCDC 2013). Predation, hunting, and habitat loss/alteration due to industrial development are listed as potential causes of decline (Dzus 2001; McLoughlin *et al.* 2003; Wittmer *et al.* 2007; Environment Canada 2008). Wildfires are also thought to affect caribou populations by reducing cover and biomass of lichens (Klein 1982; Dunford *et al.* 2006; Collins *et al.* 2011; Barrier and Johnson 2012), the principal winter food of caribou (Scotter 1967; Thomas and Hervieux 1986; Joly *et al.* 2003; Dunford *et al.* 2006).

Recurrent and often extensive wildfires are a natural component of boreal forest ecosystems, and wildfire is the dominant ecological process determining the vegetative landscape of the Boreal Shield in Saskatchewan. Fires initially remove all or portions of the lichen mat which is followed by a succession in the composition, biomass and cover of lichens over time (Dunford *et al.* 2006; Collins *et al.* 2011). Newly burned habitats are generally considered unsuitable for caribou until lichens have recovered sufficiently (Joly *et al.* 2003; Dunford *et al.* 2006; Collins *et al.* 2011). The Recovery Strategy for the Woodland Caribou, Boreal population in Canada, applies a threshold of 40 years beyond which habitat becomes suitable for Woodland Caribou following a wildfire (Environment Canada 2012). As much as 55% of the area in the Boreal Shield of Saskatchewan (SK1) has been affected by wildfires that have occurred in the last 40 years (Environment Canada 2012). Also, climate warming may result in increased wildfire frequencies associated with warmer and drier summers (Balshi *et al.* 2009; Joly *et al.* 2012). Consequently, detailed knowledge of lichen recovery dynamics following fire is an important component of caribou critical habitat management in the region.

Several studies have been conducted on changes in lichen abundance following fire in other northern caribou ranges. In Alaska's taiga, Collins *et al.* (2011) found that lichen rarely exceeded 1-2 percent cover until 60-70 years post fire. In northern Quebec (Morneau and Payette 1989, Arsenault *et al.* 1997) and western Canada (Coxson and Marsh 2001), terrestrial lichens appeared within 20 years post fire; however, maximum lichen cover was not achieved until after 100 years. Joly *et al.* (2003; 2010) documented winter habitat use by female caribou in Alaska, and found that the animals avoided habitat less than 50 years old. They hypothesized that the primary factor was reduced availability of caribou forage lichens following fire.

Lichen productivity is likely unequal across caribou ranges of North America, and it is expected that succession of lichens may occur at faster or slower rates depending on soil type, hydrology, latitude, and regional climate. In a study of lichen abundance in peatlands of northern Alberta, Dunford *et al.* (2006) found that lichen recovery was relatively rapid, and that cover was comparable to mature sites within 30-40 years post fire. Dunford (2003) also found that caribou avoided only the most recently burned peatland habitats, and that home range locations did not shift and size did not differ significantly following extensive fire. Although lichen species assemblages and fire regime in the Boreal Shield of Saskatchewan may be similar to that of the above-mentioned studies, less research has been conducted on succession of terrestrial lichen cover following wildfires in this region. In one study from the Boreal Shield, Carroll and Bliss (1982), observed that macroscopic lichen appear 1-3 years post fire, and that some *Cladonia* species achieve maximum cover within 20 years. They also found that this initial phase of vegetation recovery is followed by the development of a *Cladina mitis*-dominated lichen mat. They noted that this phase of the recovery lasted until <40-50 years post fire, however, it is not stated at which rate, and within what time frame *C. mitis* becomes dominant. It is unclear therefore when lichen cover in burned areas returns to levels observed in unburned areas.

In the Canadian Species At Risk Act, critical habitat is defined as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (Government of Canada 2002). For Boreal Woodland Caribou, critical habitat identification describes the habitat that is necessary to maintain or recover self-sustaining local populations throughout their distribution. In some of the areas identified as critical habitat, the quality of habitat will need to be improved for recovery to be achieved (Environment Canada 2012). In the Recovery Strategy for the Woodland Caribou, Boreal Population, (Environment Canada 2012) critical caribou habitat is identified for all Canadian Boreal Woodland Caribou ranges, except for the Boreal Shield region of northern Saskatchewan. The relatively high fire disturbance (55%) combined with the very low anthropogenic disturbance (3%) in northern Saskatchewan, represents a unique situation that falls outside the range of variability observed in the data that informed the development of the disturbance model used by Environment Canada (2012). Therefore, the disturbance model that informed the identification of critical habitat has not been applied for this range (Environment Canada 2012). Identifying the effect of wildfires, and documenting when lichens appear after fire, as well as long term trends (100^+ years) in lichen cover will contribute to the identification of an element of critical habitat for Woodland Caribou in the Boreal Shield of Saskatchewan.

The three main goals of this study are to 1) document and quantify the short-term (1-50 years) succession of terrestrial lichen cover in upland conifer stands following wildfire; 2) quantify long term lichen succession (30-150^+ years after fire) to identify when or if terrestrial lichen cover stabilizes; and 3) compare short term and long term differences in lichen cover.

MATERIALS AND METHODS

Study area

The study was conducted in the Boreal Shield Ecozone of northern Saskatchewan (54°30'-59°16'N, 101°50'-110°00'W) (Figure 1). The ecozone is dominated by a broadly rolling mosaic of uplands and associated wetlands, as well as numerous small to medium-sized lakes (Acton *et al.* 1998). The most abundant ecosite on the Boreal Shield is Jack Pine (*Pinus banksiana*)-dominated (McLaughlan *et al.* 2010), which varies between young, extremely dense stands to old, open, park like stands (Carrol and Bliss 1982). This is a consequence of the frequent wildfires mentioned above, as fires favour the spread of Jack Pine (Acton *et al.* 1998). In the absence of fires, this cover type tend to transition toward a Black Spruce (*Picea mariana*)-dominated cover type, which is considered a climax forest condition in the Boreal Shield (McLaughlan *et al.* 2010). Due to the relatively high fire disturbance (55%), this is a less common cover type generally limited to islands, peninsulas, and other areas less prone to wildfires. Ground cover is dominated by reindeer lichens (primarily *Cladina mitis*) or feather mosses (primarily *Pleurozium schreberi*). Ericaceous shrubs such as Blueberry (*Vaccinium myrtiloides*), Bog Cranberry (*V. vitis-ideae*), and Labrador Tea (*Ledum groenlandicum*) are common in the shrub layer, along with the occasional willow (*Salix* spp.) or Green Alder (*Alnus viridis*). Poorly drained lowlands are characterized by an open canopy of Black Spruce and, to a lesser extent, Tamarack (*Larix laricina*). The understory is largely ericaceous shrubs, and ground cover is represented by peat (*Sphagnum* spp.), and feather mosses. Tamarack is the dominant tree species in well-drained lowlands with an understory dominated by willow species, birch species (*Betula* spp.) and ericaceous shrubs.

Data sources

Two separate and independently collected data sets were used in this study. The first ('short-term') data set contains botanical, sample site, and habitat structure data collected by HAB-TECH Environmental Ltd. during detailed baseline vegetation surveys at several Cameco Corporation operations between 2007 and 2012. The short-term data set comprises a total of 103 sample locations. The second ('long-term') data set is comprised of 436 samples, and contains similar data collected in the same region by the Saskatchewan Ministry of Environment for development of the Field Guide to the Ecosites of Saskatchewan's Provincial Forests (McLaughlan *et al.* 2010). The distribution of plots for the two data sets is displayed in Figure 1. Because the data sets differ in terms of number of plots, age distribution and sampling design, they were analyzed separately. Coarse scale comparisons may, however, be drawn between the two datasets.

Sample site selection

For both data sets, upland conifer stands were chosen because they are important foraging habitats for caribou during winter (Metsaranta and Mallory 2007; Metsaranta 2008). For the short-term analysis, sample sites were completed in upland stands dominated by regenerating Jack Pine ranging from 1 to 60 years since fire. Remote sensing imagery (Landsdat and Ikonos) as well as Saskatchewan Environment Fire Mapping Data (acquired from Fire Management and Forest Protection Branch, Prince Albert, Saskatchewan, which has fire mapping dating back to 1945) were used to locate Jack Pine-dominated stands at appropriate ages. During the field visit, if a site was deemed suitable (i.e., a uniform polygon dominated by regenerating Jack Pine), the survey crew walked towards the center of the polygon the length of a survey plot (to avoid transitions between two different age classes) and established the plot starting point. In cases where the plot location was on a slope, the plot was located along the contour to avoid differences in moisture regimes. If the area was flat, the plot was oriented North.

Because the goal of this aspect of the study was to identify development of lichen cover during the early seral stages following fires, it was important to have high precision of fire estimates. Therefore, the age estimates from the Fire Mapping Data were verified by sampling cores of representative trees within sampling sites, and/or by counting branch whorls on trees in very young

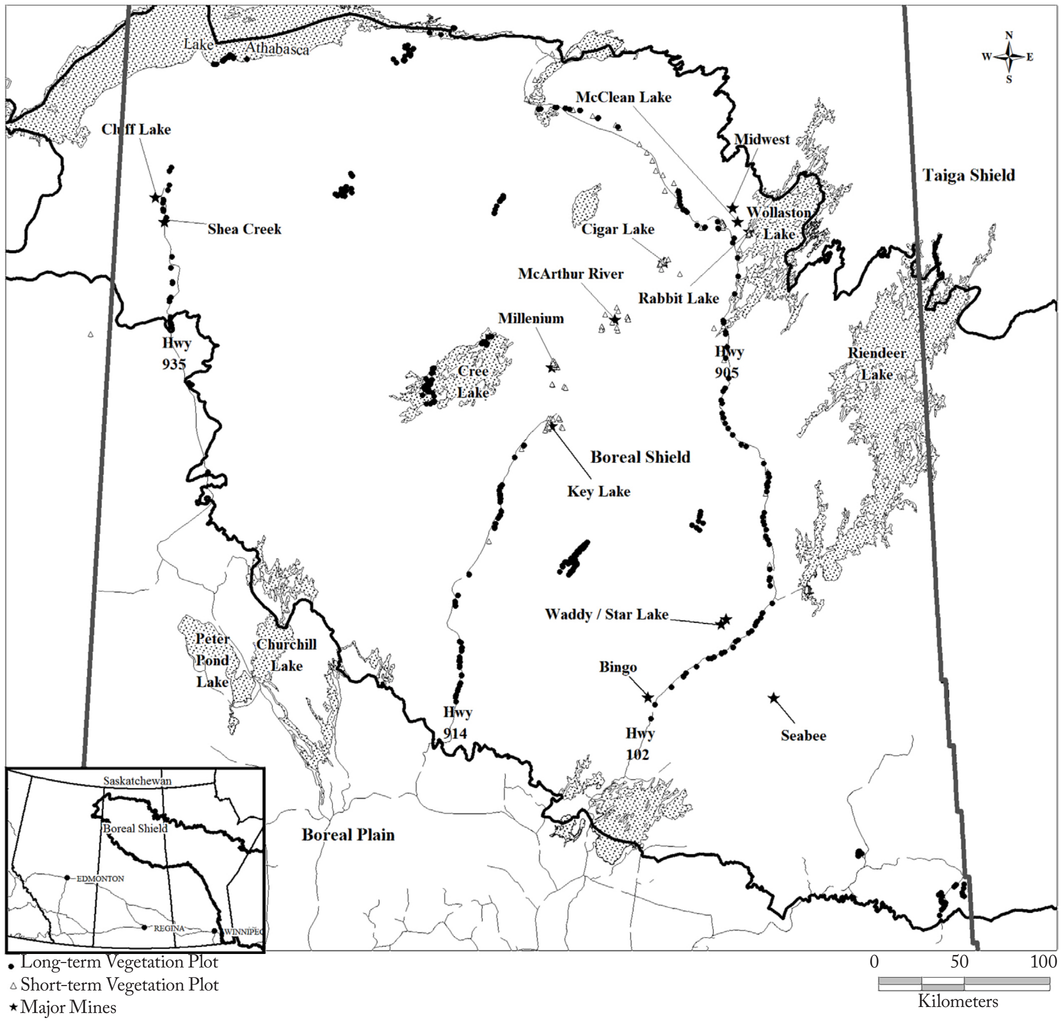

Figure 1. Study area and distribution of plot locations for short-term and long-term datasets within the Boreal Shield of Northern Saskatchewan, Canada.

stands. The cores were obtained from 1.3 m above ground providing 'breast height age'. Because we were interested in the total age of the tree, an age adjustment factor of 8 years was applied based on guidance from Saskatchewan Environment (2004). If the counts of whorls or age corrected cores were significantly higher (i.e., 10 years) than estimated fire age it was assumed that the stand had not burned during the mapped fire event (i.e., it was either a residual or inaccurately mapped as burned), and the sample site was therefore discarded.

For the analysis of the long-term data, sample sites were completed for both upland Jack Pine-dominated stands and upland spruce-dominated stands (predominantly Black Spruce but also White Spruce (*Picea glauca*)). Minimum stand ages at these sites ranged from 31-250 years. Tree ages were obtained from cores as close to the root collar as possible of representative trees within sampling sites (Jiricka *et al.* 2002). Because the cores were obtained from close to the root collar, no age adjustment factor was utilized for this set. If the ages of the two samples for a species varied by more than 10 years, a third tree of that species was sampled. If the age of the third tree was not within 10 years of either of the other two, the stand was considered to be multi-aged. In these instances and for analytical purposes, the oldest tree was used as "stand age". Because accurate fire mapping was not available for the region before 1945, it was not possible to verify that the trees selected for aging were in fact established immediately after fire. Therefore the age estimates for the long-term plots are considered "minimum stand age" rather than fire age for the plots in this data set. This is a relatively commonly used approach (e.g., Caners and Kenkel 2003; Harelson and Matlack 2005; Johnstone and Kasischke 2005), although it does have some limitations. Inclusions and low severity fires can leave surviving trees, so this technique may not, in all cases, provide a minimum stand age. The potential bias in minimum stand age *versus* fire age increases with time. Therefore, our analysis of older stands in the long-term data set cannot be analyzed with the same level of accuracy in terms of actual ages. When analyzing the older data, we therefore grouped all plots older than 100 years old into one group to reduce likelihood of using plots with false old ages. This reduced some precision in these estimates, however it also avoided assuming higher accuracy in age estimation than was realistically achievable.

A generalized plot location was assigned to positions along permanent road networks or along the shore of a lake or river by randomly selecting points along the road or shore. Actual plots were located in each selected stand at a random and predetermined distance from either the road-side or lake/river shore tie-in points.

Sample plot layout and sampling design

Both the short-term and the long-term data were collected using visual estimates of percentage cover rather than other known methods, such as biomass or mat thickness, despite known weaknesses to this approach (e.g., Floyd and Anderson 1987). Using this approach however, allows for comparison between the two studies, and with other studies using percentage cover as the response variable.

The plot layout and sampling design differed between the short-term and long-term data sets. The short-term data set main plot was a 30-m-long transect along which five 20 cm x 50 cm sub-plots were systematically distributed at 5 m intervals. Visual estimates at a continuous scale to the nearest percent were made of each sub-plot covered by terrestrial bryophyte and lichen species, as described in British Columbia Ministry of Forests (1998). The value for percentage cover was then calculated for each main plot from the average estimated percentage cover in the five sub-plots for each species. The approach of using a continuous scale is prone to yield some inaccuracy in estimates, however by calculating a mean average cover for each main plot from the values of each of the five sub-plots we reduced the variation in the estimates. Also, because the sub-plots were small (20 cm x 50 cm), the bias is further reduced compared to using larger plots (McCune and Lesica 1992). A total of three different observers collected the data for the short-term study. At the initiation of each field visit, observers would work together to calibrate in making cover estimates to minimize bias.

The long-term data set plot consisted of a 10 m x 10 m main plot with two 2 m x 2 m sub-plots placed at opposite corners (N/W and S/E). The cover of lichen species in these plots was visually estimated according to a modified Braun-Blanquet scale (Mueller-Dumbois and Ellenberg 1974), where class #2 (5-25%) was split into two finer classes (5-15% and 15-25%). The finer classes were created to accommodate concerns that the range of 5% to 25% was too broad to accurately describe species arrangement on the site for less abundant plant species (Jiricka *et al.* 2002).

Data used for analysis

The response variable was percent cover of terrestrial lichen species or groups of species, with the predictor variable being stand age (10-year intervals). Categorizing stand age into groups provided a means to do statistical comparisons and testing between different groups. It also allowed for describing the data within each group with a mean and standard error. We concentrated on lichen species known to be used as forage by caribou. Two sets of analyses were conducted: one analysis addressed genera known to be consumed by caribou; the second analysis was for terrestrial lichen species known to be preferred by caribou. If different recovery rates are documented between the preferred species and the genera known to be consumed, it may have implications for caribou management in the area. *Cladina* spp., *Cladonia* spp., *Peltigera* spp., *Stereocaulon* spp., *Cetraria* spp. and *Flavocetraria* spp. were classified as lichen genera known to be consumed by caribou (Banfield 1954; Scotter 1967; Inglis 1975; Miller 1976; Thomas and Hervieux 1986; Johnson *et al.* 1998). Selection of the preferred species in the second analysis were based on Scotter (1967) and Collins *et al.* (2011), and included *Cladina mitis*, *C. rangiferina*, and *C. stellaris*. *Cladina mitis* and C. arbuscula were grouped as one forage species because of difficulty in readily distinguishing them in the field.

Analysis

Four analyses were conducted on the species *known to be consumed* by caribou:

1. The relationship of lichen species percentage cover to age since fire were analyzed using data from the short-term study only – to clarify short-term recovery of lichen species after fire.
2. Comparison of lichen cover in Jack Pine stands between the short-term and long-term studies in the interval where the two data sets overlap (31-50 years) – to identify whether there are significant differences between the two data sets at this interval.
3. Comparison of lichen cover between the age groups in the short-term study with data we classified as old (minimum stand age at least 100 years post fire) in Jack Pine stands in the long-term study– to identify if there are significant differences in lichen cover between young and old Jack Pine stands. For this analysis, all plots with minimum stand age more than 100 years old were included in the analysis.
4. Comparison of young (31-40 years) *vs.* intermediate age groups (41-90 years) of Jack Pine stands using data from the long-term study only – to identify whether there are significant differences between young and intermediate aged stands in terms of lichen cover.

Three analyses were conducted on the species *known to be preferred* by caribou:

1. Trends in the development of lichen cover for each of the three preferred species using both the short-term and the long-term datasets.
2. Comparison of lichen cover between the age groups in the short-term study with data classified as 100^{+} years post fire

in Jack Pine stands in the long-term study – to identify if there are significant differences in cover of preferred lichen species between young stands and old stands.

3. Comparison of lichen cover of each of the preferred species in Jack Pine *vs.* spruce stands 100+ years post fire – to identify whether the two forest cover types support significantly different lichen covers of these species.

We factorized time since fire by coding it into age groups with 10-year intervals (1-10, 11-20, … 241-250 years). Because Saskatchewan Environment Fire Mapping Data only dates back to 1945, data was available dating back 67 years from 2012. As such we had six complete 10-year intervals from which to analyze data from the short-term data set. The fires in the years 1945 to 1952 were not included in the analysis because data from part of the 10-year interval was lacking.

Next we calculated the average percent cover of lichen for each age group. Because we were interested in the variation between age groups rather than the variation within groups, the precision of this mean value was quantified by calculating standard error of the mean (SE). Groups with low *n* will generally yield large error bars, and make the graphical display of data chaotic. Therefore, age groups with low sample size were excluded in the graphical display of data. However, all groups are included in the analysis and are listed in the tabular version of the data.

Statistical analyses were conducted using two different tests. For groups that were found to have normal distribution, two-sample *t*-tests (not assuming equal variances) were run to verify whether or not differences in mean values between compared groups were statistically significant ($P<0.05$). The sample data within each group (data set, species and age group) was tested for normality using the Kolmogorov-Smirnov normality test. For the majority of the groups, the normality assumption was found to be valid ($P>0.05$); however, in a few of the groups in the long-term data set, the data did not conform to the normal distribution ($P<0.05$). For these groups, Mann-Whitney tests were run to determine whether there were significant differences ($P<0.05$) in the distributions of the two groups. All data was analyzed using Minitab v. 16.2.4 (Minitab Inc., State College, Pennsylvania, USA).

RESULTS

Cover of lichens known to be consumed

Table 1 summarizes percent cover of lichens known to be consumed by caribou, SE and sample size for all age groups for both the short-term and the long-term data sets. For the short-term data, lichen cover in Jack Pine stands showed slow but significant recovery from 1-10 to 11-20 years (*t*-test, $P\leq 0.001$),

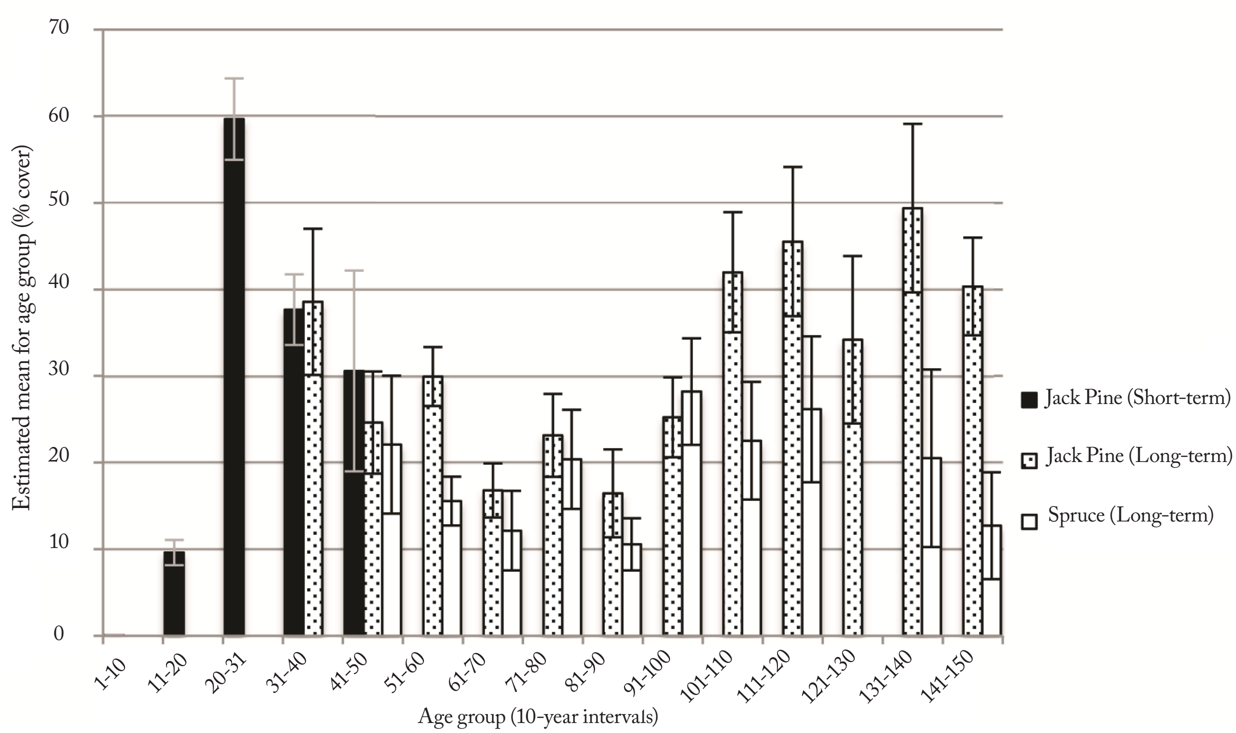

Figure 2. Relationship between age and average cover of known Woodland Caribou forage lichen species in study sites in the Boreal Shield of Northern Saskatchewan, Canada. Black columns show data for the short-term study 1-50 years post fire. The grey and white columns show data for long-term data with minimum stand age of 31 to 150 years. The error bars are standard errors around the means. Groups with low *n* will generally yield large error bars, and make the graphical display of data chaotic. Therefore, age groups with low sample size were excluded in the graphical display of data. However, all groups are included in the analysis and are listed in Table 1.

Table 1. Summary of mean cover (%) of lichen species known to be consumed by Woodland Caribou, standard error (SE) and sample size (*n*) for each of the age groups in the short-term study (Jack Pine stands) as well as each of the age groups for the long term study (Jack Pine and spruce stands).

Age Group (Years)	**Short-term study Jack Pine**			**Long-term study Jack Pine**			**Long-term study Spruce**		
	%	SE	*n*	%	SE	*n*	%	SE	*n*
1-10	0.1	0.0	20						
11-20	9.6	1.5	19						
21-30	59.7	4.7	23						
31-40	37.7	4.1	32	38.6	8.5	7			
41-50	30.6	11.6	7	24.6	5.9	13	22.1	8.0	7
51-60	58.4	21.5	2	29.9	3.4	67	15.6	2.8	30
61-70				16.8	3.1	48	12.1	4.6	16
71-80				23.1	4.8	30	20.4	5.7	17
81-90				16.5	5.1	15	10.6	3.0	12
91-100				25.2	4.6	22	28.2	6.1	15
101-110				42.0	6.9	18	22.5	6.8	15
111-120				45.5	8.6	11	26.2	8.4	10
121-130				34.2	9.7	8	17.4	8.8	6
131-140				49.4	9.7	13	20.5	10.3	7
141-150				40.3	5.7	11	12.7	6.2	7
151-160				34.6	5.6	2	4.0	13.5	4
161-170				28.4	13.5	6	46.0	1.6	2
171-180				39.0		1	2.9	9.0	2
181-190				60.6	13.9	2	11.0		2
191-200				63.1	13.1	2			
201-210							20.8		1
211-220				32.8		1	10.0	2.3	2
221-230				98.8		1			
231-240									
241-250							23.3		1

and increased abruptly from 11-20 years to 21-30 years (*t*-test, $P \leq 0.001$) with an initial peak at 60% in the 21-30 years post fire group (Figure 2). It was then followed by a sharp decrease to 38% from 21-30 years to 31-40 years (*t*-test, P=0.001). The trend of decreasing cover continued in the 41-50 years group, although this decrease was not statistically significant (*t*-test, P=0.581) (Table 2).

No significant difference (*t*-test, P>0.05) was documented between the short-term and the long-term study for Jack Pine stands in the interval of overlap (31-40 and 41-50 years), indicating the data sets are comparable irrespective of different methodologies used for collecting the data (Table 2).

The comparison of Jack Pine stands between the short-term age groups and the combined 100^+ years minimum stand age (old group) revealed that the age groups 1-10 and 11-20 years post fire had significantly lower lichen cover than the old group (*t*-test, $P \leq 0.001$), and that the 21-30 years post fire had significantly higher lichen cover than the old group (*t*-test, P=0.006) (Table 2).

The long-term data showed a trend of lower lichen cover in Jack Pine plots of intermediate ages between 61-90 years when compared to the 31-40 years minimum stand age and this reduction was significant between age groups of 31-40 and 61-70 years (Mann-Whitney test, P=0.024), and between the 31-40 and 81-90 years age groups (Mann-Whitney test, P=0.032) (Table 3).

After 100 years, lichen cover increased again, to approximately 42%. Following this increase, lichen cover appeared to stabilize around 40% in the 100-150 year age groups (Table 2). The spruce plots generally showed lower overall lichen cover than did the pine plots, although they followed a similar pattern with an increase around 101 to 120 years post fire (Figure 2).

Table 2. Test statistics for analysis of differences in estimated average values between age groups for Jack Pine stands. Two-sample *t*-tests, not assuming equal variances between age groups, were run to verify whether or not differences in mean values between compared groups were statistically significant (*P*<0.05).

Variable	Difference in %	Df	*t*-value	*P*-value
Short-term study				
1-10 years *vs.* 11-20 years	-9.5	18	-6.52	≤0.001
11-20 years *vs.* 21-30 years	-50.0	26	-10.18	≤0.001
21-30 years *vs.* 31-40 years	22.0	48	3.53	0.001
31-40 years *vs.* 41-50 years	7.1	8	0.58	0.581
41-50 years *vs.* 51-60 years	-27.9	2	-1.14	0.371
Short-term *vs.* long-term overlap				
Short-term *vs.* long-term (31-40 years)	-1.0	9	-0.11	0.913
Short-term *vs.* long-term (41-50 years)	5.9	9	0.45	0.661
Young age groups *vs.* old stands				
1-10 years *vs.* 100+ years	-43.2	75	-13.31	≤0.001
11-20 years *vs.* 100+ years	-33.5	93	-9.36	≤0.001
21-30 years *vs.* 100+ years	16.5	45	2.89	0.006
31-40 years *vs.* 100+ years	-5.4	71	-1.04	0.300
41-50 years *vs.* 100+ years	-12.6	7	-1.05	0.329

Table 3. Test statistics for analysis of differences in distributions between age groups for Jack Pine stands. Mann-Whitney tests were run to verify whether or not differences in distributions between compared groups were statistically significant (*P*<0.05) at a confidence level of 95.0. The difference in % is calculated from values of mean percentage cover in Table 1.

Variable	Difference in %	W	*P*-value
Long-term *vs.* intermediate			
31-40 years *vs.* 40-50 years	14.0	91.5	0.166
31-40 years *vs.* 50-60 years	8.7	323.0	0.268
31-40 years *vs.* 60-70 years	21.8	286.0	0.024
31-40 years *vs.* 70-80 years	15.1	173.5	0.121
31-40 years *vs.* 80-90 years	22.2	111.5	0.032

Cover of preferred lichen species

Cladina mitis was the most abundant species in all age groups for upland Jack Pine plots in both the short-term (Table 4) and the long-term (Figure 3) data sets. *Cladina rangiferina* and *C. stellaris* were generally recorded at higher percent covers in old stands, both in Jack Pine and spruce plots (Figures 3 and 4). Neither of these two species were abundant in the younger age groups (Table 4).

The covers of *C. rangiferina* and *C. stellaris* were very low, even for older (>100 years) stands (Table 4), therefore comparisons between young and older plots were conducted using all three preferred species combined. The 11-21 years age group had significantly lower cover of preferred species than did older plots (Mann-Whitney test, *P*≤0.001) (Table 5). The other young age groups (21-50 years old) showed no significant difference in preferred lichen cover compared with the older stands (Mann-Whitney test, *P*>0.05). Jack Pine stands older than 100 years had a significantly higher cover of *C. mitis* than spruce stands (Mann-Whitney test, *P*≤0.001), and a slightly, but significant, higher cover of *C. stellaris* than spruce stands (Mann-Whitney test, *P*=0.019). There were no significant differences in covers of *C. rangiferina* between these two habitat types (Mann-Whitney test, *P*>0.05) (Table 5).

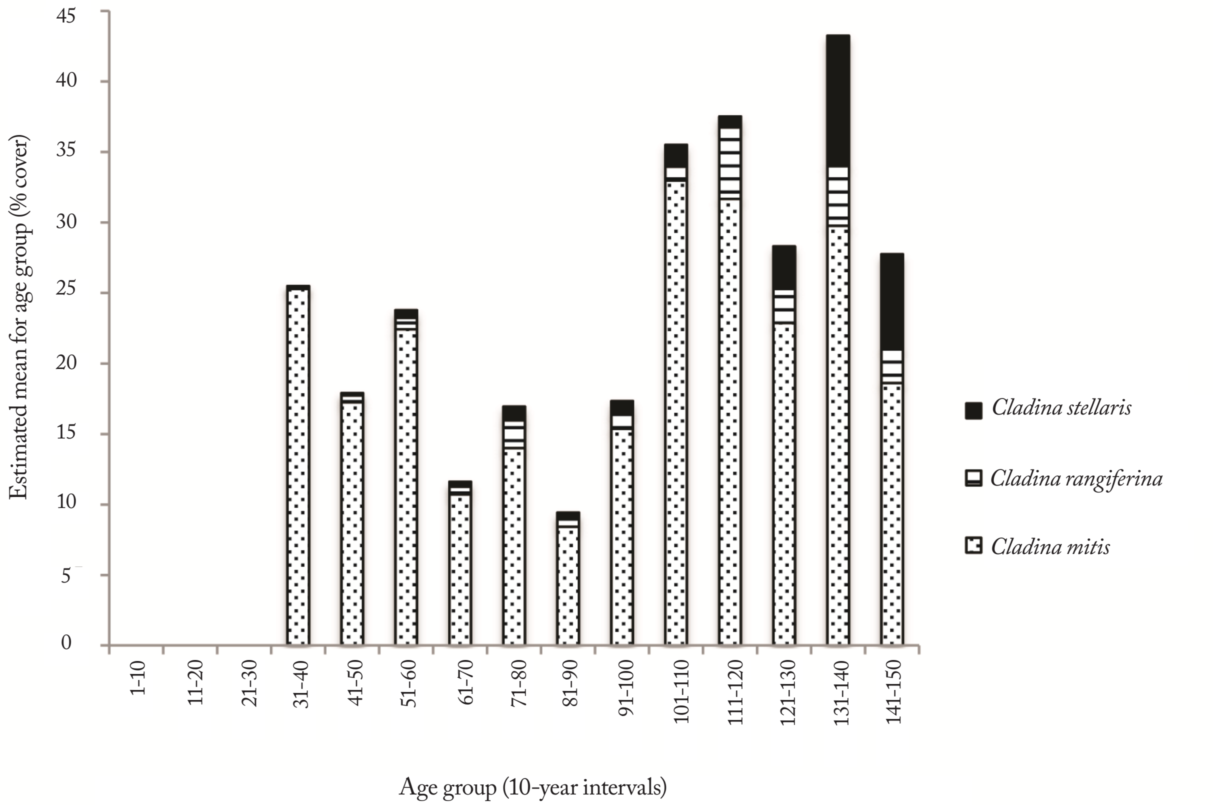

Figure 3. Relationship between minimum stand age and average cover of three preferred Woodland Caribou forage lichen species at 263 Jack Pine long-term study sites in the Boreal Shield of Northern Saskatchewan, Canada.

Table 4. Summary of mean cover (%) of preferred Woodland Caribou lichen species for each of the age groups in Jack Pine plots in the short-term study as well as for the old mature Jack Pine and spruce plots (100+ years old) in the long-term study.

		Cladina mitis		*Cladina rangiferina*		*Cladina* ***stellaris***	
Age group (years)	*n*	%	SE	%	SE	*n*	%
1-10	20	0.0	0.0	0.0	0.0	0.0	0.0
11-20	19	3.2	1.2	0.0	0.0	0.0	0.0
21-30	23	39.8	4.6	0.0	0.0	0.0	0.0
31-40	32	28.8	3.7	0.0	0.0	0.0	0.0
41-50	7	17.1	10.8	1.0	1.0	4.3	4.3
Jack Pine (100+)	76	28.3	3.0	2.7	0.7	4.6	1.3
Spruce (100+)	59	8.7	2.0	1.4	0.6	3.3	1.1

DISCUSSION

The rate at which lichens recover after fire in northern Saskatchewan Jack Pine stands is faster than observed in similar studies at northern latitudes (Morneau and Payette 1989; Arsenault *et al.* 1997; Coxson and Marsh 2001; Joly *et al.* 2003, 2010). The establishment and increase of lichen following wild fires in our study followed a similar pattern as reported for Alaska's taiga (Joly *et al.* 2003, 2010; Collins *et al.* 2011), in that there was a delay in recovery immediately following fire. The delay in the Alaska studies however, was much longer at 60 to 70 years as opposed to 21-30 years for our study.

Table 5. Test statistics for analysis of differences in cover of preferred lichen species between age groups. Mann-Whitney tests were run to verify whether or not differences in distributions between compared groups were statistically significant ($P<0.05$) at a confidence level of 95.0. The difference in % is calculated from values of mean percentage cover in Table 4. Tests for the 1-10 years could not be completed because all values were zero.

Variable	Difference in %	W	*P*-value
Young age groups *vs.* old stands			
1-10 years *vs.* 100$^+$ years	-35.5	-	-
11-20 years *vs.* 100$^+$ years	-32.2	391.0	≤0.001
21-30 years *vs.* 100$^+$ years	7.2	1320.0	0.162
31-40 years *vs.* 100$^+$ years	-5.5	1647.5	0.518
41-50 years *vs.* 100$^+$ years	-11.2	250.0	0.476
Jack Pine *vs.* spruce (100$^+$ years)			
Cladina mitis	19.6	6306.0	≤0.001
C. rangiferina	1.3	5554.0	0.087
C. stellaris	1.4	5672.5	0.019

Although Carol and Bliss (1982) observed that, in Northern Saskatchewan, a *Cladina mitis*-dominated lichen mat developed within <40-50 years post fire, it is not stated at which rate, and within what time frame *C. mitis* became dominant. Therefore it is not possible to draw any detailed conclusions from this study as to when lichen cover may have recovered.

It is noteworthy that one of the preferred caribou forage species (*C. mitis*) recovers with very high cover as early as 21-30 years post fire. The reason for the faster recovery rate in our study area is unknown, but could be due to difference in productivity for lichen in the Boreal Shield of Saskatchewan compared to the higher latitudes of Alaska and Northwest Territories, facilitating a faster establishment rate. In Quebec, Morneau and Payette (1989) reported an earlier initial recovery of lichen species, where several *Cladonia* and *Cladina* species were present 14 years after fire. However, this study found it took 65 years for lichen to reach maximum cover.

The bimodal pattern of a sharp increase in lichen cover after wildfire with a temporary reduction in cover in mid-seral stages (50 to 100 years), followed by a second increase in older upland pine stands (>100 years) may be explained by the nature of vegetation growth following wild fires in general. In the first years after fire, the tree canopy is relatively open, which is beneficial for lichen since they require sunlight and are tolerant to dry conditions (Sulyma and Coxson 2001). The success of lichens in early stand succession after fire is associated with the harsh conditions suitable for lichens, which can extract nutrients from rocks and soil that are unavailable to plants (Uotila *et al.* 2005). As Jack Pine trees increase in height and foliar cover with stand age, the density of the forest canopy increases. This causes increased levels of shading and consequently increased moisture availability resulting from reduced incident solar radiation. This in turn causes a shift from lichens to feather moss on the forest floor (Pharo and Vitt 2000; Sulyma and Coxson 2001). In northern Saskatchewan, upland Jack Pine stands that escape burning for 80$^+$ years either experience a subsequent self-thinning in predominantly well drained soils, or, in less well drained soils, succeed to a spruce-dominated habitat (Carroll and Bliss 1982). Self-thinning appears to create competition conditions more favorable for lichen than for mosses because more light becomes available and microclimate gets drier. Lichens like *C. mitis* also have a competitive advantage on soils that are well drained (Brodo *et al.* 2001). This likely explains the second increase of lichen cover after 100 years post fire. A study from the northern limit of the boreal forest also showed that, in open forest, lichens were able to maintain dominance in the absence of disturbance (Morneau and Payette 1989). The stands that succeed to spruce tend to have a denser canopy (Carroll and Bliss 1982), and a resulting development of shrubs such as Labrador Tea. The denser canopy along with less well-drained soil may explain the lower average lichen cover in Black Spruce-dominated stands *vs.* Jack Pine-dominated stands (Figures 3 and 4).

Our findings that *C. mitis* is the dominant lichen species in early stages post fire, and that *C. rangiferina* and then *C. stellaris* appear at later stages, are supported by other studies (Carrol and Bliss 1982; Morneau and Payette 1989). Morneau and Payette (1989) documented the same trend although with a somewhat later peak of *C. mitis*. They also observed maximum cover for *C. mitis* at approximately 40%. Carrol and Bliss (1982) also noted that *C. rangiferina* and *C. stellaris* become established and may achieve high cover in spruce co-dominated stands more than 80 years old.

There are, however, several factors other than lichen percent cover which may be of importance in terms of caribou use of an area such as lichen mat thickness (Carroll and Bliss 1982) and lichen biomass (Thomas and Kiliaan 1998; Dunford *et al.* 2006;

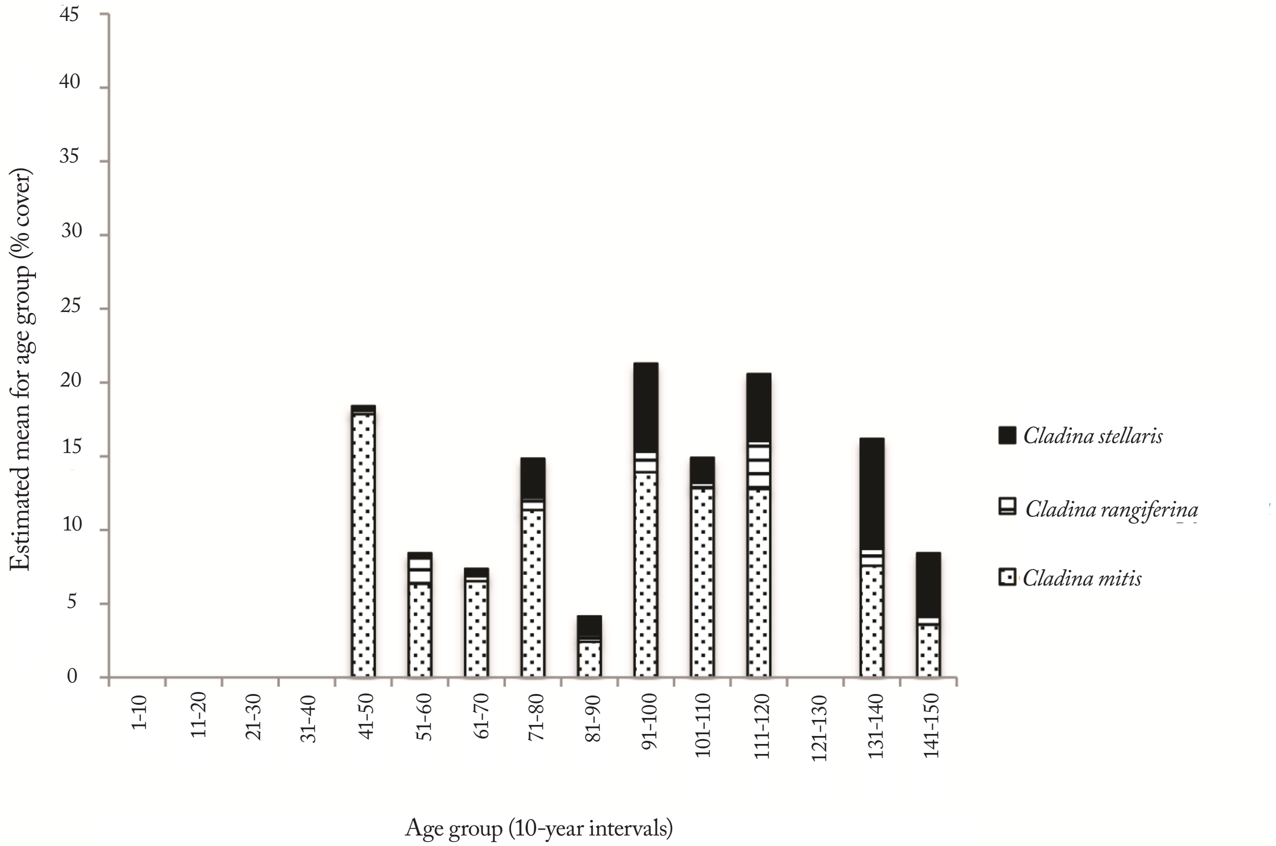

Figure 4. Relationship between minimum stand age and average cover of three preferred Woodland Caribou forage lichen species at 136 upland spruce long-term study sites in the Boreal Shield of Northern Saskatchewan, Canada.

Collins *et al.* 2011; Barrier and Johnson 2012), as they play an important role for caribou foraging behavior. Lichen mat thickness is shown to increase gradually with age (Carroll and Bliss 1982). It is therefore likely that mat thickness may be lower in the first peak (21-30 years post fire) compared to the second peak (around 101-110 years post fire) even though the percentage lichen cover is similar. However, Thomas and Kiliaan (1998), Dunford *et al.* (2006) and Collins *et al.* (2011) documented linear relationships between percentage cover and biomass. We therefore conclude that information on percentage cover is generally appropriate also to make predictions about forage supply for caribou.

Other factors affecting caribou use of young forest may include increased accumulations of snow and deadfall reducing ease of movement and/or forage accessibility (Metsaranta and Mallory 2007); and increased cover of deciduous species resulting in increased Moose (*Alces alces*) and consequently Gray Wolf (*Canis lupus*) populations (Bergerud and Elliot 1986; Seip 1992; Joly *et al.* 2012). In addition, higher stem density/hiding cover may reduce use of young stands by caribou as they tend to choose areas with low visual obstruction from which they can see approaching predators (Pinard *et al.* 2012).

An ongoing telemetry-based study on habitat use by Woodland Caribou in the same region will ultimately address some of these factors, and provide answers related to use and avoidance of these young stands. Based on lichen cover alone, however, our results show that Jack Pine stands as young as 21-30 years may be more suitable for Woodland Caribou than intermediate aged habitat. Therefore our findings indicate that young stands in combination with old stands may play a more important role sustaining Woodland Caribou in the Boreal Shield of Saskatchewan than do intermediate stands from 50 to 100 years old.

MANAGEMENT CONSIDERATIONS

There are two major management-related findings of this study. First, based on lichen cover, areas younger than 40 years old may be more suitable for forage intake than areas with intermediate ages since fire (50 to 100 years). In a region with such a high percentage of areas burned that are less than 40 years of age (55% according to Environment Canada 2012), this amount of relatively young habitat may not have the same additive negative impact ('fire + buffered anthropogenic') on caribou that has been modeled by Environment Canada (2012). The western Boreal Shield has historically been an area with high fire intensity, therefore caribou in the region are likely well-adapted to this fire regime, and our results offer some insight into how caribou populations have persisted in this region for several thousand years.

Second, the later increase of lichen cover at 100+ years post fire likely comprises optimal habitat for Woodland Caribou containing a greater diversity of preferred lichen species. Our evidence supporting a bi-modal pattern of lichen recovery in Jack Pine stands after fire may have significance for Woodland Caribou management and the delineation of critical habitat in the Boreal Shield of Saskatchewan. Because lichen is recovering more quickly in upland topography, this may provide an opportunity for caribou to utilize a mix of younger and older habitats. It may therefore be more appropriate to include two phases of caribou habitat availability in models, rather than using a single threshold after which habitat is deemed suitable.

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