# TOWARDS AN UNDERSTANDING OF THE MANAGEMENT OF PINE-LICHEN WOODLANDS IN THE OMINECA REGION OF BRITISH COLUMBIA

by Randall G. Sulyma, R.P.F. B.S.F. University of British Columbia, 1991

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#### ABSTRACT

In the Omineca region of British Columbia, forest companies have traditionally overlooked the use of pine-lichen woodlands, primarily because of the low economic value of timber in them. These woodlands are now facing increased harvesting pressure as sources of wood fibre become more valuable. They also provide important winter habitat for northern caribou (*Rangifer tarandus* Linnaeus) that range in the area. Caribou use pine-lichen stands that are 70 to 140 years old because they provide a source of high value forage. A recent understanding of the successional trend of pine-lichen woodlands in the area has been developed by Coxson et al. (1999) who noted that pine-lichen woodlands succeed to a feather moss phase beyond 140 years of age. This thesis examines the functional aspects of forest characteristics as they relate to the succession process and the forest management of these stands.

The characteristics of the microclimate at the forest floor strongly influence which plants can exist there. Lichens predominate when the microclimate precludes the development of pleurocarpous mosses and vascular plants. This relationship was assessed by evaluating how stand structure influenced irradiance on the forest floor. Stand architecture variables (basal area, volume and biomass) were evaluated and related to leaf area index values. Plots with a component of feather moss had higher values for leaf area index and all stand characterization variables compared to those plots without it. Organic accumulations were also found to be higher on microsites where feather moss was present.

The evaluation of stand characterization variables provided guidance for using a geographic information system to identify pine-lichen woodlands on the landscape. A relatively high level of success (68% accuracy) was attained by querying forest cover and terrain mapping

for the location of pine lichen woodlands. Variables assessed were the leading tree species, the composition of the leading species, site index and aspect. Combining this classification with the concepts of succession, forecasts regarding the availability of pine-lichen woodlands into the future were made. The forecasts are dynamic outcomes relative to the management regimes that are applied to the landscape. Two separate models were run to express contrasting results of managing lichen woodlands. Regardless of the model applied, a decrease in the abundance of pine-lichen woodlands in a favourable state for foraging was evident over the next 90-year period. Applying different management strategies, however, can reduce the duration when this abundance is low.

A retrospective study of cut-blocks in pine-lichen woodlands was conducted to identify general trends of lichen recovery after mechanical disturbance. On sites with well-drained sand soils, terrestrial lichens recovered to >40% cover 20 years after harvesting. The rapid rate of recovery is speculated to be a function of creating favourable microclimate conditions for the lichens and for providing a lichen dispersal mechanism that is not existent under a natural disturbance process. The results of the retrospective study lead us to believe that a subset of terrestrial lichen sites in the Omineca region may be more resilient to forest harvesting than is currently recognised.

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In memory of Lau Christensen

#### **CHAPTER 1 - INTRODUCTION**

Terrestrial lichens express dominance on sites influenced by extreme environmental conditions where other forms of vegetation are unsuccessful. They are able to survive in harsh environments because they are adapted well for persisting through periods of heat stress yet are able to re-hydrate and photosynthesize in a very short period of time (Lechowicz & Adams 1973, Tegler & Kershaw 1980, 1981). Unlike most other forms of vegetation, lichens do not have roots, thus they gather all required resources from the atmosphere (Rowe 1984). This trait enables lichens to colonise on substrates that are unfavourable for other forms of vegetation. Regarding a direct relationship with the growing substrate, lichens simply require a suitable microsite to anchor.

Though lichens can survive with limited resources, their ability to compete is very poor. Thus, if conditions are present that can support bryophyte or vascular plant communities, lichen presence is quickly minimised. Crawley (1997) identified that a plant's distribution in the field can be viewed as a refuge from competitors or enemies, rather than a place that provides the plant with the optimal conditions to grow. This concept holds very true for defining the ecological niche of terrestrial lichens. They are generally present on a site not because they outcompete other forms of vegetation, but because other forms of vegetation cannot persist under the harsh environmental conditions that lichens can.

The niche that lichens dominate is very susceptible to change and has been the subject of many successional studies (Brulisauer et al. 1996, Carroll & Bliss 1982, Coxson et al. 1999, Johnson 1981, Maikawa & Kershaw 1976, Morneau & Payette 1988, Oksanen 1986, Payette et

al. 2000). Across Canada, this niche is often characterised by forest stands that are influenced by a continental climate and are dominated by pine (*Pinus Contorta* Dougl. *ex* Loud. or *P. banksiana* Lamb.) or spruce (*Picea mariana* (P. Mill.) B.S.P.) forest overstoreys (Ahti 1977, Johnson 1981). The soils of these sites tend to be coarse textured and the stands are generally initiated by wildfire. The sites traverse a successional pattern resulting in a reindeer lichen phase (dominated by *Cladina* spp.) that exists between 70 and 150 years (Carroll & Bliss 1982, Coxson et al. 1999, Maikawa & Kershaw 1976). Beyond 150 years, the seral development has varying outcomes depending on the region where the site is situated. In the Omineca region of north-central British Columbia, Coxson et al. (1999) documented a chronosequence of lichen woodlands that culminates in a plant community dominated by feather moss mats.

The succession trend resulting in a feather moss climax raises concerns when considering the importance of terrestrial lichen as a source of forage for northern caribou. If these sites are left untouched as in a preservation approach, indications are that lichen abundance will decline. In turn, it is often recognized that some form of disturbance must be applied to the landscape to promote the rejuvenation of terrestrial lichen communities. Currently, the most significant form of disturbance on the landscape is forest harvesting.

The history of forest companies harvesting trees from pine-lichen woodlands is limited. Though companies have been active in the Omineca region since the mid 1970's (P. Valk, pers. comm.), initial harvesting was in the higher value stands of white spruce (*Picea glauca* (Moench) Voss) and lodgepole pine. Harvesting the low volume, poor growing sites of pinelichen woodlands did not exist due to economics and operability constraints. In recent years, however, the technology related to both harvesting and processing of timber has improved. Once undesirable stands are now considered an important source of fibre, thus, the area of pinelichen woodlands being harvested is increasing.

The lack of past forestry activities in pine-lichen woodlands has helped maintain the availability of management options that can be conducted in them. The current demand for fibre sources, however, has increased the demand for information on these ecosystems. If resource managers can develop an understanding of the environmental conditions required for a lichen community to be successful, it may be possible to develop strategies that ensure the retention of lichen woodlands on the landscape. Forestry activities may provide the means of creating the desired conditions. Prior to proposing management strategies, however, the various factors necessary for the success of terrestrial lichen must be understood.

In this thesis, I assess stand level factors as they relate to the succession of lichen sites in the Omineca. Specifically, I compared the development of the forest overstorey between lichendominated and moss-dominated microsites, as well as the composition of the surface organic mat between selected microsites. Information from the stand structure of lichen woodlands was then utilised in a geographic information system (GIS) as a tool for identifying their location on the landscape. Results from GIS queries were applied in a time step modelling process to forecast the presence of terrestrial lichen communities taking succession into consideration.

The role of wildfire as the primary disturbance agent on the landscape is currently being replaced by forest harvesting. In general, forestry is considered detrimental to terrestrial lichen because activities can reduce the abundance of them immediately after harvesting. This relationship, however, is poorly understood (Stevenson 1991) and damage may only have a short term effect (Webb 1998, Woodard 1995). In fact, some sites may benefit from mechanical

treatments, especially when they contain lichen species that rely on fragmentation as a reproduction technique (Harris 1996, Webb 1998). Findings from a retrospective study in the Omineca region support the proposition that lichen woodlands on coarse textured soils may be more resilient to mechanical disturbances than is currently believed by resource managers throughout British Columbia.

# CHAPTER 2 - MICROSITE REPLACEMENT OF TERRESTRIAL LICHENS BY FEATHER MOSS MATS IN LATE SERAL PINE-LICHEN WOODLANDS OF NORTH-CENTRAL BRITISH COLUMBIA<sup>1</sup>

#### **SUMMARY**

Pine-lichen woodlands in north-central British Columbia show a long period of successional development where reindeer lichens (comprised of predominantly *Cladina spp.*) dominate plant cover at the forest floor surface. In mid- to late-successional stands, however, lichen cover is replaced in a mosaic of surface microsites by feather moss mats (largely Pleurozium schreberi (Brid.) Mitt.), with moss mats often burying lichen mats that previously had occupied these microsites. We compared moss- and lichen-dominated microsites at this stage of stand development, looking at the influence of canopy structural variables and development of forest floor plant communities on microsite expression. Microsites with high feather moss mat cover had greater canopy leaf area index values, compared to microsites where lichen cover predominated. Leaf area index values were highly correlated with stand level structural variables, including basal area, total volume, and biomass of the dominant canopy tree species, lodgepole pine (Pinus Contorta Dougl. ex Loud.). Changes in stand architecture were further associated with the accumulation of litter and organic matter at the forest floor surface. These factors suggest that the manipulation of stand structure in managed forests, for instance through partial-cut harvesting, may delay successional changes and promote continued lichen growth in these forest types. This is an important consideration in the management of pine-

<sup>&</sup>lt;sup>1</sup>Chapter has been accepted for publication as: R. Sulyma and D.S. Coxson.

stands in northern BC, where lichen mats provide significant forage values for caribou populations.

## **INTRODUCTION**

Lichen woodlands dominate coniferous forests across large areas of northern Canada (Kershaw 1978). These woodlands are typically characterized by a post-fire seral sequence where mat-forming lichen communities at the forest floor surface are replaced by feather moss mat dominated communities late in stand life. Within pine-lichen forests of Western Canada, reindeer lichens are most prolific in 80 to 100 year old lodgepole pine stands (Johnson 1981, Rowe 1984, Stevenson 1991). This stage, in absence of stand destroying fires, is followed by a feather moss-dominated stage, which occurs approximately 150 years after a stand initiation (Carroll & Bliss 1982, Maikawa and Kershaw 1976, Payette et al. 2000).

The shift between a lichen-dominated mid-seral stage and a moss-dominated late-seral stage is often associated with stand characteristics at a site (Brulisauer et al. 1996, Johnson 1981, Lesica et al. 1991, Maikawa & Kershaw 1976). Among factors that have been postulated as important in this respect are increased levels of shading and resultant changes in moisture availability that result from reduced incident solar radiation at the forest floor surface (Johnson 1981, Lesica et al. 1991). This has been expressed in general terms as a reference to crown closure increasing as a stand ages, which creates shaded conditions more suitable for feather moss to become established (Carroll and Bliss 1982, Maikawa and Kershaw 1976).

These same trends occur in pine-lichen woodlands of north-central British Columbia (Coxson et al. 1999, Coxson & Marsh 2001). However, the reference to crown closure does not appear to adequately describe the functional components that influence the transition from lichen to moss-dominated ground cover in these sites. This is primarily based on the reasoning that crown closure of pine stands occurs long before forest floor lichen communities shift to a feather moss-dominated stage (Farnden 1996). The processes involved appear to be complex, involving overall stand development, particularly changes in total tree biomass. Recent findings by Pharo and Vitt (2000) further point to the role of stochastic events in determining the development of bryophyte and macro-lichen cover in local microsites.

We characterized spatial distribution of reindeer lichens and feather moss mats (comprised predominantly of *Pleurozium schreberi* (Brid.) Mitt.) within canopy gaps in latesuccessional pine-lichen woodlands from the Omineca region of north-central British Columbia, correlating changes in the relative cover of lichens and mosses with changes in overstorey forest canopy structure and biomass. These factors have recently assumed greater significance to forest managers, as attempts are made to extend the duration of lichen-dominated successional phases within managed pine forests to provide forage for caribou populations (Harris 1996, Racey et al. 1996, Rosso & Rosentreter 1999).

## MATERIALS AND METHODS

#### Study Area

Pine-lichen woodlands were located in an area 300 km northwest of Prince George, BC, in the vicinity of Germansen Lake (Figure 2.1). This area falls within the Omineca River watershed and is in the boreal white and black spruce (BWBS) biogeoclimatic zone. The chosen



Figure 2.1. Stand sampling areas in the Omineca study area.

sites fall under a dry cool variant of the BWBS biogeoclimatic zone identified as the dk1 (Meidinger and Pojar 1991).

In the Omineca region, the BWBS zone is found from valley bottoms up to 1100 m elevation in an area roughly north of 54° N latitude (Meidinger and Pojar 1991). Characterized by a northern continental climate, the zone has long cold winters and a short growing season. Average monthly temperatures remain below 0°C for 5-7 months of the year and rise above 10°C for only 2 to 4 months of the year. July is the warmest month with a mean summer temperature of 13.0° C (Anonymous 1993). Between 330 and 570 mm of precipitation falls annually, 35 to 55 percent of this falling as snow.

Study sites in pine-lichen woodlands were chosen to represent stands at a similar stage of late successional development, from 100 to 130 years in age, where the forest floor surface was dominated by terrestrial lichen mats, predominantly *Cladina mitis* (Sandst.) Hustich and *C. rangiferina* (L.) Nyl. Stands were labelled as West Germansen, Germansen Lake, and Manson. Terrain at the West Germansen and Manson sites was flat-uniform, while terrain at the Germansen Lake site was slightly more variable ranging from flat-uniform to slightly rolling.

## Methods

Measurements within pine-lichen woodlands were taken at 2 different scales. Stand-level plot measurements were conducted within  $625 \text{-m}^2$  plots that were centred on a candidate canopy gap within the stand as outlined in Figure 2.2. Within this canopy gap, detailed microsite plot measurements were taken, using  $1\text{-m}^2$  quadrats located within the perimeter of a canopy gap (Figure 2.2).



Figure 2.2. Layout of stand sampling protocol. Top, stand sampling area centred on canopy gap; bottom, detailed location of sample plots within canopy gap.

A total of 30 stand-level plots were established in natural gaps within the pine-lichen woodland, 10 at each study site (Table 2.1). These gaps result from self-thinning during the first century of stand development. Five of the stand-level plots at each site were selected based on the dominant expression of reindeer lichens at the forest floor surface and 5 were selected based on the dominant expression of feather moss mats. A quick assessment was conducted to determine if moss-dominated microsites had the potential to support lichens. This was done by looking for remnant or buried lichen mats within or under existing moss mats.

Microsite plots were established within each canopy gap, these centred within the standlevel plots as outlined in Figure 2.2. This allowed for the detailed characterization of forest floor plant communities within canopy gaps and of surrounding canopy structure within the stand. A systematic format of data collection was employed. The stages involved were:

1) laying out the nested design within the stand-level plots;

2) obtaining percent cover measurements within all microsite plots based on estimation within the following categories: *Cladina* spp, i.e. reindeer lichens; foliose lichens, e.g. *Peltigera* spp.; other lichens; feather moss mats, predominately *Pleurozium schreberi* (Brid.) Mitt.; other mosses; mineral soil; rock; coarse woody debris; litter; and forbs. Although these categories for the estimation of non-vascular plant cover are based on morphology, in many ways these groups, particularly the differentiation between "reindeer lichens" and feather-moss mats, act as functional groups in that they delineate mid- and late-seral successional stages within these stands (Coxson and Marsh 2001);

3) measuring the presence or absence of all vascular and selected non-vascular (macro-lichens, mosses and liverworts only) plant species within randomly selected microsite plots;

		Latitude			Stand Ages					
Site	Longitude		Elevation	Plot type	Oldest	Mean	(D)			
					Tree	Age	SD	n		
West Company Sites	125° 06' 50"	55° 38' 55"	1120 m	Lichen	153	119	10	100		
West Germansen Sites				Moss	147	121	6	100		
		55° 42' 05"		Lichen	150	117	3	100		
Manson Sites	124° 34' 00"		955 m	Moss	154	114	4	100		
	124° 56' 53"	55° 40' 50"	1045 m	Lichen	160	113	2	100		
Germansen Lake Site				Moss	146	114	12	100		

Table 2.1. Plot locations in the Omineca region of north-central British Columbia.

4) measuring tree density in all 4 quarters of the stand-level plots and obtaining detailed measurements of other tree parameters (basal area, tree volume, tree biomass, crown biomass, and crown area) within the south quarter of stand-level plots (the south side of each plot location having the greatest influence on direct light interception within the canopy gap);
5) sampling randomly chosen microsite plots for organic matter accumulation, separated by aboveground components (the cumulative biomass of lichens, acrocarpous moss and litter) and below-ground components (humus accumulation) including all litter, above the mineral soil horizon; and

6) measuring leaf area index in all microsite plots.

This sampling protocol ensured that vegetation cover estimates were obtained prior to other stand-level measures being taken, thereby minimizing disturbance effects on surface vegetation.

Detailed assessments in the stand-level plots were conducted using standard forest mensuration techniques to collect tree data (Husch et al. 1993). Qualitative assessments on tree form and overall health were also recorded. A subset of 20 stems, based on the 10 largest and another 10 chosen from a range of diameter classes, was selected to determine the age of each stand plot. Core samples were taken at stump height (0.30-m) and rings were counted in the field. A correction factor of seven years was applied to determine total age, based on comparisons with trees destructively sampled at the forest floor surface. Tree volumes were subsequently calculated using the volume equations in the Forestry Handbook (Watts 1983). Biomass figures were determined using equations derived by Standish et al. (1985) and crown area was determined using equations from Cade (1997). The composition of forest floor plant communities and organic matter accumulation was assessed in a minimum of 10 randomly chosen quadrats for each microsite plot series. Species composition within microsite plots was determined using visual estimates taken within 0.71 x 0.71-m (0.5-m<sup>2</sup>) quadrats nested in the southwest corner of the larger 1-m<sup>2</sup> quadrat. Nomenclature of lichens, mosses, liverworts and vascular plants, respectively, followed Esslinger and Egan (1995), Lawton (1971), Stotler and Crandall-Stotler (1977) and Hitchcock and Cronquist (1973). Voucher specimens for lichens and bryophytes were housed in the University of Northern British Columbia (UNBC) herbarium.

Leaf area index (LAI) was measured in microsite plots using the remote mode procedure of the LAI-2000 (LI-COR inc., Lincoln Neb.) plant canopy analyser. LAI data were collected during time periods when there was no direct radiation on the foliage, under conditions of diffuse overcast sky.

## Data Analysis

Measured values are reported as the mean plus or minus one standard deviation ( $\bar{x} \pm 1$  SD) except for species mean cover values presented in Table 2.1 which are reported as the mean plus or minus one standard error ( $\bar{x} \pm 1$  SE). Treatment effects (moss versus lichen-dominated microsites) were examined by analysis of variance at each stand location. The statistical significance of treatment effects in microsite plots (leaf area index and soil litter/organic matter content) at each stand was examined using paired t-tests. These comparisons are denoted as significant in the text when probability values in any of the stand locations were <0.05. To determine if differences existed with stand characterization variables (which could be correlated to the microsite level), the significance level was set at 0.1. This reduced the probability of a

Type II error resulting from extraneous data in the sample. T-tests were also used to evaluate the significance of correlation coefficients (Fisher 1990).

Leaf area index values were compared between quadrats with <1% percent cover of feather moss versus those with  $\ge 1\%$ . This threshold represents the percent cover that can be clearly expressed through ocular evaluation of quadrats. An index value of moss was derived for each plot based on the coding of moss presence for each quadrat. This code was compared to the average LAI value for each plot. The correlation between the two variables, moss presence code and LAI, indicated the relationship between them.

Not all quadrats within the chosen openings were used in the analysis of leaf area index. Assessment of the raw data indicated that most outlier data points occurred in quadrats that were adjacent to a tree or that had a tree within the quadrat. Tree stems within one metre of the sensor blocked out a large portion of the visible sky but did not accurately represent foliage interceptance cover. In turn, all quadrats around the perimeters of the gaps were dropped. Though the relationship was consistent between the raw data and the data not containing quadrats on the perimeter, the effect was greater where outliers were dropped.

#### RESULTS

The species composition of vascular plants within moss- or lichen-dominated microsites showed little variation between plot types (Table 2.2). Likewise, this consistency was maintained among the three sites, supporting the classification of all three sites into the same plant association. The two exceptions are the presence of *Vaccinium membranaceum* Dougl. *ex* Hook. at the West Germansen site and not at the other two sites and the absence of

		West G	ermansen	Sites	Germar	isen Lake	e Sites	Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover
Vascular Plants										
Arctostaphylos uva-ursi (L.)	lichen	0	0	-	28.6	0.21	0.15	33.3	0.54	0.33
Spreng	moss	0	0	-	27 <b>.9</b>	0.32	0.14	56.8	0.49	0.11
Arnica cordifolia Hook.	lichen	0	0	-	0	0	-	0	0	-
	moss	3.1	0	-	0	0	-	0	0	-
Calamagrostis	lichen	0	0	-	0	0	-	0	0	-
(Michx.) Beauv.	moss	0	0	-	0	0	-	2.7	0	0
Calamagrostis purpurascens R.	lichen	0	0	-	0	0	-	0	0	-
Br.	moss	0	0	-	2.3	0.01	0.01	0	0	-
Cornus canadensis L.	lichen	76.5	0.41	0.12	85.7	0.47	0.27	0	0	-
	moss	87.5	0.86	0.12	65.1	0.37	0.08	13.5	0.07	0.03
Empetrum nigrum L.	lichen	11. <b>8</b>	0.09	0.06	0	0	-	0	0	-
	moss	46.9	1.02	0.3	2.3	0.02	0.02	<b>8</b> .1	0.23	0.19
Epilobium angustifolium L.	lichen	0	0	-	14.3	0.01	0.01	0	0	-
	moss	0	0	-	18.6	0.02	0.01	0	0	-

Table 2.2. Percent frequency occurrence and mean percent cover by species (± 1 SE) in moss-<br/>and lichen-dominated microsite plots at West Germansen, Manson, and Germansen Lake<br/>Sites. Total n for lichen- and moss-dominated microsite plots was 36 and 112<br/>respectively.

		West G	ermansen	Sites	German	isen Lake	Sites	Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover
Geocaulon lividum (Rich)	lichen	0	0	-	0	0	-	16.7	0.04	0.04
rem.	moss	0	0	-	0	0	-	0	0	-
Linnaea borealis L.	lichen	23.5	0.09	0.05	71.4	0.44	0.17	58.3	0.58	0.24
	moss	43.7	0.2	0.05	72.1	0.91	0.23	83.8	0.57	0.12
Lycopodium complanatum	lichen	0	0	-	0	0	-	0	0	-
(L.) Holub	moss	34.4	0.4	0.15	0	0	-	0	0	-
Oryzopsis asperifolia	lichen	5.9	0.01	0.01	14.3	0.07	0.07	16.7	0.05	0.04
Michx.	moss	18.8	0.04	0.02	11.6	0.04	0.02	21.6	0.11	0.04
Oryzopsis punjens (Torr.)	lichen	5.9	0.03	0.03	42.9	0.16	0.1	16.7	0.13	0.09
Hitchc.	moss	3.1	0.02	0.02	25.6	0.07	0.02	16.2	0.04	0.02
Pyrola asarifolia Michx.	lichen	5.9	0.06	0.06	0	0	-	0	0	-
	moss	3.1	0.02	0.02	2.3	0.01	0.01	0	0	-
<i>Pyrola secunda</i> L.	lichen	0	0	-	0	0	-	0	0	-
	moss	3.1	0	0	0	0	-	0	0	-
<i>Rosa acicularis</i> Lindl.	lichen	0	0	-	28.6	0.16	0.14	8.3	0.01	0.01
	moss	9.4	0.07	0.06	27.9	0.15	0.1	8.1	0.01	0

# Table 2.2. Continued

		West Germansen Sites			German	isen Lake	Sites	Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent	Mean percent cover	SE of cover
Vaccinium caespitosum	lichen	88.2	0.65	0.16	0	0	-	16.7	0.08	0.06
Michx.	moss	84.4	1.66	0.45	9.3	0.06	0.05	2.7	0.01	0.01
Vaccinium membranaceum	lichen	41.2	0.28	0.13	0	0	-	0	0	-
Dougl. <i>ex</i> Hook.	moss	59.4	0.45	0.1	0	0	-	0	0	-
Vaccinium vitis-idaea L.	lichen	0	0	-	100	0.39	0.07	66.7	1.71	0.97
	moss	0	0	-	90.7	0.93	0.13	78.4	1.03	0.23
Non-vascular Pla	nts				·					
Barbilophozia lycopodioides	lichen	52.9	0.19	0.06	100	0.34	0.13	83.3	1.25	0.43
(Wallr.) Loeske	moss	56.3	5.82	2.82	53.5	0.17	0.04	64.9	0.45	0.09
Cetraria cucullata (Bell.)	lichen	0	0	-	0	0	-	8.3	0.01	0.01
Ach.	moss	0	0	-	4.7	0	0	13.5	0.04	0.02
Cetraria ericetorum Opiz	lichen	94.1	0.42	0.04	85.7	0.2	0.08	91.7	0.46	0.04
	moss	40.6	0.14	0.04	27.9	0.17	0.12	86.5	0.41	0.04
Cetraria nivalis (L.) Ach.	lichen	0	0	-	0	0	-	8.3	0.01	0.01
	moss	6.3	0.03	0.02	2.3	0	0	2.7	0	0
<i>Cladina mitis</i> (Sandst.) Hustich	lichen	100	21 <b>.9</b> 4	3.98	100	9.71	2.13	91.7	6.08	0.79
	moss	68.8	3.23	0.96	97.7	8.24	1.48	100	5 <b>.8</b> 7	1.03

		West Germansen Sites			Germar	nsen Lake	e Sites	Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover
Cladina rangiferina (L.)	lichen	70.6	2.04	0.55	85.7	1.09	0.41	91.7	2.92	0.9
Nyl.	moss	81.3	4.33	0.88	83.7	2.5	0.7	100	2.46	0.44
Cladina stellaris (Opiz)	lichen	0	0	-	0	0	-	0	0	-
Brodo	moss	9.4	0.23	0.17	2.3	0.05	0.05	0	0	-
Cladonia bellidiflora	lichen	0	0	-	0	0	-	0	0	-
(Ach.) Schaer.	moss	18.8	0.08	0.03	0	0	-	0	0	-
Cladonia borealis Stenroos	lichen	5.9	0.03	0.03	0	0	-	0	0	-
	moss	9.4	0.02	0.02	0	0	-	0	0	-
Cladonia carneola (Fr.) Fr.	lichen	41.2	0.11	0.05	14.3	0.01	0.01	8.3	0.04	0.04
	moss	18.8	0.05	0.03	4.7	0	0	5.4	0.02	0.01
Cladonia cenotea (Ach.)	lichen	5.9	0.01	0.01	0	0	-	16.7	0.05	0.04
Schaer.	moss	6.3	0.01	0	2.3	0	0	8.1	0.02	0.01
<i>Cladonia</i> <i>cervicornis</i> subsp. <i>Vericillata</i> (Hoffm.) Schaer	lichen	29.4	0.08	0.04	14.3	0.01	0.01	33.3	0.1	0.06
	moss	12.5	0.04	0.02	7	0.01	0	13.5	0.04	0.02
Cladonia chlorophaea	lichen	35.3	0.11	0.05	28.6	0.03	0.02	33.3	0.17	0.07
(somm.) spreng.	moss	31.3	0.09	0.03	18.6	0.02	0.01	40.5	0.13	0.03

		West Germansen Sites			Germar	nsen Lake	e Sites	Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover
Cladonia cornuta (L.)	lichen	76.5	0.29	0.06	71.4	0.24	0.09	91.7	0.43	0.05
Hoffm.	moss	53.1	0.18	0.04	62.8	0.18	0.03	86.5	0.36	0.03
Cladonia crispata (Ach.)	lichen	47.1	0.19	0.07	71.4	0.31	0.14	58.3	0.27	0.09
Flot.	moss	46.9	0.55	0.23	37.2	0.12	0.03	56.8	0.23	0.04
Cladonia deformis (L.)	lichen	58.8	0.18	0.05	0	0	-	25	0.09	0.06
Hoffm.	moss	25	0.08	0.03	18.6	0.03	0.01	27	0.09	0.03
Cladonia	lichen	100	1.29	0.37	85.7	0.33	0.14	83.3	0.75	0.31
Leight.	moss	78.1	0.46	0.07	62.8	0.22	0.04	83.8	0.37	0.04
Cladonia fimbriata (L.) Fr.	lichen	41.2	0.14	0.05	14.3	0.01	0.01	41.7	0.14	0.06
	moss	21.9	0.06	0.03	0	0	-	40.5	0.13	0.03
Cladonia gracilis (L.)	lichen	0	0	0	28.6	0.09	0.07	16.7	0.05	0.04
Willd.	moss	31.3	0.23	0.08	4.7	0	0	29.7	0.06	0.02
Cladonia multiformis	lichen	5.9	0.01	0.01	0	0	-	0	0	-
Merr.	moss	21.9	0.1	0.04	0	0	-	5.4	0.01	0
Cladonia phyllorophora	lichen	70.6	0.21	0.05	85.7	0.31	0.09	58.3	0.29	0.07
Hoffm.	moss	25	0.09	0.03	32.6	0.11	0.03	51.4	0.19	0.04

		West G	ermansen	Sites	Germar	nsen Lake	e Sites	Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover
Cladonia	lichen	0	0	-	28.6	0.03	0.02	8.3	0.01	0.01
Schaer	moss	21.9	0.08	0.03	7	0.02	0.01	16.2	0.02	0.01
Cladonia pyxidata (L.)	lichen	47.1	0.19	0.06	14.3	0.01	0.01	0	0	-
Hoffm.	moss	12.5	0.03	0.02	0	0	-	10.8	0.01	0.01
Cladonia sulphurina	lichen	64.7	0.21	0.06	28.6	0.14	0.09	25	0.03	0.01
(Michx.) Fr.	moss	34.4	0.25	0.16	18.6	0.02	0.01	32.4	0.11	0.03
Cladonia uncialis (L.)	lichen	47.1	1.5 <b>8</b>	0.7	85.7	1.09	0.67	91.7	0.85	0.39
Wigg.	moss	34.4	0.28	0.13	55.8	0.26	0.07	78.4	0.87	0.24
Dicranum spp.	lichen	82.4	0.69	0.24	85.7	0.51	0.15	75	0.77	0.24
	moss	84.4	4.87	2.16	76.7	0.44	0.07	97.3	1.33	0.27
Nephroma spp.	lichen	5.9	0.01	0.01	14.3	0.43	0.43	0	0	0
	moss	0	0	0	7	0.12	0.1	0	0	0
Pannaria pezizoides	lichen	0	0	0	0	0	0	0	0	0
(G.Web.) Trev.	moss	0	0	0	2.3	0	0	0	0	0
Peltigera aphthosa (L.)	lichen	35.3	0.6	0.47	57.1	1.94	1.68	83.3	1.84	0.74
Willd.	moss	46.9	0.19	0.05	83.7	1.21	0.33	94.6	1.53	0.29

# Table 2.2. Continued

		West Germansen Sites			Germansen Lake Sites			Manson Sites		
Species	Micro plot type	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover	Percent frequency	Mean percent cover	SE of cover
Peltigera malacea (Ach.) Funck	lichen	17.6	0.09	0.06	71.4	1.61	1.26	58.3	1.55	0.84
	moss	28.1	0.22	0.11	55.8	0.45	0.12	45.9	0.84	0.3
<i>Pleurozium schreberi</i> (Brid.) Mitt.	lichen	76.5	0.44	0.13	85.7	0.44	0.12	66.7	0.38	0.11
	moss	90.6	17.46	4.3	100	22.68	3.64	100	16.82	3.32
Pohlia spp.	lichen	58.8	0.29	0.12	14.3	0.01	0.01	16.7	0.08	0.06
	moss	50	0.28	0.07	30.2	0.03	0.01	40.5	0.19	0.04
Polytrichum juniperinum Hedw.	lichen	52.9	0.31	0.12	85.7	0.33	0.14	50	1.04	0.56
	moss	56.3	0.45	0.19	39.5	0.24	0.08	54.1	0.87	0.31
Ptilidium pulcherrimun (G.Web.) Hampe	lichen	0	0	-	0	0	-	0	0	-
	moss	0	0	0	2.3	0	0	0	0	0
<i>Ptilium</i> crista-castrensis (Hedw.) De Not.	lichen	5.9	0.03	0.03	57.1	0.06	0.02	8.3	0.04	0.04
	moss	40.6	0.21	0.07	30.2	0.1	0.05	18.9	0.11	0.04
<i>Stereocaulon</i> alpinum Funck	lichen	52.9	0.39	0.13	71.4	0.26	0.14	41.7	0.18	0.09
	moss	43.8	0.18	0.04	39.5	0.18	0.1	54.1	0.36	0.15

*Arctostaphylos uva-ursi* (L.) Spreng from West Germansen, though it was present at both the other sites. Regarding relationships between moss- and lichen-dominated microsites, *Empetrum nigrum* (L.) was the only vascular plant that expressed a weak trend of higher cover on moss-dominated microsites.

The cover of non-vascular plants and cryptogams also expressed limited variation at the species level when assessed both between different types of microsites and between sites. *Pleurozium schreberi* (Brid.) Mitt. was the only species to express a significant difference in the percent cover between microsite types. Another weak trend was the tendency for higher cover of *Cladonia* spp. at lichen microsites compared to moss microsites. This trend concurs with the successional development of lichen woodlands in the Omineca (Coxson and Marsh 2001).

Table 2.3 lists percent cover estimates by evaluation category. Lichen and litter coverrelated categories expressed consistent trends of higher values at the lichen-dominated microsites. Only moss-related estimates showed trends of higher values in moss-dominated microsites. The Feather Moss group was the sole category to express significant differences between moss- and lichen-dominated microsites.

At all three sites, consistent relationships were found between stand structure and the presence of moss- or lichen-dominated microsites (Table 2.4). Analysis of variance indicates a significant "treatment" effect between moss- or lichen-dominated microsites and canopy structural variables within each stand. At each site, plots with dominant moss cover had significantly higher values for total plot tree basal area, total plot tree volume, total plot tree biomass, and total plot crown biomass compared to lichen-dominated plots. An additional variable that supported this trend was crown area, although, it was found to be significantly

	% Cover by Functional Group										
Site	n	Reindeer Lichens	Other Lichens	Foliose Lichens	Feather Moss	Other Moss	Mineral Soil	Rock	Coarse Woody Debris	Litter	Forbs
West Germansen											
Lichen- Dominated Microsites	88	24.8 ± 17.9	4.6 ± 4.3	$\textbf{0.1} \pm \textbf{0.4}$	0.0	$\textbf{3.0} \pm \textbf{2.9}$	$0.1\pm0.3$	$1.2 \pm 0.3$	3.5 ± 5.5	$\boldsymbol{6.8\pm6.9}$	$4.6\pm5.4$
Moss- Dominated Microsites	167	11.8 ± 12.0	$2.7\pm2.6$	0.4 ± 1.0	$16.5\pm~20.9$	3.1 ± 3.3	0.0	$0.5\pm0.2$	$\textbf{5.06} \pm \textbf{11.2}$	$\textbf{4.2} \pm \textbf{2.9}$	8.1 ± 6.5
Manson Sites											
Lichen- Dominated Microsites	90	12.1 ± 5.7	1.0 ± 0.9	$1.4\pm2.2$	0.2 ± 0.2	1.5 ± 2.2	0.0	$0.2\pm0.5$	1.7 ± 3.0	9.1 ± 5.8	$4.8\pm2.7$
Moss- Dominated Microsites	94	9.6 ± 6.9	1.6 ± 1.5	$2.3\pm2.6$	9.3 ± 11.3	2.6 ± 1.6	$\textbf{0.1} \pm \textbf{0.4}$	$\textbf{0.1} \pm \textbf{0.4}$	$2.1 \pm 3.7$	$6.5\pm2.6$	$4.6\pm2.4$
Germansen Lake Site											
Lichen- Dominated Microsites	92	12.9 ± 5.3	$0.9\pm0.6$	2.5 ± 3.5	$\textbf{0.1} \pm \textbf{0.2}$	<b>1.0</b> ± 1.2	0.0	0.6 ± 1.0	0.3 ± 0.8	7.8 ± 5.8	5.6 ± 2.6
Moss- Dominated Microsites	22	11.5 ± 9.0	0.7 ± 1.3	2.5 ± 2.9	21.8 ± 19.8	2.1 ± 3.4	0.0	1.1 ± 2.2	0.3 ± 1.3	6.6 ± 7.3	4.2 ± 2.6

Table 2.3. Mean percent cover estimates by category (± 1 SD) for moss-dominated and lichen-dominated microsite plots at WestGermansen, Manson, and Germansen Lake sites.
Table 2.4. Mean stand-level plot values (± 1 SD) for basal area, tree volume, tree biomass, crown biomass, and crown area from stand plots centred on gap openings (see Figure 2.2 for layout), these respectively selected for moss presence, denoted as 'Moss' Stand Plots, or for moss absence, denoted as 'Lichen' Stand plots. T values and significance values are shown for T-test comparisons between 'Moss' and 'Lichen' plots; values in parenthesis are n-1 for each stand plot combination.

Plot Variable	Site	'Moss' Plots	'Lichen' plots	Significance Value
Tree Basa	l Area (m²/ha)			
	West Germansen	25.7±2.2	19.7±3.5	T(9)=3.24 P=0.018
	Germansen Lake	31.7±2.8	26.1±5.6	T(9)=2.01 P=0.100
	Manson	32.9±2.3	28.8±4.0	T(9)=1.96 P=0.098
Tree Volu	me (m <sup>3</sup> /ha)			
	West Germansen	160.9±15.0	130.2±23.4	T(9)=2.77 P=0.028
	Germansen Lake	259.3±15.4	209.3±28.3	T(9)=3.48 P=0.013
	Manson	245.9±33.8	209.1±26.6	T(9)=1.91 P=0.097
Tree Bion	nass (kg/m <sup>2</sup> )			
	West Germansen	11.94±0.69	9.15±1.45	T(9)=3.87 P=0.012
	Germansen Lake	16.10± <b>8</b> .27	12.96±2.11	T(9)=3.10 P=0.027
	Manson	15.83±1.53	13.66±1.56	T(9)=2.22 P=0.062
Crown Bi	omass (kg/m²)			
	West Germansen	2.55±0.07	1.89±0.27	T(9)=5.32 P=0.027
	Germansen Lake	2.71±0.17	2.19±0.49	T(9)=2.24 P=0.089
	Manson	2.79±0.14	2.50±0.26	T(9)=2.16 P=0.074
Crown Area (m <sup>2</sup> /m <sup>2</sup> )				
	West Germansen	1.21±0.11	0.9±0.13	T(9)=2.78 P=0.027
	Germansen Lake	1.46±0.22	1.30±0.41	T(9)=0.81 P=0.46
	Manson	1.69±0.16	1.38±0.26	T(9)=2.21 P=0.069

different at only two of the three sites. Consistent trends were observed between stand structural variables and the presence or absence of moss within each of the sampling locations. However, structural variables for both plot types (moss and lichen) were lower at the West Germansen site.

Leaf area index values (direct measurements) showed the same trends as crown area estimates (derived from stand structural values), with higher values in both cases for moss plots (Tables 2.4 and 2.5). Significant relationships, as determined by Pearson correlation coefficients (r), existed between LAI and each of the three stand characterization variables: basal area (r =0.738), tree volume (r = 0.686), and total tree biomass (r = 0.735). T-tests supported the significance of all three correlation coefficients. A significant relationship between the presence of moss and leaf area index values was also found, as represented by a Pearson correlation coefficient of 0.511.

Isopleth plots provided a visual representation of these trends towards higher leaf area index values in moss-dominated quadrats (Figure 2.3). Feather moss quadrats were most abundant in portions of the plot openings protected from solar exposure. In this example, the south portion of the plot was provided greater cover by the adjacent stand than the north half of the plot. This pattern was supported by the LAI contour plot. In general, the location of the feather moss morphological group was found in microsite plots with greatest LAI values.

The assessment of biomass on a subset of intensively sampled quadrats revealed trends similar to the percent cover data. The only statistically significant finding was noted when comparing cover groups that form unfavorable substrates for feather moss establishment, such as rock and coarse woody debris. The biomass of lichens, acrocarpous mosses (i.e. mosses with the sporophyte at the apex of the main stem) and litter was significantly greater for lichen quadrats Table 2.5. Mean microplot values (± 1 SD) for leaf area index and organic matter accumulation, the latter separated by above-ground components (the cumulative biomass of lichens, acrocarpous moss and litter) and below-ground components (humus accumulation). Significance values are shown for T-test comparisons between 'Moss' and 'Lichen' plots; numbers in parenthesis are n-1 values for indicated microplot conditions.

Plot Variable	Site	Moss Quadrats	Lichen Quadrats	Significance
Leaf Area Index (m <sup>2</sup> /m <sup>2</sup> )				
	West	1.617±0.267	1.551±0.235	T(254)=4.62 P<0.0001
	Germansen	1.700±0.259	1.637±0.136	T(113)=3.75 P=0.0004
	Manson	1.961±0.418	1.787±0.281	T(183)=3.67 P=0.0003
Sum of lichens, acrocarpous mosses and litter (kg/m <sup>2</sup> )				
	West	0. <b>8</b> 4±0.40	1.26±0.26	T(45)=4.36 P=0.0001
	Germansen	0.95±0.37	1.18±0.30	T(28)=2.29 P=0.03
	Manson	1.09±0.25	1.27±0.29	T(44)=2.28 P=0.028
Humus (kg/m <sup>2</sup> )				
	West	0.91±0.48	0.77±0.36	T(48)=1.17 P=0.25
	Germansen	1.11±0.82	0.85±0.67	T(49)=0.98 P=0.34
	Manson	1.00±0.42	0.83±0.40	T(48)=1.34 P=0.19



Figure 2.3. Isopleth plot of forest floor in representative canopy gap in pine-lichen woodlands. From top: Leaf Area Index, Percent Cover of *Cladina spp.*, and Percent Cover of Feather moss mats.

compared to moss quadrats at all three sites (Table 2.5). Organic matter content over surface soil horizons indicated an opposite trend to the assessment of unfavourable moss substrates. Although not statistically significant, there was a trend at all three sites towards greater organic matter content at quadrats with a moss component versus those without it (Table 2.5).

### DISCUSSION

The distribution of bryophytes and lichens at any given site reflects the combined interactions of past and present propagule availability and site characteristics, both of which interact to determine subsequent establishment and growth of plant communities. In general, for lichens to be successful, these factors must interact to create environments that preclude competitive displacement by other plants, due to the more "stress-tolerant" life history strategy adopted by many lichens (Grime 1977).

When considering site characteristics, features of the mineral soil (i.e. soil horizons below the surface organic layers and that contain <20% organics) are typically among the most influential in changing the nature and distribution of the overstorey plant canopy in lichen woodlands. Of particular importance is the effect of edaphic factors on growth rates and live biomass of the dominant trees species on a site. On lichen sites that succeed to a moss woodland state, succession is considered to be a function of the forest overstorey development (Carroll and Bliss 1982, Maikawa and Kershaw 1976). These factors interact through time, with periodic stand destroying fires "resetting" both edaphic and successional factors.

The influence of the forest canopy on non-vascular plant communities at the forest floor surface may be expressed through several mechanisms. The more well-developed the canopy structure is, the greater will be the direct interception of precipitation, reducing available water at the forest floor surface (Rutter 1975). Although this factor is important at a watershed level in changing patterns of runoff and total streamflow, the impact on moss and lichen communities may be small, expressed mainly in a reduced magnitude of wetting during small precipitation events, when the canopy intercepts most of the throughflow precipitation. More importantly, exposure to direct solar radiation after precipitation events can result in transient high rates of photosynthetic uptake, but leads to rapid dessication of non-vascular cryptogams at the forest floor surface in pine stands (Coxson 1987).

In pine-lichen woodlands, the nature of stand initiation can also play an important part in contributing towards the legacy of residual canopy structure and the early initiation of more shaded conditions at the forest floor surface. On sites where stand destroying fires are less severe in nature, the greater retention of organic soils and seed/propagule pools may result in a community structure that contains more elements from previous seral stages. This was evident while selecting sites in this study. In pine stands that had many fire-scarred trees (evidence of canopy retention after the last major fire), there tended to be a greater abundance of moss in the understorey, compared to stands that did not contain trees with fire scars (and presumably had a total loss of canopy structure during the last fire).

Overstorey canopy development can also influence surface cryptogams through the deposition of litter on potentially slow growing lichen mats and through the buildup of surface organic horizons. A trend of greater soil organic matter development on microsites dominated by moss was evident in our study area, although it cannot be stated whether this is a causal factor or merely the result of greater litter accumulation after moss establishment. This effect is

consistent with the findings of Steijlen et al. (1994), who found that microsites dominated by moss had significantly higher organic biomass compared to sites with just lichen.

The overall success of feather moss mats at the forest floor surface, however, may be determined most by changes in overstorey architecture. On all sites studied, the biomass of the forest overstorey was greater where feather moss was present. One method used to assess this was by evaluating leaf area index. In the Omineca region, LAI in pine-lichen woodlands was highly correlated with stand overstorey variables. In stands that have both a greater biomass of trees, and large tree sizes, LAI was higher. Larger trees, and thus higher leaf area index values, corroborate with lower levels of available solar radiation and the greater likelihood of microsites having feather moss present.

Although changes in canopy structure are covariate with time since stand initiation, recent findings of Coxson and Marsh (2001) indicate that low-impact (winter-harvest) removal of overstory canopy can result in the short-term return (at 30 years after harvest) of sites to a lichen-dominated status. This supports arguments that the development of moss- or lichen-dominated microsites within a stand reflects small-scale differences in the immediately subtending canopy structure. The development of these small-scale variations in canopy structure is time-dependant, reflecting previous stages of stand development and disturbance history.

Stochastic events early in stand development also will play a role in determining the nature of initial propagule establishment. Pharo and Vitt (2000), for instance, did not find a strong correlation between canopy density and local variations in moss and lichen cover in montane forests of Alberta and speculated that early establishment events may be more

important than we have previously thought. The burial of existing lichen mats through infilling by feather moss mats on our sites strongly suggests that the balance of competitive interactions between these species changes in localized microsites late in stand development. It is interesting in this regard that we observed small stems of *Pleurozium schreberi* (Brid.) Mitt. widely coexistent within terrestrial lichen mats in younger pine-lichen woodland stands near our sites (Coxson and Marsh 2001), suggesting a common point of initiation early in stand life for both functional groups. However, as in the case of epiphytic lichen communities (McCune and Antos 1982), competitive interactions are ultimately linked to environmental gradients involving both stand age, and available light and moisture at specific microsites. What is uncertain is whether the nature of these interactions may change within managed stands (Esseen et al. 1996).

The data set developed for this project does not provide critical thresholds for stand characterisation variables that can be used to differentiate moss versus lichen areas. Stand characterisation data express variation between the three sites. In particular, lower values for all characterisation variables were found at the West Germansen site, which is the highest elevation of all three in this study. Based on elevation alone, the West Germansen site could be classed as being in the Engelmann Spruce - Subalpine Fir (ESSF) biogeoclimatic zone and have a slightly different microclimate. Because the vegetation community and soils were not different from the other two sites, it was considered to be within the BWBS.

The notion of microclimatic variation is supported by anecdotal information from residents in the study area. They indicated that snow depths in the vicinity of the West Germansen site can be deeper than those found at the other two sites. It is probable that the West Germansen site is transitional to the higher elevation sites in the ESSF and could be considered a slightly different phase from the other two sites that are truly in the BWBS. The interaction of stand structure and surface microsite development, however, was similar in all three sites, despite these elevational differences.

The values determined for LAI within this study represent two-dimensional relative measures from microsite sampling plots, each representing the portion of the sky that is blocked out of view by foliage (Welles and Norman 1991). High LAI measures therefore correspond to high foliage biomass of trees and subsequent greater interception of solar radiation (Cable 1958, Cade 1997). The structure of trees is also an important factor in determining light and wind penetration to the forest floor (Korzukhin and Ter-Mikaelian 1995). Taller trees with greater vertical structure of the crown expose more leaves to incoming radiation than do shorter trees. This results in an improved efficiency of the absorption of solar radiation. Using equations derived by Standish et al. (1985), the calculated biomass of the crowns at each site was greater at the plots selected for moss presence than those selected for its absence.

Another important factor associated with the presence of larger trees is a decrease in the ventilation through a stand. Ventilation is a critical factor impacting growth rates for many lichen species. Reducing the air flow through a stand reduces the amount of moisture drawn away from a microsite. This increases the availability of atmospheric moisture (humidity) to plants, which is an important precondition for the establishment of feather moss mats (Tamm 1964). Although both lichens and moss, in general, respond favourably to longer hydration episodes, which increase the duration of physiological activity, in practice, many lichen species seem to be excluded from sites with prolonged duration of hydration (Goward 1998). This may reflect the sensitivity of lichen symbiosis to prolonged wetting (Tysiaczny and Kershaw 1979).

Additionally, under conditions of slow drying, respiratory carbon loss from fungal symbionts may have an adverse effect on long-term growth of *Cladina* (Tegler and Kershaw 1980). This constraint is not as severe in feather mosses such as *Hylocomium splendens* (Hedw.) B.S.G., where respiratory carbon loss at low water contents does not represent as high a proportion of overall carbon budgets (Sonesson et al. 1992).

A final constraint on the future development of pine-lichen woodlands is the widespread adoption of fire-suppression as a management policy in the past several decades. Future development of managed stands may differ greatly from those of historical fire-origin ones (Coxson and Marsh 2001). Factors such as tree stocking, density at planting, stand tending, and rotation length to harvest each influence the development of understorey plant communities. Our research findings indicate that stand structure is an important variable in retaining or enhancing the growth of reindeer lichens. Once overstorey forest biomass and resultant LAI values exceed threshold values, the transition of forest floor cryptogamic communities to a feather-mossdominated stage may occur quite rapidly.

Understanding the relationship between stand structure and lichen presence will provide resource managers with greater ability to retain a diversity of lichen communities in managed forests. However, care must be taken so that the effects of stand level manipulations are considered in context of landscape level trends in lichen diversity and abundance (Dettki and Esseen 1998). In the Omineca region of north-central British Columbia, integrating information on stand structure and lichen development provides additional means towards insuring future availability of terrestrial lichen mats and the maintenance of related habitat values, such as forage for northern caribou.

# CHAPTER 3 - CHANGES IN TERRESTRIAL LICHEN AVAILABILITY AND WOODLAND CARIBOU HABITAT IN NORTH-CENTRAL BRITISH COLUMBIA: A GIS-BASED QUERY<sup>1</sup>

#### SUMMARY

The age class distribution of pine-lichen woodlands in the Omineca region of northcentral British Columbia reflects extensive fires that occurred in the late 1800's. Terrestrial lichen mats in these mid-seral woodlands provide critical winter forage for caribou populations. In land use plans throughout British Columbia, a reoccurring recommendation is to preserve tracts of land containing terrestrial lichens. Using a GIS-based query focussing on forest inventory variables such as site index and leading tree composition, we categorized the availability and age class distribution of pine-lichen woodlands within an area bounded by the Nation Lakes and the Omineca River. Using a static landscape model (applied to a subset of the area), the approach allows for natural stand aging, but excludes large scale disturbances such as fire. GIS simulations of this model indicated that successional changes associated with lateseral replacement of terrestrial lichens by feather moss mats will greatly reduce caribou habitat over the next 30 to 60 years. A disturbance-based landscape model, with evenly dispersed (time and space) regeneration of woodlands (on a 140-year return interval), showed the same shortfall of terrestrial lichen availability after 30 years, although caribou habitat values rebuild into the next century. These findings indicate that for a period from 30 to 60 years hence, the availability of caribou habitat will be a critical concern in the Omineca region. Our ground truthing indicated that changes in forest structural variables, especially basal area of pine, accompany this late seral loss of caribou habitat. These findings support the recommendations that alternative

<sup>&</sup>lt;sup>1</sup>Chapter has been submitted for publication with the following authorship: R. Sulyma and D.S. Coxson

forest harvesting techniques can be utilized to bridge the shortfall of terrestrial lichen availability, and point to the importance of landscape level planning when considering habitat availability.

## **INTRODUCTION**

Lichen-dominated woodlands occur throughout northern Canada, typically on well drained glacially modified sites (Kershaw 1978). In western Canada, the regeneration of pinelichen woodlands and the subsequent development of forest floor plant communities is intimately tied to the frequency and intensity of prior fire events, which act as a landscape level disturbance agent. General patterns that have been documented contain three or four interim phases of succession (Brulisauer et al. 1996, Carroll & Bliss 1982, Johnson 1981, Maikawa & Kershaw 1976, Morneau & Payette 1988, Payette et al. 2000, Rowe 1984, Thomas & Alaie 1996). Common late-seral plant communities are dominated by one of *Stereocaulon spp.*, *Cladina spp.* or feather mosses such as *Pleurozium schreberi* (Brid.) Mitt.

Terrestrial lichens provide an important forage source for northern caribou (*Rangifer tarandus* Linnaeus). The sustained availability of this forage requires a landscape mosaic containing a range of age classes, particularly in areas where lichen mats are replaced in late successional stages by feather moss mats. In pre-industrial landscapes, fire was the main agent of stand initiation. In modern landscapes, however, forest management practices and fire suppression can change the seral stage distribution of lichen woodlands and the ecological processes that regulate the development of forest floor lichen communities.

In recognition of these changing landscapes, many jurisdictions have implemented

caribou management strategies. This has resulted in management paradigms that focus on providing maximum lichen availability for foraging while reducing predation pressure and human disturbance (Bergerud & Elliot 1998, Seip 1998). These management strategies have been given additional impetus because of the recent consideration of caribou as a threatened species in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2000). In British Columbia, land use plans for most areas with caribou populations recommend special strategies for caribou management (Anonymous 1995a, 1997, 1999).

A critical aspect towards the management of caribou populations requires, as a starting point, detailed information on the extent of pine-lichen woodlands, their stage of seral development, and the degree to which forest harvesting practices have changed seral stage development. In the past, this was often accomplished through manual searches of hard copy maps and images for desired features. More recently, geographic information systems (GIS) have been used as a tool to perform the desired queries. This process has been aided by improvements in software development, which bring GIS tools within the reach of resource managers.

Common attributes of pine-lichen woodlands in western-Canada are well-drained sites with a poor nutrient regime (Johnson 1981, Rowe 1984, Stevenson 1991). We have therefore focussed on determining if measures of forest productivity, specifically site index measures (defined as the height of the average dominant trees at a given age, e.g., 50 years), can be used to differentiate pine sites that contain terrestrial lichens from those that do not. Site index is a value that is easy to determine and is an attribute within the British Columbia Government Survey (BCGS) forest cover data base.

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Our sampling procedures were developed to assess a range of sites stratified by site index classes. This stratification allows for the recognition of site and stand features between pine-lichen woodlands and pine forests with other (non-lichen) ground covers. We used this information, along with an assessment of the physical features associated with pine-lichen woodlands, to develop a GIS-based query of a digital map database for the Omineca region of north-central British Columbia.

This query identifies sites that have a high likelihood of containing pine-lichen woodlands and allows for the examination of future availability of caribou habitat under different management conditions using a simple time-step modelling procedure. The two management strategies examined were a "Static Landscape Model" (SLM) and a "Disturbance Landscape Model" (DLM). The SLM strategy focuses on minimizing the disturbance that occurs to lichen woodlands in any time period, whereas the DLM strategy allows ongoing landscape level disturbance, which over the course of several decades creates a more even-aged distribution of pine-lichen woodlands.

#### **MATERIALS AND METHODS**

#### Study Area

Pine-lichen woodlands were located in the Omineca region, approximately 350-km northwest of Prince George (Figure 3.1). This area is bounded by the Nation Lakes to the south, the Omineca River to the north, the Germansen Range to the east and Takla Lake to the west. Fieldwork was concentrated in the vicinities of the Kwanika Creek, Silver Creek, Indata Lake, Valleau Creek and Ominicetla Creek (Table 3.1).



Figure 3.1. Location of the "GIS project" study area within the Omineca region of north-central British Columbia.

Field Site	General Location	Notes
Kwanika Creek	N 55° 34' 22" W 125° 15' 52"	11 plots in the ESSF <sup>1</sup> mv3 5 plots in the SBS <sup>2</sup> mk1
Silver Creek	N 55° 42' 50" W 125° 28' 24"	4 plots in the SBS mk1 6 plots in the BWBS <sup>3</sup> dk1
Indata Lake	N 55° 22' 38" W 125° 15" 55"	10 plots in the SBS mk1
Valleau Creek	N 55° 22' 50" W 124° 54' 25"	14 plots in the ESSF mv3
Ominicetla Creek	N 55° 54' 37" W 125° 45' 02"	26 plots in the BWBS dk1

Table 3.1. Geographic location of field sampling areas.

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Engelmann spruce sub-alpine fir biogeoclimatic zone
Sub-boreal spruce biogeoclimatic zone
Boreal white and black spruce biogeoclimatic zone

The large geographic extent of the area assessed falls under three biogeoclimatic zones, the boreal white and black spruce zone (dry cool variant - BWBS dk1), the Engelmann spruce sub-alpine fir zone (moist very cool variant - ESSF mv3) and the sub-boreal spruce zone (moist cool variant - SBS mk1) (Meidinger and Pojar 1991). In general, pine types are found on sites that are drier and more nutrient poor than sites expressing climatic climax vegetation communities (zonal sites) for these zones (Meidinger and Pojar 1991).

## **Map Attributes**

GIS queries were run on the BCGS forest cover map-base (BC Ministry of Forests 1994) and terrain resource inventory mapping (TRIM) (BC Ministry of Environment, Lands, and Parks 1996). Safe Software Inc.'s (Surrey, BC) Feature Manipulation Engine was used to prepare the digital files for analysis. All GIS activities were done using ArcView 3.2 (Environmental Systems Research Institute Inc., Redlands, CA). To prepare maps for field activities, a query was applied to select mapped strata (polygons) that contained a predominant cover of lodgepole pine. "Predominant" was defined as  $\geq$ 90% composition by basal area of the total tree cover. The pine sites were further stratified by site index (SI<sub>50</sub>) (Table 3.2) to ensure a sampling plan that would assess a range of site productivities.

## **Ground Truthing**

Seventy-six plots were sampled in five areas of the Omineca region in north-central British Columbia (Table 3.1). Transects ranging from 0.2 to 6-km long were established throughout the study area. Plots were located along the transect based on the polygon boundaries determined by the GIS query. In some instances, where extreme variation in the

Group	Site Index at Age 50
1	<10
2	10.1 - 12.0
3	12.1 - 13.0
4	13.1 - 14.0
5	14.1 - 15.0
6	15.0 - 16.5
7	> 16.5

Table 3.2. The breakdown of site index classes used in the field evaluation procedures to ensure sampling over a range of productivity classes.

dominant forest floor cover occurred within a single polygon, multiple plots were established. Plot measurements were taken in 0.02-ha fixed area circular plots (7.98-m radius). Measurements within these plots established the % cover of dominant plant species (visual estimation), and information on tree characteristics (species, diameter and height) (Husch et al. 1982). Physical features of each site were also assessed, including hand texturing of soils and visual estimates of coarse fragments. Aspect and slope were evaluated for each plot location and a lichen woodland class was derived (Table 3.3).

The lichen woodland class was determined according to a process developed by Lance and Eastland (1999, 2000). The system uses a combination of ecological information, visual estimates of the % ground cover of four forage categories, and data from a "step-point" transect to determine a woodland class (see Table 3.3- Footnote 2 for the description of a step-point transect). The class value is the result of navigating through a dichotomy of decision nodes that result in an index value ranging from 0 to 4. With this system, 0 identifies a site with no forage (or no value as northern caribou winter range) and a 4 indicates a site with abundant forage .

To analyse field data, sites were grouped into 2 categories based on the Lance and Eastland classification scheme. Sites with moderate or high value as caribou winter range because of forage potential (classes 3 and 4) were combined into a category called "lichen plots". Sites with little value for caribou, due to little or no forage being available (classes 0, 1 and 2) were combined into a category labelled "moss plots." Comparisons of site attributes between plot groups utilized T-tests to assess significance levels, based on tests meeting or exceeding a threshold of p = 0.05.

Table 3.3. A generalisation of the Lance and Eastland (1999) terrestrial lichen woodland
classification scheme developed for the Omineca region of north-central British
Columbia.

Description	Lichen Woodland Class		
No terrestrial lichens present at the site.	Class 0 - no value as caribou winter range.		
There is at least 25% cover of preferred forage lichens plus an additional 25% cover of lichens regardless the forage	Class 4 - high value as caribou winter range.		
If the above 2 points are not met, a steppoint survey is conducted <sup>2</sup> .			
Greater than 50% of the tally points are preferred forage.	Class 4 - high value as caribou winter range.		
Between 26% and 50% of the tally points are preferred forage.	Class 3 - moderate value as caribou winter range.		
Between 11% and 25% of the tally points are preferred forage.	Class 2 - low value as caribou winter range.		
Less than 10% of the tally points are preferred forage and lichen is present at the site.	Class 1 - minimum value as caribou winter range.		

1. Forage categories: 0) No lichens; 1) Preferred forage species: *Cladina* spp., *Cetraria* spp., and *Stereocaulon* spp.; 2) Less preferred forage species: *Cladonia* spp., *Peltigera* spp.; 3) All other terrestrial lichens (from Lance and Eastland 1999).

2. The step-point survey involved taking two-paces (approximate distance of 1-m) and tallying the presence of the dominant forage category at the toe of one boot. Thirty tally points were evaluated in each step-point survey (Lance and Eastland 1999).

#### Lichen Availability in Future Landscapes

The GIS query of stand characteristics was used to develop a simple lichen forecast model by modifying the results of the query by seral stage development. This was the basis for scenario generation under different management regimes. The area assessed was located in the Kwanika Creek area and is located between  $124^{\circ}$  48' 00" and  $125^{\circ}$  12' 00' longitude and 55° 42' 00" and  $55^{\circ}54'$  00" latitude. This area covers >1200 km<sup>2</sup> and is representative of the landscape trends within the surrounding region. Using two strategies, a Static Landscape Model, where natural processes were limited to aging of existing stands, and a Disturbance Landscape Model, where stands were presumed to regenerate (by either natural or man-made events, see below) every 140 years, seral stage conditions were forecast for pine-lichen woodlands over a time period of the next 160 years. The process incorporated a GIS query, based on our evaluation of maps and ground truthing activities, with the following parameters: leading species of lodgepole pine, % composition of leading species ≥90%, a site index (at age 50) <14.5 and an aspect between 45 and 315 degrees. The GIS query then used one of two assumptions on lichen succession to forecast future lichen conditions.

In the SLM model, an assumption was made that as the stands age, the forest overstorey characteristics and lichen habitat ultimately change to a feather moss seral stage, as described by Coxson et al. (1999) for woodlands of the Germansen-Omineca region, and as described by Carroll & Bliss (1982), Maikawa & Kershaw (1976), and Payette et al. (2000) in other regions. In the DLM approach, we assumed that a natural, i.e., similar to that of a fire-origin stand, pattern of succession was reset. The disturbance interval for the DLM approach was set at 140

years. This value represents an ecological time frame representative of fire-return intervals for interior boreal forests in BC (DeLong 1998), and provides for the maximum development of terrestrial lichen mats (Stevenson 1991). A similar time scale is also suitable as the target rotation length for logging within these dry pine sites (British Columbia Ministry of Forests 2000).

To organize the analysis output, most sites were categorized by the age class distribution utilized by the BC Ministry of Forests (Anonymous 1986). The one exception was age class eight, which was broken into two classes to allow for a secondary classification by succession phase as reported by Coxson et al. (1999) for the Omineca Region of BC. The lower portion of age class eight (8-) incorporates all sites between 141 years and 155 years. Age class 8+ incorporates all sites between 156 years and 250 years. A detailed breakdown of age range and succession phase (Coxson et al. 1999) for each age class category is identified in Table 3.4.

To model the SLM approach, sites were aged in 10-year increments. The area in each age class/succession phase was tallied. For the DLM approach, aging in 10-year increments was also conducted; however, a set of sites totalling an area of approximately 340-ha per decade was chosen as the area to be reset to year 0 after disturbance. This area was determined for the study area by dividing the total area of pine-lichen woodlands identified with our GIS query by the disturbance return interval of 140 years and then summing the value per decade. Preference for the selection of polygons to be disturbed was given to the oldest sites. Where there were >340-ha in the oldest age class, polygons were selected on a random basis.

BC Ministry of Forests Age Class	Age Range (years)	Succession Phase
1	1 - 20	Polytrichum
2	21 - 40	Cladonia
3	41 - 60	Cladonia
4	61 - 80	Cladonia
5	80 - 100	Cladina/Stereocaulon
6	101 - 120	Cladina/Stereocaulon
7	121 - 141	Cladina/Stereocaulon
8-	141 - 155	Cladina/Stereocaulon
8+	156 - 250	Feather Moss
9	251+	Feather Moss

Table 3.4. Definition of age ranges and succession phase for each age class.

## RESULTS

## Ground Truthing for Site Productivity Values

The query procedure run on the forest cover attribute information had an accuracy rate of 68 %. Of the 76 plots established in the field, 52 were correctly classified by the GIS query. Table 3.5 presents a summary of the classification results for both woodland class and plot type.

Sites assessed all had flat to gently rolling terrain. All but one had a dominant cover of lodgepole pine. The ages (after fire origin) of the stands sampled were variable, with the youngest stand being 42 years in age and the oldest 359 years in age.

The aspect of all but 2 lichen plots fell between 45 and 315 degrees, and both of these had a slope < 10%. The average slope of lichen plots was  $3.6\pm0.6\%$ . They all had coarse textured soils dominated by sand. The coarse fragment content was variable. Seven plots had pure sands for mineral soil with no coarse fragments. When coarse fragments were present, however, the average content was  $56.2\pm3.6\%$ . Average coarse fragment content of all lichen plots combined was  $52.3\pm4.0\%$ .

The average slope of all moss plots was  $6.2\pm1.08\%$ . The soil texture of these plots was more variable than in the lichen plots. A range from silt-clay-loam to sand occurred. The coarse fragment content of all moss plots averaged of  $40.3\pm4.77\%$ .

The mean values for the forest structure variables assessed are summarised by plot in Table 3.6. Site index values derived from the GIS map-based query were significantly different (T(57)=2.69, P=0.0092) for moss and lichen plots. The upper confidence limit for site index was 14.49 ( $\alpha = 0.05$ ), calculated from the digital attribute information for the lichen plots. Site index values for moss and lichen plots from field data were also significantly different

Lichen Woodland Class/ Plot Type	Total Number of Plots	Correctly Classified Plots Using GIS Query
0	22	13
1	6	5
2	5	4
Total "moss plots"	33	22
3	17	12
4	26	18
Total "lichen plots"	43	30
Total plots	76	52

Table 3.5. Summary of the number of correctly classified plots for "woodland class" and "plot type".

Variable	Average ( $\bar{x} \pm 1$ SD)		
	Lichen Plots (n=43)	Moss Plots (n=33)	
Site Index <sup>1</sup> Site Index <sup>2</sup>	13.8±0.3 11.8±0.4	15.4±0.5 13.6±0.7	
Total Basal Area <sup>2</sup> (m <sup>2</sup> )	24.4±1.0	33.4±1.6	
Tree Height <sup>2</sup> (m)	16.2±0.5	18.8±0.9	
% Composition of Pine in Stand <sup>2</sup>	<u>96.6±1.1</u>	87.4±3.4	

Table 3.6 Summary of forest structure variables.

Measurements derived from BCGS map base using GIS query.
Measurements based on field plot ground truthing.

(T(54)=2.16, P<0.035). A site index upper confidence limit of 12.66 ( $\alpha = 0.05$ ) was calculated from the field data for the lichen plots. On average, site index values determined from the field data were lower than the values identified in the forest attribute information. This trend was most notable with the lichen plots, which showed a significant difference (T(77)=3.76, P=0.0003). The trend was also evident with moss plots, although, it was not significant.

The structure of the forest overstorey also differed between lichen and moss plots. Lichen plots had a significantly lower total basal area (T(53)=4.88, P<0.0001), shorter trees (T(50)=2.43, P=0.019) and a higher percent composition of lodgepole pine (based on basal area) (T(39)=2.57, P=0.014) (Table 3.6). The percent composition of the leading species is used as a threshold value in the GIS query. Evaluating the field data, the lichen plots had a lower confidence limit ( $\alpha = 0.05$ ) of the percent composition of the leading species (pine) equal to 94.3%.

#### GIS Map Query and Landscape Simulation

The digital query of forest cover maps identified a total of 4728-ha of pine-lichen woodlands from a possible 122,884-ha of terrestrial area amounting to <4% of the land base. The existing age class distribution of pine-lichen woodlands in this area is heavily skewed towards age class 6 (Figure 3.2). The results of the SLM strategy (Figures 3.3, 3.4 and 3.5) showed that the amount of available lichen woodland suitable for foraging would decline from 3972 ha at year 0, to 156 ha by year 90. One hundred and fifty-six hectares are equivalent to 3.3% of the total area under pine-lichen woodlands.

Applying the DLM approach, the same decline of area in the *Cladina/ Stereocaulon* phase (age classes 5 - 8<sup>-</sup>) was seen up to year 90, as noted in the SLM scenario. Rather than a

Figure 3.2. Area by age class and lichen succession phase for the Kwanika Creek portion of the study area: Current Situation -Year  $\rm 0$ 





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Figure 3.4. Area by age class and lichen succession phase for the Kwanika Creek portion of the study area: Static Landscape Model - Year 90



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decline after 90 years, however, an increase to steady-state levels occurs. At year 140, there was 1800 ha in the *Cladina/Stereocaulon* phase, equivalent to 38% of the total area under pine-lichen woodlands (Figures 3.6, 3.7 and 3.8).

## DISCUSSION

The age class distribution of pine lichen woodlands in the Omineca region of north-central British Columbia was heavily skewed towards older age classes. Applying successional trends documented across northern Canada (Coxson and Marsh 2001, Carroll & Bliss 1982, Maikawa & Kershaw 1976, Payette et al. 2000), the lichen cover in these forests will soon be replaced by moss mats. Thus, future lichen availability may soon be a constraint on caribou populations that require terrestrial lichens as a forage source (Johnson et al. 2000). For example, the static landscape model suggests that in 60 years, many of the present-day pine-lichen woodlands will have converted, or be in the process of converting into a feather moss phase of succession. Unresolved is the question of whether these same seral sequences, observed in fire-origin stands, will happen in harvest-origin stands.

Several issues arise from our utilization of a GIS-based query on forest inventory information to predict future caribou habitat availability. Although this approach identifies stands with a high likelihood of containing terrestrial lichen mats (> 68% accuracy rate), errors in the assignment of polygon attributes must be considered carefully.

Among these errors, based on our observations of stand characteristics, is the assessment of the polygon size and uniformity in the map database. Where areas were incorrectly classed as pine-lichen woodlands, they often still had patches of lichen available for foraging. Commonly, Figure 3.6. Area by age class and lichen succession phase for the Kwanika Creek portion of the study area: Disturbance Landscape Model - Year 60

















polygons that showed this discrepancy were found within the SBS biogeoclimatic zone. We found in some instances that adjacent plots (within 100-m of each other) within a single polygon in the SBS expressed different conditions (moss dominance versus lichen dominance), thus attesting to the variability within these types. Though the data was not coded to tally for variation at the polygon level (only at the plot level), it was estimated that 15 to 20% of errors in identifying stand attributes could be accounted for by considering this variation. Despite this fact that some areas may not be considered large homogenous pine lichen-woodlands, they do contain a component of lichen range which is suitable for use as early winter caribou habitat.

The other significant factor contributing to errors in identifying stand attributes in map calls was the large range of ages in the stands sampled. Coxson and Marsh (2001) reported that succession to a feather moss climax exists in the Omineca. In the Ominicetla Creek area, nine plots were located in stands >200 years old. Of these, 4 were classified as lichen sites, but 5 were not. Of the 5, at least 3 were considered to be late succession pine-lichen types. The error associated with incorrect classification due to succession could account for a further 10 to 15% of the incorrect calls made by this study. Considering >25% of the error calls can be accounted for through variation of lichen development, both spatially and temporally, with more reliable inventory information, the accuracy of this classification system could be improved to > 75%.

In general, terrestrial lichen sites in western Canada are associated with a pine overstorey and xeric, nutrient poor growing conditions (Johnson 1981, Rowe 1984, Stevenson 1991). Our stand characterization variables (basal area, tree height, site index, and tree species composition) support these trends.

In the biogeoclimatic zones assessed under this study lodgepole pine leading stands are
associated with the driest and most nutrient poor site series, or plant associations (DeLong et al. 1993). It was for this reason we used lodgepole pine as a predictive factor for identifying lichen sites. In the GIS query, we applied a threshold of 90% composition of lodgepole pine, however, upon evaluating field data, a more accurate threshold would have been 94%.

Unfortunately, the quality of the digital forest inventory attribute information is not to the same level of accuracy as the field information. In the digital files, values for the species composition are rounded to the nearest ten percent. Thus, sites with 94% for example, are presented as 90%. Though more accurate thresholds have been defined by our data, the quality of the current digital attribute information does not permit further refining of our GIS query. This variation between the field information and digital attribute data provides a further source of error when assessing the overall accuracy of our GIS query.

Understanding the spatial and temporal relationships between forest attributes and the presence of terrestrial lichens allows managers an avenue to forecast what the conditions of terrestrial lichen sites may be under different treatment regimes. A simple time-step model can then be used to express these trends without the use of complex algorithms. This information is vital in determining land use strategies that focus on maintaining low elevation winter forage opportunities for northern caribou.

The limited availability of management tools that are specific to northern caribou and forestry issues has been a major obstacle in the development of successful integrated resource management plans for these resources. Site level tools available consist of lichen abundance identification schemes such as the Lance and Eastland (1999, 2000) lichen assessment procedure and lichen presence prediction tools such as developed byBrown et al. (2000). Landscape level

tools consist of GIS applications such as the query developed under this project. The application of models that incorporate GIS queries closes the gap between site and landscape level tools by providing a means to evaluate the cumulative effects of site level actions over a large area.

Within the Omineca region specifically, our findings raise concerns about the future availability of pine-lichen woodland seral stages that will support terrestrial lichens, and by extension caribou habitat. This future shortfall of caribou habitat will be particularly severe in the next 30 to 60 years. Large scale fires of the late 1800's, combined with fire suppression practices of the last several decades, have dramatically reduced the availability on the landscape of younger seral stages that can provide future caribou habitat. Recent policy decisions to place high-quality caribou habitat in protected areas will not resolve this dilemma, in absence of the reintroduction of landscape level disturbance events. Even with immediate reintroduction of fire (or comparable logging practices) as a landscape disturbance event, our findings indicate that a severe shortfall of caribou habitat will persist for several decades.

Unresolved at the present time is whether or not stands initiated through forest harvesting will follow a seral sequence similar to that found in fire-origin stands. A growing body of evidence points to different ecological processes in harvest plots compared to fire-origin stands (Nguyen-Xuan et al. 2000, Webb 1998). Nonetheless, current landscape management will dictate that forestry practices be used as much as possible to promote the regeneration of lichendominated communities upon which caribou depend (DeLong 1998, Harris 1996). The increasing accessibility of GIS to foresters and biologists provides a mechanism to simplify the expression of spatial relationships between these two resources, thus, providing a tool to integrate the management of them at the landscape scale.

# CHAPTER 4 - A RETROSPECTIVE STUDY OF TERRESTRIAL LICHEN DEVELOPMENT IN HARVESTED STANDS LOCATED IN THE OMINECA REGION OF NORTH-CENTRAL BRITISH COLUMBIA<sup>1</sup>

### **SUMMARY**

The availability of terrestrial lichen mats in pine woodlands of north-central British Columbia has historically required fire as an agent of stand development to initiate lichen growth. In face of recent timber harvesting pressures, this has led to concerns about the future availability of terrestrial lichen mats that provide important forage for northern caribou populations. We assessed post-harvest development of terrestrial lichen mats in pine-lichen woodlands of the Omineca region, examining three age classes and two soil classes in the Pine-Feathermoss-Cladina plant association (03 site series) of the SBS mk1 biogeoclimatic zone. On sites where soils were well drained and the mineral component comprised predominantly sand, the mean cover of Cladina spp.was greater than 40% 20 years after harvesting. On pine-lichen sites where mineral soils contained additional silt and/or clay components, the mean cover of terrestrial lichen mats after the same time period was only 14%. In both cases, lichen cover was slow to reestablish, with mean cover values remaining below 15% in the first decade after harvesting. On sites with well-drained soils, however, the redevelopment of lichen mats did not appear to be affected by post-harvest stand regeneration. Conversely, our findings suggest that the redevelopment of terrestrial lichen mats may be delayed or diminished in pine stands where mineral soils contain greater amounts of silt and/or clay and where stand regeneration does not include fire as a disturbance agent.

<sup>&</sup>lt;sup>1</sup>Chapter has been submitted for publication with the following authorship: R. Sulyma and D.S. Coxson.

# **INTRODUCTION**

Wildfires are a critical component of disturbance regimes associated with the development of terrestrial lichens in pine-lichen woodlands of western Canada (Klein 1982). They reset site characteristics, creating conditions suitable for initiating succession processes, and ensure the perpetuation of terrestrial lichens during later stages of stand development. Where the frequency of stand initiating fires is reduced, the subsequent development of late-seral closed canopy conditions can trigger the replacement of terrestrial lichen mats by feather moss mats (Carroll & Bliss 1982, Maikawa and Kershaw 1976, Payette et al. 2000), reducing habitat values for caribou populations that rely on terrestrial lichen mats. Johnson et al. (2000) identified lichens commonly consumed by caribou in the Omineca region of north central BC as *Cladina* spp, *Cladonia* spp. and *Stereocaulon* spp. Based on species presence in the young stands that we assessed, the species tallied in our reindeer lichen functional group consisted of *Cladina mitis* (Sandst.) Hustich, *C. rangiferina* (L.) Nyl., *Cladonia uncialis* (L.) Wigg., *C. ecmocyna* Leight., and *Stereocaulon* spp.

Ecological processes that govern the regeneration of pine-lichen woodlands after harvesting may differ in several ways from those initiated by wildfire. The abundance of forbs and shrubs may increase more rapidly in post-harvest sites than in fire-origin stands. Forest harvesting and associated silviculture treatments have traditionally been considered detrimental to terrestrial lichens, due to overexposure, fragmentation and burial of existing lichen mats (Kranrod 1996, Harris 1996). Finally, lichen communities that have developed under a closed canopy may not be able to withstand abrupt changes in insolation exposure that accompany loss of the canopy overstorey at time of harvest. These limitations have led forest managers to consider ways in which silvicultural and harvesting practices can emulate ecological processes in fire-origin stands. If management regimes can be developed to recognize these factors, detrimental impacts upon terrestrial lichen mats may be reduced. Current forestry trials, for instance, in the Itcha-Ilgatchuz region of central British Columbia, are assessing the impacts of alternative silviculture systems on the retention of terrestrial lichens (Anonymous 1996, Miège et al. 2001a).

The extent, or duration, of changes in lichen successional trajectories after forest harvesting is additionally dependant on regional climate and other environmental factors (Brulisauer et al. 1996, Lesica et al. 1991). Regional variation in the climate has been proposed as one of the primary factors influencing the development of lichen communities (Johnson 1981, Morneau & Payette 1988). Microsite variations also play an integral role in the distribution of lichens. The environmental requirements of terrestrial lichens are similar to those of many of the species of feather moss with which they compete. In the absence of competition, reindeer lichens may do well under late-seral canopy conditions. However, because they are poor competitors, they may be limited to microsites that have more severe growing conditions.

This study reports our assessment of the rate and extent of the recovery of reindeer lichens in the first 30 years after harvest in pine-lichen woodlands of the Omineca region in BC. This information is an important component in developing resource management strategies for forestry activities in caribou winter ranges and will assist in developing strategies for an adaptive management trial focussing harvesting of pine-lichen woodlands in the Omineca.

### **MATERIALS AND METHODS**

#### Study Area

The areas assessed under this study are located approximately 50 km west of the town of Mackenzie in the Mackenzie Forest District (Figure 4.1) and are located between 123°00' to 125° 30' longitude and 55°00' to 55°35' latitude. The plots fall within the Phillips, Tudyah and Manson operating areas of Slocan Forest Products. Plot locations were selected from cutblocks that contained the 03 site series of the Mossvale moist, cool subzone (mk1) of the Sub-Boreal Spruce (SBS) biogeoclimatic zone.

The SBS is "characterised by seasonal extremes of temperature; with cold snowy winters; relatively warm, moist, and short summers; and moderate annual precipitation" (Meidinger & Pojar 1991). The primary difference between boreal and sub-boreal biogeoclimatic zones is that the climate is slightly moderated in the sub-boreal zone.

The area of interest falls within Natural Disturbance Type 3 as classified in the Forest Practices Code of BC, Biodiversity Guidebook (British Columbia Ministry of Forests 1995). A mosaic of even-aged stands of different ages characterizes this disturbance type. The most common form of natural disturbance is wildfire, with a mean event interval of 125 years. Wildfires in this disturbance type can vary in size from a few to several thousand hectares, leaving an intricate patchwork of different age classes across the landscape.

The field sites assessed had flat to rolling terrain and moderately coarse to coarse textured soils. The coarse fragment content of the soils varied between 0 and 70% and was dominated by gravel-sized material. The aspect of all of the sites was either southerly or flat.



Figure 4.1. Location of the "retrospective project" study area within the Omineca region of north-central British Columbia

All sites were harvested within the past 30 years and had a dominant tree cover of lodgepole pine (*Pinus Contorta* Dougl. *ex* Loud.). Other tree species present in minor amounts were white spruce (*Picea glauca* (Moench) Voss), black spruce (*P. mariana* (P. Mill.) B.S.P.), sub-alpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and trembling aspen (*Populus tremuloides* Michx.). In the SBS, lodgepole pine is recognised as a seral species; it is however, common as a leading species in mature forests in the drier portions of the zone (Meidinger & Pojar, 1991).

# **Methods**

A GIS layer was prepared using forest cover information for the southern third of the Mackenzie Forest District (BC Ministry of Forests 1994). A query was applied to these data to identify cutblocks with lodgepole pine as the leading tree species in the inventory label. The blocks from the query were categorised by site index. Those with a site index value (SI<sub>50</sub>) below 14.5 were considered likely candidates for containing features representative of pine lichen woodlands, and that would also be within the 03 site series of the SBS mk1. The level of certainty associated with this query was low and a field reconnaissance was required to confirm the classification.

A walk-through assessment was conducted for the cutblocks identified by the query, regardless of site index. Observations of the soil conditions, vegetation community and tree species composition were used to determine the ecological association of polygons within the cutblocks. For those polygons that appeared to have the characteristics of the 03 site series of the SBS mk1, a plot was established in a representative location. Sample data were collected on stand characteristics, vegetation ground cover, soil texture, and ecological association.

The reconnaissance phase resulted in the identification of 40 cutblocks that contained

polygons with the required ecological criteria. The ages of these varied from 2 to 30 years. An assessment of the reconnaissance information revealed thresholds for three age-classes (0-5 years, 6-12 years, and 13-30 years). Based on hand texturing (DeLong et al. 1993), polygons were stratified into two groups, those with pure sand or loamy sand and all others. A 3x2 sampling matrix was developed separating the polygons based on age and soil class. In each grouping within the matrix, a minimum of three plots were randomly selected within which detailed measures were conducted.

At each of the selected polygons, assessments were conducted using a modified Daubenmire quadrat-transect methodology (Daubenmire 1959, Habitat Monitoring Committee 1996). A 100-m long transect was established through the polygon. Assessments of species composition and the percent cover of ground vegetation were made using ten randomly selected 0.5 m<sup>2</sup> quadrats. At each site, a soil pit with approximate dimensions of 10 x 10 x 20 cm, was dug within a randomly selected quadrat location. Five 3.99-m fixed-radius sub-plots were established at 20-m intervals along the transect. At each sub-plot, all tree stems were tallied by species and diameter class. The two largest diameter trees were measured to assess site index (Anonymous, 1995b). The age and height of the first 10 trees located in a counter clockwise direction from a line due north of the sub-plot centre were also recorded.

### Analysis

A total of 20 sites were intensively sampled for this project. A two digit "Plot Code" was created to separate the sites into six categories. The first digit was assigned to separate the types by age class (coded as a 1, 2 or 3) and the second digit of the code was used to separate the sites by soil texture. Sites were coded with a 0 if they contained pure sand or loamy sand

(referred to as sand soils) and a 1 if the soils were classed as having a slightly finer texture (referred to as sandy-loam soils). Analysis utilized ANOVA to support the significance of relationships between variables in the Plot Code groupings. Values presented within this chapter are means plus or minus one standard error ( $\bar{x} \pm 1$  SE).

# RESULTS

A number of trends were exhibited by the various species and reindeer lichen group assessed in this study. One of the more notable trends was with the development of the dominant ground-cover reindeer lichens. With the exception of *Cladonia ecmocyna* Leight, which did not follow any consistent trend for the age and soil texture variables assessed, a common trend was seen with all of the other reindeer lichens, where cover decreased over the first 12 years of stand development after harvest. After 12 to 30 years of stand development, reindeer lichen abundance on sites with sand soils (Plot Code 30 sites) recovered to a point where cover values were significantly higher than all other Plot Code groups (F(5,14)=12.9, P<0.001) (Figure 4.2).

A similar trend was seen between early post-harvest comparisons on sites with finer soil texture classes (Plot Code 11, 21 and 31 sites). However, unlike sites with predominantly sandy soils, lichen recovery in the older-age classes in sites with small amounts of clay and/or silt showed little appreciable further development over younger stands. Changes in abundance of *Cladonia deformis* (L.) Hoffm. and *C. sulphurina* (Michx.) Fr. were similar to those seen for other reindeer lichens (Table 4.1 and Figure 4.3), although, the abundance of these two species did not appear to be restricted by soil texture. *C. deformis* (L.) Hoffm. had a significantly higher



Figure 4.2. Percent cover of the reindeer lichen functional groups in post-harvest pine-lichen woodlands of the Omineca region of north-central BC, grouped by soil texture class and age class. The 75<sup>th</sup> quartile, median, and 25<sup>th</sup> quartile are shown respectively in each whisker box plot, with the upper and lower lines indicating data that are beyond the range of the quartiles but not considered outliers.



Figure 4.3. Percent cover of *Cladonia deformis* (L.) Hoffm. (cross hatched) and *C. sulphurina* (Michx.) Fr. (no hatching) in post-harvest pine-lichen woodlands of the Omineca region of north-central BC, grouped by soil texture class and age class. The 75<sup>th</sup> quartile, median, and 25<sup>th</sup> quartile are shown respectively in each whisker box plot, with the upper and lower lines indicating data that are beyond the range of the quartiles but not considered outliers.

Species/	Plot Code	Mean Percent	Standard Error	Minimum	Maximum
Functional Group	(n)	Cover (%)	(%)	Value (%)	Value (%)
Reindeer Lichen	10 (3)	14.6	5.8	4.2	24.1
	11 (3)	8.9	2.3	6.2	13.4
	20 (4)	11.1	2.2	4.8	14.4
	21 (3)	6.8	5.0	0.8	16.7
	30 (3)	44.3	3.3	37.7	48.6
	31 (4)	13.9	3.3	8.9	23.5
Cladina mitis (Sandst.) Hustich	10	7.4	3.4	2.1	13.6
	11	5.4	1.5	3.7	8.5
	20	6.0	1.1	2.9	8.1
	21	2.7	1.8	0.4	6.2
	30	26.3	5.5	15.7	33.9
	31	8.5	1.5	6.6	12.8
Cladina rangiferina (L.) Nyl.	10	3.3	1.2	1.1	4.9
	11	1.8	0.5	1.2	2.8
	20	3.0	1.4	0.6	6.7
	21	1.2	0.9	0.1	3.1
	30	10.7	3.9	4.7	17.9
	31	2.5	0.8	1.0	4.8
Cladonia uncialis (L.) Wigg.	10	1.0	0.5	0.1	1.6
	11	0.7	0.3	0.1	1.1
	20	0.8	0.4	0.1	1.9
	21	2.3	2.0	0.0	6.3
	30	2.7	0.4	2.0	3.4
	31	0.9	0.6	0.2	2.6
Cladonia deformis (l.) Hoffm.	10	0.1	0.1	0.1	0.2
	11	0.0	0.0	0.0	0.1
	20	0.1	0.0	0.0	0.2
	21	0.0	0.0	0.0	0.0
	30	0.9	0.2	0.6	1.3
	31	1.2	0.1	0.9	1.4
Cladonia sulphurina (Michx.) Fr.	10	0.0	0.0	0.0	0.0
	11	0.0	0.0	0.0	0.1
	20	0.0	0.0	0.0	0.1
	21	0.0	0.0	0.0	0.0
	30	0.4	0.1	0.2	0.6
	31	0.2	0.2	0.0	0.8
Vaccinium caespitosum Michx.	10	2.5	1.3	0.0	4.2
1	11	2.3	1.0	0.6	4.2
	20	4.9	3.7	0.3	15.9
	21	1.1	1.0	0.1	3.2
	30	8.6	4.4	1.2	16.4
	31	0.8	0.6	0.0	2.5
Arctostaphylos	10	0.0	0.0	0.0	0.0
uva-ursi (L.) Spreng	11	0.2	0.2	0.0	0.5
	20	2.3	2.0	0.0	8.3
	21	0.1	0.1	0.0	0.4
	30	2.8	0.9	1.0	4.0
	31	0.3	0.3	0.0	1.0
Cornus canadensis L.	10	1.0	0.5	0.2	2.0
	11	6.5	2.7	2.0	11.2
	20	0.6	0.4	0.0	1.7
	21	1.6	0.9	0.1	3.3
	30	0.9	0.8	0.0	2.6
	31	2.1	0.4	0.9	2.8

Table 4.1. Percent cover ( $\bar{x} \pm 1$  SE) of primary lichen and forb species in post-harvest pinelichen woodland sites in the Omineca Region of north-central British Columbia. Sample size (n) for all plot codes groups is 3 except plot code 20 and 31 (n=4).

cover on age class 3 sites, compared to younger ones (F(5,14)=32.97, P<0.001).

Two trends were indicated by presence (and abundance) of low shrubs and forbs. *Vaccinium caespitosum* Michx. and *Arctostaphylos uva-ursi* (L.) Spreng had a low percent cover for the first five years of stand development. In stands that were at least six years old and had pure sand soils (Plot Code 20 and 30 sites), both of these shrubs increased slightly in abundance (Table 4.1). In contrast, *Cornus canadensis* L. was more common on sites that had finer textured soils. The abundance of *C. canadensis* L. on Plot Code 10 sites was significantly greater than the other age and soil classes (F(5,14)=3.71, P=0.024) (Table 4.1). It is evident that as sites aged beyond six years, the presence of *C. canadensis* L. declined to a relatively stable level. It did not show signs of rebounding to higher levels during the time frame of the chronosequence assessed by this study.

The slight variations in soil texture did not appear to impact the development of regenerating trees. Comparison of plots within the same age class did not reveal significant differences in density, height, and age. Along the age class gradient, however, height and average age of the trees fit the expected trend of increasing values over time. There was no apparent change in the density of trees over the age class gradient assessed (Table 4.2). A tally of total stems by diameter class for each age class is presented in Table 4.3.

The assessment of various site factors such as the percent cover of exposed rock and soil, or the cover of coarse woody debris did not reveal any significant trends. The presence of surface organic litter, however, did change significantly through the different age classes (F(2,17)=16.24, P<0.001). Accumulations were greater in age class 1 sites as compared to the other two age classes. Average percent cover values by age class were  $54.6\pm6.3\%$ ,  $15.5\pm2.8\%$ ,

Plot Code	n	Average Number of Years From Disturbance Date	Average Tree Age (yrs)	Average Tree Height (cm)	Growth Intercept SI50	Stand Density (Stems/ha)
10	3	$3.3 \pm 0.3$	$3.9 \pm 1.3$	37.6 ± 13.4	-	4987 ± 1575
11	3	4.7± 0.3	$3.9 \pm 0.3$	$60.0\pm6.7$		$4053\pm376$
20	4	$11.0 \pm 0.4$	$6.5 \pm 0.5$	$137.0\pm19.5$	$23.1 \pm 0.8$	$10580\pm2402$
21	3	$10.7 \pm 0.7$	$5.3 \pm 1.0$	$129.2 \pm 36.2$	$22.9 \pm 3.6$	$7373\pm338$
30	3	$18.3 \pm 3.5$	$12.0\pm0.5$	$250.5 \pm 24.2$	$20.2 \pm 0.6$	$9627\pm3038$
31	4	$16.0\pm1.8$	$10.1 \pm 1.5$	315.6 ± 60.1	$23.7\pm0.5$	$4250 \pm 507$

Table 4.2. Tree characteristics for post-harvest pine-lichen woodlands in the Omineca Region of north-central BC. All values are expressed as  $\bar{x} \pm 1$  SE.

Plot Code	n	Diameter Class					
		< 1.3 m tall	0 cm - 5 cm	5.1 cm - 10 cm	> 10 cm	Total Stems	
10	3	4507±1133	480±480	0	0	4987±1575	
11	3	3973±416	80±40	0	0	4053±376	
20	4	5310±783	5270±1722	0	0	10580±2402	
21	3	5200±991	2173±1257	0	0	7373±338	
30	3	2813±1462	6693±1707	120±120	0	9627±3038	
31	4	1130±149	2890±480	210±151	20±20	4250±507	

Table 4.3. Mean stem density by diameter class for the Plot Code groupings. All values are expressed as  $\bar{x} \pm 1$  SE.

and 26.8±5.3% for age class 1, 2 and 3 sites respectively.

A significant relationship (F(2,17)=18.40, P<0.001) was found between site characterization variables (average tree height and age, and soil texture) and the cover of reindeer lichen. The relationship is expressed in Equation 1 ( $r^2=0.775$ ). This relationship is only for sites within the SBS mk1 03 that have a dominant cover of lodgepole pine.

Equation 1.

Cover of Reindeer = -4.95 - 0.012 Av Tree Ht + 6.39 Av Tree Age - 3.07 Soil Texture<sup>1</sup> Lichens

# DISCUSSION

The development of terrestrial lichen mats after forest harvesting in the Omineca region was surprisingly rapid on sites with well drained sandy soils. Over a period of 17 years after harvest, or the three age classes assessed under this study, a clear trend of increasing lichen cover was evident, with lichen cover recovering to levels normally associated with 70 to 100-year-old fire-origin stands (Coxson et al. 1999). This rapid recovery is speculated to be the result of creating favourable conditions for lichens by removing the mature forest overstorey, while providing abundant lichen fragments for site recolonization.

During harvesting, mechanical disturbance reduces the cover of most understorey

<sup>&</sup>lt;sup>1</sup>Soil texture is based on an ordinal coding of soil texture classes as identified in DeLong et al. (1993) with 1 representing fine textures soils and 5 representing coarse textured soils.

vegetation, resulting in patches of exposed mineral soil and organic debris accumulations. A further reduction in vegetative cover occurs with high levels of insolation exposure. For example, cover values of *Cornus canadensis* L. in Plot Code 11 sites indicated that it was a dominant plant in the understorey of the mature stands prior to the removal of the overstorey. However, cover was significantly reduced in the older post-harvest age classes. Two other species that showed signs of physical damage from overexposure were *Cladonia ecmocyna* Leight. and *Pleurozium schreberi* (Brid.) Mitt. Declines in vegetative cover of forest floor shrubs and forbs were largely confined to the first five-years after harvesting.

Disturbance regimes created by forest harvesting may favour the establishment of lichens that propagate via fragmentation rather than spore dispersal. *Cladina mitis* (Sandst.) Hustich was the most prevalent terrestrial lichen to take advantage of the newly created microsites. In young stands, thallus fragments were often scattered across the unit. The dispersal of these fragments was a function of mechanical crushing during harvesting, with subsequent spread facilitated by both mechanical means and wind (Webb 1998). As stands age, young trees start to provide some shade and reduce the severity of drying events, yet, they do not create an environment that is suitable for feather moss to flourish. This allows growth of established thallus fragments, particularly in sites where sandy soils limit the establishment of higher plants. The development and persistence of lichen mats after harvesting is therefore closely related to mineral soil texture. In this study, lichens were prevalent on coarse textured soils that limit growth of other vegetation. Where soils were characterised by finer textures, higher plant establishment appeared to preclude substantive redevelopment of lichen mats.

Interestingly, direct correlations between soil texture and the structure of higher plant

communities were not immediately evident in our data set. However, regression analysis considering average tree age and height in association with the soil texture code revealed a significant relationship with the cover of reindeer lichens on the 03 site series of the SBS mk1. The equation suggests that as stands age, reindeer lichen cover increases where the trees are shorter and the soils are a coarser texture. This relationship is consistent with the estimation of site productivity and the conjecture that lower productivity sites support better lichen communities.

The information on tree density did not provide significant insight towards the development of lichen communities. High density stands are often considered to be detrimental to the success of terrestrial lichens. With the data set assessed, however, no significant differences of stand densities were noted between the plot code groupings. In fact, some of the most well developed carpets of lichen were associated with individual stands that had high tree densities. Where lichens persist in an abundant state they do so because of the extreme sites they are on, not because they exclude other species. This ability to function on extreme sites has lead to the classification of lichens as being stress tolerators (Grime 1977). Their inability to compete with other vegetation, such as feather mosses, is an important factor associated with their lack of presence on zonal sites in the SBS.

Site history records indicated that a wide variety of site treatments were used across the sampling matrix with little consistency being found in any single age and soil grouping. The most notable trend was that many of the age class one sites were harvested using a cut-to-length harvesting system, whereas full tree harvesting systems were used on the older sites. Based on the field samples alone, no trends of ground surface disturbance were evident, however, the

different systems could impact terrestrial lichen distribution in two manners. First, forwarding systems used in cut-to-length harvesting may not distribute lichen fragments across a unit as ground skidding (used in full-tree harvesting) does. Cut-to-length systems may also result in a higher accumulation of organic litter and debris that is scattered across a setting (Miège et al. 2001b).

Litter accumulation after harvesting may also degrade lichen sites. When considering the removal of organic biomass during a disturbance event, litter accumulation from harvesting accounts for one of the greatest differences between wildfires and harvesting systems. On sites with coarse textured soils, wildfires create growing conditions that are not suitable for many plant species to grow. Forest harvesting does not create equally severe conditions and may allow for many species that would normally be eliminated from early seral stages to be present sooner in the life history of a stand. The impact of accumulating organic debris is important in considering both the short- and long-term effects of lichen development. In the short-term, lichen mortality can be caused when communities are covered with organic litter (Webb 1998, Miège et al. 2001b). In the long-term, soil nutrient properties at a site may be modified to provide a more suitable growing medium for competitor species (Klein 1982).

#### Summary

Most concerns regarding caribou and forestry interactions involve the possible impacts of logging on terrestrial lichen sites (Cumming 1992). In the Omineca, forestry activities do not necessarily destroy lichen sites, however, they do set them up for a different pattern of community development than sites disturbed by wildfire. Understanding the ecological differences of sites that have been harvested is important towards developing strategies for managing lichen as a source of forage on caribou winter ranges. This can only be conducted by establishing a database containing both pre- and post-harvest measurements related to the ecology of these sites. Three key elements that future research projects must address are an assessment of lichen response to different levels of overstorey removal, lichen response to disturbance to the forest floor, and lichen response to varying levels of organic litter accumulations.

The abundance of terrestrial lichens varies as a function of successional stage. Forestry activities in the Omineca tend not to concentrate on the best lichen producing sites because these are often the poorest for forest production. Sites targeted for harvesting are often characteristic of late successional lichen types. The abundance of lichen in these can vary from plentiful to very scarce. On sites with plentiful lichen, minimizing the impacts of overexposure from solar radiation and disturbance to the forest floor may prove to be an optimal strategy for caribou forage management. Conversely, on sites where lichen is scarce, optimizing exposure and disturbance may promote the most productive lichen community for the site. Future research must address the question of how much exposure to solar radiation is required to have a positive response from lichen communities that are in different states of development at the time of harvesting. Likewise, information must also be collected regarding the levels and types of disturbance to the forest floor that are appropriate for the success of terrestrial lichen communities.

The accumulation of organic litter on a site is considered detrimental towards the longterm success of terrestrial lichen communities. To confirm this speculation, research activities must be coordinated to assess the impacts of litter accumulations. Documenting the relationship of litter buildup will provide insight into the long-term productivity of sites for terrestrial lichens. In addition, an assessment of areas that have undergone prescribed burning (as a means of promoting long-term regeneration of lichen) would also provide valuable insight towards understanding the ecology of these sites.

Finally, in sites within the Omineca region, greater consideration will have to be placed on reintroducing fire as a natural agent associated with stand regeneration, especially in areas where present day pine-lichen woodlands occur on finer textured soils. These areas may otherwise be lost as future caribou habitat, as vascular plants replace understorey terrestrial lichen mats.

#### **CHAPTER 5 - CONCLUSION**

The factors influencing how terrestrial lichen communities develop are not well documented. Most previous research has focussed on identifying the temporal changes on sites influenced by wildfire (Brulisauer et al. 1996, Carroll & Bliss 1982, Coxson et al. 1999, Johnson 1981, Maikawa & Kershaw 1976, Morneau & Payette 1988). Generalisations have been made regarding the mechanisms resulting in succession. For instance, it has been identified that succession is associated with changes in the wetting and drying events that occur at the forest floor (Brulisauer et al. 1996, Lesica et al. 1990), the cause of which has been generalised as an effect of crown closure occurring (Carroll & Bliss 1982, Maikawa & Kershaw 1976). This concept, however, is too simplified because the reference to crown closure does not provide an accurate description of stand architecture, or of the resulting functional attributes that are related to the interception of solar radiation. Crown closure is a two-dimensional measurement that does not take the depth of the crown into consideration. The distance that incoming radiation must pass through vegetation has a strong influence on the potency or harshness of the resulting microclimate that is created at the forest floor.

More appropriate measures of stand structure involve indirect assessments that consider the growth and total size of the trees in relation to their impacts on the microclimate at the forest floor. Examples of suitable variables are volume and biomass. Basal area, an area measure of the cross section of tree stems on an area of land, also provides for a suitable assessment. In this project, I assessed the development of the forest overstorey as it relates to the interception of incoming solar radiation and the influence that changes have on the severity of drying events at the forest floor. Assessing stand characterisation variables such as tree basal area, tree volume and tree biomass, I found that as stands age, sites succeeding to a feather moss phase had larger trees that were more capable of intercepting solar radiation. The influence of larger trees results in a moderation of the severity of drying events, thus, allowing feather mosses to become established on suitable microsites.

In Chapter 2 of this thesis, I identified that the severity and frequency of the drying events appears to be the ultimate limiting factor regarding the succession of lichen sites. This premise is based on the reasoning that under the appropriate stand conditions, feather moss will occupy the same site that was once occupied by lichen. Thus, assuming moisture input levels (i.e., the severity and frequency of wetting events) remain constant during the life of a stand, if they are suitable for feather moss to proliferate in stands greater than 150 years of age, then they should also be suitable during any other time in the development of the stand, given that other conditions are acceptable.

Developing management strategies to maintain reindeer lichens will involve the manipulation of the tree cover to create a microclimate that is not favourable for bryophytes and vascular plants. The natural mechanism that creates the desirable conditions is wildfire. However, wildfires do not appear as prevalent on the landscape as they once were. This means resource managers must determine methods to create the desired conditions via mechanical means. From a forestry perspective, technology is available to support the manipulation of the forest overstorey to create the desired microclimate conditions with little difficulty in the management of stands. Uncertainties at the forest floor considering damage to potential lichen communities and organic mats, however, raise concerns associated with the impacts of treatments.

One of the assessments in Chapter 2 looked at the accumulations of organic biomass and the potential influence on the composition of species in the forest floor plant community. I found a trend consistent with Steijlen et al. (1994) that microsites supporting moss communities had a greater accumulation of organic biomass than adjacent lichen-dominated microsites. An intact organic mat moderates the drying that occurs from the surface mineral soil, thus, lessening the impact of severe drying events. The moderation of the drying events permits feather moss to establish on a site. Once established, there is an accelerated level of organic matter accumulation. This creates a positive feedback response which further supports the growth of feather moss. It is expected that increased litter inputs, whether from overstorey leaf litterfall or feather moss accumulation, will alter the forest floor surface environment.

The response of lichen communities to mechanical disturbance regimes is poorly understood. The development of the lichen communities on sites that have been harvested appears very different from ones that have undergone wildfires. On lichen sites that are logged, the lichen communities present in 20-year-old re-establishing stands are similar in species composition and structure to the communities that are found in 100-year-old stands that develop after wildfires. The long-term implications of this temporal shift in vegetation community structure are unknown. In the short term, however, it is clearly evident that we may be able to simultaneously manage for both forestry and caribou and provide mutual benefits for both resources.

Succession of pine-lichen sites is a function of the availability of moisture and nutrients for bryophytes and vascular plants. As a result, pine-lichen woodlands have distinct characteristics that can be used to identify their presence on the landscape. The expressions of these attributes are present as variables in different inventory databases. In Chapter 3, forest inventory information was used to key out lichen sites. Specific factors assessed were the percent composition and species of the dominant tree cover, site index and aspect. In the Omineca region, typical characteristics associated with pine-lichen woodlands were sites that have well drained, nutrient poor, coarse textured soils, a south aspect and a forest overstorey dominated by lodgepole pine.

Site index was used to differentiate the ecological regimes associated with moisture, nutrient and soil textures. If terrestrial-ecosystem, or predictive-ecosystem mapping were available, results may be more accurate than in this study because the ecosystem association label within these databases provides a more direct assessment of the ecological factors that are assessed. Site index is a surrogate representing the productivity of the site which indirectly expresses the moisture and nutrient regime of a site. It is, however, a variable in the BC forest inventory database, thus is available for the entire province. Both terrestrial ecosystem and predictive ecosystem mapping are limited in their availability.

Within this thesis, I have begun to address several questions associated with the management of terrestrial lichens. I have recognised stand characteristics as factors associated with the succession of lichen sites and thus propose the manipulation of them to create desirable attributes for maintaining terrestrial lichens. Uncertainties associated with mechanical disturbance to the forest floor, however, confound the outlooks regarding the results of treatments on these sites. Incomplete documentation of cut-block history for those units assessed in the retrospective study in Chapter 4 further clouds the image of what may or may not

be acceptable.

The ecological system of pine-lichen woodlands is based on a wildfire natural disturbance regime. Whether resource managers have the ability to create the environment that results from wildfire via mechanical means has yet to be seen. Indications from the retrospective study of this thesis, as well as studies in Alberta and Ontario, are that an alternative forest floor plant community dominated the early years of a stand after forest harvesting compared to those that were burned. The predominant lichens found in young stands that have been mechanically treated were *Cladina* species. In natural stands of equal age, *Polytrichum* and *Cladonia* species are more dominant (Coxson et al. 1999). If caribou will forage in stands that are 30 to 50 years old, the temporal shift in species presence and distribution may not cause problems, rather, the result may be a favourable outcome for managing caribou and forestry interactions. Until managers can say with confidence that this is the case, however, strategies must be used to keep all options open.

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