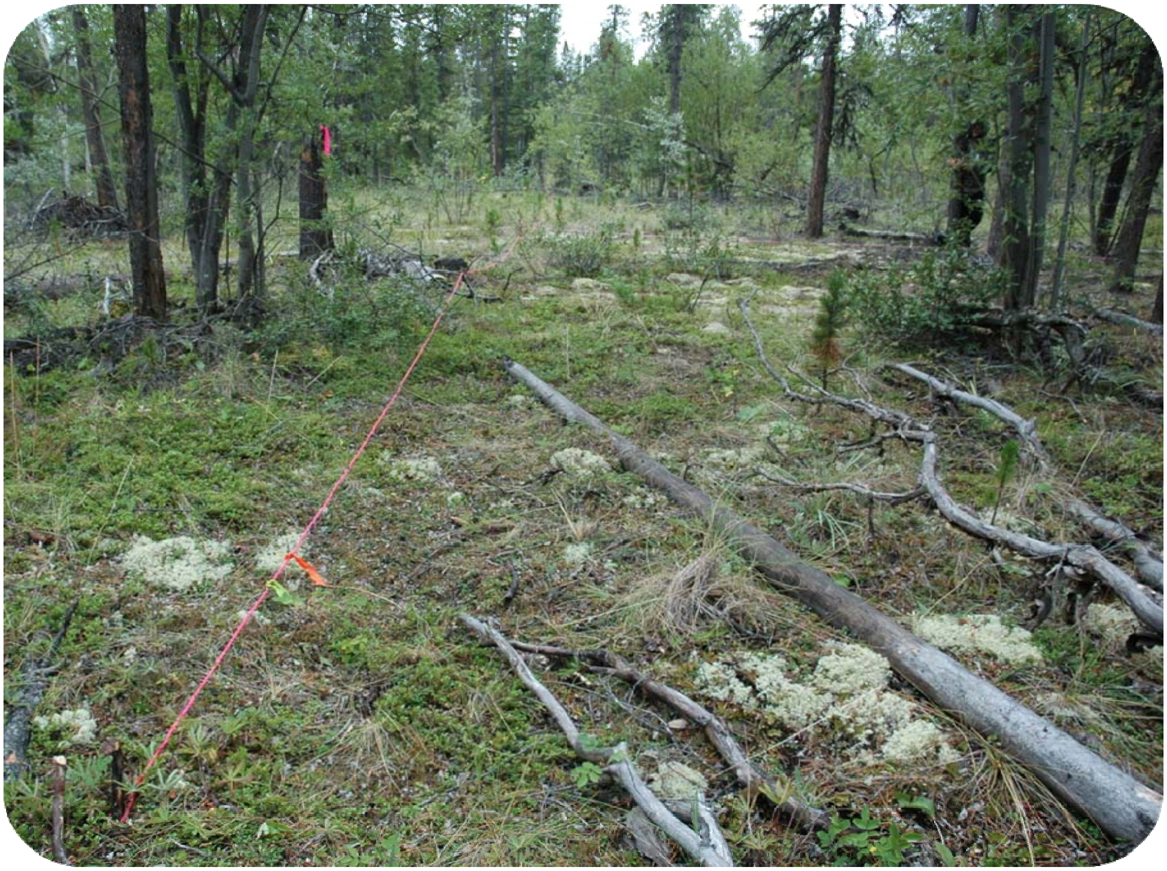
EFFECTS OF HISTORICAL TIMBER HARVESTING PRACTICES ON CARIBOU FORAGE LICHEN ABUNDANCE NEAR MARSH LAKE, YUKON



PHASE 1 FINAL REPORT

Prepared by Angeline Gough, M.Sc.
Sustainable Forest Management Research Group,
University of British Columbia

For:
Forest Management Branch,
Department of Energy, Mines and Resources
Government of Yukon

June 2010

Executive summary

The purpose of this study is to assess the effects of retention harvesting (10—40% retention) on lichen abundances in the Southern Lakes ecoregion of Yukon. Lichen, especially *Cladina, Cetraria,* and *Flavocetraria* spp., are important winter forage for caribou (*Rangifer tarandus caribou*) and the focus of efforts to harmonize forest management with caribou management in the Southern Lakes. The assessment used historically harvested areas to passively test the hypothesis that there is an effect on lichen abundances due to harvesting; no new harvesting was undertaken in this study. Regression analysis using lichen abundance as the dependent variable revealed that there are negative, predictive relationships between lichen abundance and feather moss, ground shrub, and grass abundances as well as ground cover of live tree stems, suggesting that the direct impacts on lichen abundance come from microsite factors influencing the abundance and interactions of lichen with vascular and non-vascular plants. Furthermore, ground cover woody debris (coarse and fine) also had a negative, predictive relationship to lichen, indicating that the physical, and possibly chemical (nutrient), influences of woody debris play an important function in determining the detriment of harvesting on forage lichens. Further analysis showed that there are significant differences between harvest and control plots for these variables and other 'secondary' variables that are not significant in the regression such as canopy closure and stand volume. Further analysis also confirmed that controls have a significantly higher canopy closure and stand volume than harvested areas. The literature shows that harvesting affects seral stage, direct solar radiation hitting the understory, and available moisture. Lichen can be directly affected by these changes. The results of this study strengthens these assertions; however, lichen abundance did not differ significantly between harvest and control, suggesting that the influence of retention harvesting on lichen is predominantly indirect, e.g. through impacts on the ground cover variables that predict lichen abundance. Furthermore, the data analysis suggest that lichen abundance is negatively impacted under both treatment types, for example, through ground shrub competition by shrub species who flourish either under closed or open canopy conditions. The results also reinforce the assertion that there are physical and chemical effects of logging debris on plant community composition post-harvest and that woody debris is negatively affecting the abundance of lichen and of forage lichen in particular.

Summary of recommendations

1. Maintenance, not recruitment, of lichen patches and microsites

   Maintaining and enhancing the pre-harvest abundances of forage lichen is preferable over emulating natural disturbances that encourage lichen recruitment (e.g. surface fire). Forage lichen dominate mature seral stages (prior to crown closure) while recruitment would favour early seral stage lichen first, taking up to 50 years to achieve abundant forage lichen cover.

Maintaining as many of the lichen patches and microsite features that favour lichen abundance in the stand structure should be a key driver in designing a retention harvesting regime.

2. Further experimentation with a branch and stem harvesting regime

   One possible retention harvesting regime under a maintenance system could be branch and stem harvesting (BSH). Under a BSH regime, only needles would be left on the ground after harvest. This would supply enough nutrients to the regenerating forest to counter the nutrients removed through harvest while minimizing the physical impact to terrestrial lichen from woody debris left on the ground. As well, it may control lichen competitors by reducing the post-harvest nutrient flush that tall forbs, grasses, and fast growing shrubs can capitalize on much better and faster than slow-growing lichen.

3. High level of retention and small patch size

   In pilot trials of different harvest levels and patterns of retention in northern BC, Miege, Armleder, et al. (2001) concluded that a 30% area removal using group selection in 15m diameter circular openings has been shown to approximate the conditions in an uncut forest and produce no discernable difference in lichen abundances, mortality rates, and diversity. This is attributed to lower slash and more tree cover for lichen protection. This is congruent with the maintenance system of lichen management, although further analysis is needed to see if this would be suitable practice in the study area.

4. Post-harvest lichen success monitoring should begin immediately after logging and include
   a. Lichen seeding

      Dispersal of thallus fragments of important forage lichen species after harvest may greatly increase the chances of maintaining the pre-harvest composition and abundance of forage lichens, aiding in the success of a maintenance system of lichen management. This treatment could even be extended in the harvest planning process to include the salvaging of lichen colonies that foresters anticipate being destroyed, to use as a source of thallus fragments for re-seeding the site.

   b. Control of tall forbs and lichen ground shrub competitors

      As well as reducing the post-harvest nutrient flush through branch and stem harvesting, mechanical or manual control of terrestrial lichen competitors such as ground shrubs and tall forbs may be necessary on some more mesic sites where nitrogen and moisture are less limiting. These sites warrant more intensive treatment in order to salvage them as forage lichen producing sites because with the reduction in competition, forage lichens may become rapidly abundant with more available moisture and nutrients.

5. Further research into threshold levels for retention

   There is evidence to support a hypothesis that a canopy closure of approximately 40% may represent a threshold of cover after which feather mosses can out-compete lichen resulting in serious reductions in lichen abundance. On the other hand, crown closures of 0-40% may represent increasing benefit to lichens, especially forage lichens such as *Cladina mitis*, which is an abundant and important lichen for caribou in the region. It is important to test this hypothesis through active adaptive management, especially in light of the recommendation to use high retention levels and small patch sizes because retention levels that are too high may counteract the benefits to forage lichen that managers are seeking.

6. Use the regression model as a predictive tool

   The results of the regression are promising as a predictive tool, although much more research would have to be done to create a reliable model for use by forest managers. If constructed, this model would be helpful in selecting practices to enhance and maintain lichen abundances by using pre-harvest information on vegetative and environmental attributes to model establishment regimes for lichen and other key ground cover species.

As a final note, this study has been completed at the operational-scale and only captures site-level (also called stand-level) interactions between variables. Therefore, although these recommendations are useful for considering management decisions at broader scales, further research is necessary to understand the effect of these recommendations across the landscape. Further trials would also be necessary to test the efficacy of the recommendations in the Southern Lakes context, as these practices have been developed and tested in ecosystems which share characteristics with those found in the Southern Lakes but have some potentially important differences in climatic and edaphic conditions (for example, annual rainfall and depth of the winter snow pack). An active adaptive management phase for this project would be necessary to test the recommendations considered by the government to have the most potential for implementation. Broader-scale variables could also be included in this phase, such as natural disturbances and cumulative effects, if time and budget allowed. This study has produced a sound model on which to build scientifically-defensible lichen management practices in the region, but without an experimental phase to test the model and compliment the passive study, the use of the results and recommendations in this work is limited.

Contents

List of Tables

List of Figures

Acknowledgments

Forest Management Branch and Department of Environment staff collaborated on the planning for this project. Aynslie Ogden acted as the project coordinator for direction on project objectives and sampling design and assisted with the study site selection. Thanks to Andy Wright, Erin Dowd, Forestry STEP student Aldo Van Eyk and Habitat Programs STEP student Brodie Smith for helping to collect data on site and forest characteristics. The Department of Environment Habitat Programs team of Val Loewen, Jennifer Staniforth, Angela Milani, Tess McLeod and Lee Mennell (hired through funding provided by FMB) collected all the vegetation understory data.

This project was funded by the Forest Management Branch of the Department of Energy, Mines and Resources.

Introduction

Project goals and research questions

The goal of this study is to inform the selection of forest harvesting practices that will minimize deleterious effects of harvest on terrestrial forage lichens in winter caribou (*Rangifer tarandus caribou*) habitats of the Southern Lakes Region in south central Yukon. An abundance of formal research on terrestrial lichen and their relationship to caribou and to vegetative and environmental factors exists for other boreal forest areas in Canada and abroad, but very little has been conducted in Yukon specifically. Recognizing this, the Forest Management Branch of the Government of Yukon as undertaken a two-phase research program to meet this demand. The first phase of this study uses a passive adaptive management approach that is implemented at the operational level and focuses on site- and microsite level characteristics. Passive adaptive management constructs the best possible model based on available data (Cichowski, et al. 2001). Our passive model may be used to guide management to a limited extent but an experimental phase is necessary to test the model prior to implementing any new management practices. Furthermore, landscape-level interactions are acknowledged, but not measured, in this study, and would need to be addressed in order to assess the model at broader scales of forest management and conservation.

This report includes the methods, results, discussion, and management recommendations stemming from a retrospective study of historically harvested areas in the region and the impact of forestry on lichen abundances, as compared to uncut stands with similar site characteristics. Our primary research question is two-fold:

1. What are the site and microsite factors that influence lichen abundances in the managed forests of the Southern Lakes Region?
2. What are the site-level effects of variable retention harvest practices on lichen abundance and on the factors that influence lichen abundance in the region?

Background

Forest-dwelling woodland caribou, such as the Southern Lakes herd, are thought to be primarily predator limited (Seip 1991; Yukon Department of Renewable Resources 1996) and select range first for predator avoidance and secondarily to meet forage requirements (Bergerud, Ferguson and Butler 1990). Lack of sufficient winter forage may drive foraging behaviour where caribou are at increased risk of predation, underlining the need to maintain forage lichen abundances in the presence of forest harvesting in areas where caribou select range based on predator-avoidance (Anderson, et al. 2002). It has been suggested that if winter forage habitat is reduced through clearcut logging, predation on caribou will likely increase, underlining the need for retention harvesting regimes that allow caribou to live at low densities, avoid predators, and meet their forage lichen needs while still allowing for an acceptable stream of revenue and goods from local forests (Miege, Armleder, et al. 2001).

Wintering caribou rely heavily on abundant terrestrial lichens as forage (Farnell and McDonald 1990) (Thomas, Barry and Alaie 1996; Klein 1982; Pharo and Vitt 2000). In the Southern Lakes region, arboreal lichens are not present in great enough quantities to be an important food source. Instead, caribou utilize the abundance of terrestrial lichens, which are accessible because the snow pack in the region is low enough to allow the use of terrestrial forage year-round. Some studies assert that regional variation in climate is a primary factor influencing lichen community development (e.g., Lessica, et al. 1991) although microsite variations also play an integral role (Sulyma 2001; Harris 1996). Overall, the development of terrestrial lichen communities is thought to be determined by site characteristics (moisture, nutrients, light), disturbance history, reproduction and dispersal, and competition with terrestrial plants (Williston and Cichowski 2006). This study will focus on the effects of site characteristics, competition, and the disturbance effect of historical timber harvests at the operational-level (site or stand-level interactions). Reproduction and dispersal are outside of the scope of this project, as are landscape-level and climatic effects.

The structure and density of the stand control the quantity, quality, spatial and temporal distribution of light and influences local precipitation and air movement. These factors taken together determine the air humidity, temperature, and to some extent, soil moisture conditions (Jennings, Brown and Sheil 1999). Harvesting reduces the density of the stand and changes its structure; in doing so, soil moisture increases as evapotranspiration from trees decreases (Williston and Cichowski 2006). Concomitantly, the rate of surface evaporation increases with increasing incident solar radiation which can create microclimates that go from saturated to dry extremes more quickly than under a forest canopy (Harris 1996; Johnson 1981). For unrooted vegetation, including feather moss and terrestrial lichens (e.g., those that are acclimatized to moderate canopy cover), this can cause rapid desiccation (Harris 1996; Johnson 1981). Soil moisture conditions also temper the nature and rate of succession following disturbance; wetter soils may reach mature, closed canopy seral stages faster than drier soils (Williston and Cichowski 2006). Williston and Cichowski (2006) conclude that events that influence soil moisture will therefore influence the successional process. Testing the interactions between harvest disturbance, soil moisture, and successional process is beyond the scope of this study, however, an understanding of these relationships is important for interpreting the relationships between terrestrial forage lichens and their competitors.

Terrestrial fruticose macro-lichens such as *Cladina mitis, C.rangiferina, Cladonia uncialis, Cetraria islandica, Flavocetraria nivalis, F. cucullata* and *Stereocaulon spp.,* heretofore referred to as forage lichens, comprise the genera of terrestrial forage lichen, with *Cladina* being the common favourite for caribou (Sulyma 2001; Klein 1982; Williston and Cichowski 2006; Pharo and Vitt 2000). These lichens have a broad tolerance for moisture conditions, but seem to thrive best on dry, rapidly drained soils that are nutrient poor, particularly in cold climates (Williston and Cichowski 2006), because the success of potential competitors is limited under these conditions (Ahti 1961). For example, lichen-dominated terrestrial communities are characteristic of boreal forests (Ahti and Hepburn 1967) such as those found in the study area. The environmental requirements of forage lichens are similar to those of many of its competitors, including *Arctostaphylos uva-ursi* (kinnikinnick), *Pleurozium schreberi* (red-stemmed feather moss), *Hylocomium splendens* (stair-step feather moss), *Empetrum nigrum* (crowberry), and *Linnaea borealis* (twin-flower), suggesting that forage lichens would do well in closed canopy conditions if competition were absent (Sulyma 2001; Ahti 1961; Williston and Cichowski 2006). However, very mature forest stands may show reduced lichen productivity (Klein 1982), likely due to competition from mosses, such as *Pleurozium schreberi,* and vascular plants (Williston and Cichowski 2006; Pharo and Vitt 2000). Despite a basic understanding of competition under these conditions, the nature of competitive interactions between terrestrial lichens and moss and herbaceous species remains poorly understood (Cichowski, et al. 2001), especially under harvest disturbance and in earlier successional forest stages.

Terrestrial forage lichens are thought to be photophiles (Ahti and Hepburn 1967), although recent research has shown that these lichens can be found beneath dense and open stands (Goward 2000), suggesting that lichens are tolerant of a range of moderate to high light exposures, but are not dependent upon these exposures (Williston and Cichowski 2006). Furthermore, lichen response to increases in solar radiation may depend on the anticedent conditions in which the lichen have flourished. For example, studies suggest that lichen species that have flourished under moderately shady conditions are more vulnerable to the drying effects of the sun and are prone to dessication from the sudden and drastic increase in direct solar radiation following harvest, although the response may take up to 5 years to be fully realized (Miege, Armleder, et al. 2001; Sulyma 2001; Williston and Cichowski 2006). In addition, given the presence of forage lichens in later seral stage forests with more shade (prior to canopy closures that encourage feather moss), they are likely to be vulnerable to dessication. In species such as *Cladina rangiferina, Cetraria islandica,* and *Flavocetraria* spp., respiration and photosynthesis rates are at their maximum when lichen thalli are at or near saturation and these rates decrease dramatically as the lichen dry out (Bliss and Hadley 1964). Dessication also may depend on the species of forage lichen in question. For example, *C. rangiferina* is considered a more mesic lichen species that may decline with decrease in canopy cover while *Cladina mitis* exhibits a higher tolerance to dry conditions (Ahti and Hepburn 1967; Harris 1996). Lichen tolerance for dessication is a definite advantage over potential competitors; however, lichens require humidity for transpiration and growth (Ahti and Hepburn 1967) and an environment that provides enough humidity for these activities, as well as providing periods of dryness where lichen can out-survive competitors, is likely an ideal scenario for lichens to flourish (Williston and Cichowski 2006).

Terrestrial lichen regeneration following natural disturbances is relatively well-understood (Goward 2000; Klein 1982; Rupp, et al. 2006; Jandt, et al. 2008; Arsenault, et al. 1997). Briefly, they invade a disturbed area in the first years after fire via thallus fragments, sporedia, or apothecia (the timing and method depends on the species) (Johnson 1981). Early succession stages usually have an abundance of *Cladonia* while middle stages may be dominated by *Cladina*, which are slower to increase in abundance but can out-compete *Cladonia* species. Response to forest harvesting is not as clearly delineated and prediction may depend on how well the harvest disturbance emulates fire disturbance (Miege, Goward, et al. 2001; Webb 1998). Furthermore, caribou in the region have adapted to a fire cycle with a 100—150 year return interval (Anderson, et al. 2002), but timber harvest does not readily emulate the cyclical and temporal patterns of fire disturbance (McRae, et al. 2001), so there is limited information from fire studies that may pertain to caribou management, specifically related to lichen abundance, in harvest situations.

It is generally agreed that logging reduces terrestrial lichens (Webb 1998; Miege, Goward, et al. 2001; Bråkenhielm and Liu 1998) although the extent of the reduction depends on cutting practices (Stevenson, et al. 2001) and the amount of mineral soil disturbance (Coxson and Marsh 2001). Forest harvesting and concomitant silvicultural practices have traditionally been considered sources of over-exposure to solar radiation, fragmentation, and burial of existing lichen mats, especially if lichens have developed under moderately closed-canopy conditions (Sulyma 2001). Furthermore, lichens are easily broken and their cover can be drastically diminished by frequent disturbance from trampling (Crittenden 2000), after which their regeneration may take decades (Webb 1998). However, there are also potential benefits to lichen from harvesting, including stand rejuvenation, where tree removal and disturbance pushes the stand back to an earlier successional state where the canopy is more open. In addition, harvesting can control lichen competitors by opening up the stand and creating more extreme conditions that favour the life-history strategy of lichen over other plants. Forest practices in areas that support lichen have the potential to benefit caribou, but there are many considerations to account for before these benefits may be realized. This study looks specifically at site and microsite interactions between terrestrial lichens and the vegetation and environmental variables that may affect the abundance of these lichens as forage of wintering caribou. The study area and plot selection processes are outlined in the methods section, followed by the results of multiple regression, multivariate analysis of variance, and correlation analyses that are aimed at teasing apart the web of relationships that help predict lichen abundance. The discussion will target the immediate interpretation of the results while management recommendations take the sum of the information from the study and the large body of available literature to craft a cohesive set of actions that can inform forest practices in conjunction with management for lichen, as well as guide the development of the second phase of the Lewes Marsh Monitoring Program.

Methods

Study Area

The Southern Lakes Region is located in south-central Yukon and is characterized by large lakes, variable topography, broad valleys and numerous mountain peaks over 2000m asl (Florkiewicz, Maraj, et al. 2007). The McConnell glaciation, the region's most recent, has had a strong influence on the area topography. The landscape is dominated by glacial-fluvial deposits of gravel and sand overlain with lacustrine clays and silts. These features are associated with the fluctuating lakes and fluvial processes related to water being impounded behind the retreating glaciers (Florkiewicz, Maraj, et al. 2007). Current precipitation levels reflect the rain shadow effects of the Coast Mountains to the west— the region receives 200-325mm annually, roughly half of which falls as rain while the average snow depth is 11cm, averaged over 1971-2000 (Environment Canada 2009). Annual mean temperature for the same period is 0.7°C (Environment Canada 2009). This dry, cool landscape supports a variety of ecosystems, including open coniferous forests dominated by lodgepole pine (*Pinus contorta*) or a mix of lodgepole pine and white and/or black spruce (*Picea glauca* and/or *P. mariana*) on rapidly drained glacial-fluvial and morainal deposits (Government of Yukon 2008). The understory vegetation is dominated by shrubs such as *Sherperdia canadensi*s (soapberry)*, Ledum groenlandicum* (Labrador Tea) and *Arctostaphylos uva-ursi* (kinnikinnick)*,* bryophyte species such as *Pleurozium schreberi* (red-stemmed feather moss)*, Hylocomium splendens* (step moss)*,* and terrestrial lichens such as *Cladina mitis, Cladonia* spp. and *Peltigera* spp. Soils are predominantly Brunisols, mostly belonging to the Eutric sub-group, which overlay a variety of glacial parent materials (Government of Yukon 2008). The influence of discontinuous permafrost scattered throughout the area can be observed in some soil pedons (Smith, Meikle and Roots 2004).

Historical harvesting practices

Kirk Price, Forest Management Analyst of the Yukon Forest Management Branch (personal communication 2009) provided the following description of historical harvesting practices. Prior to the 1990's, logging was largely selective— large trees were hand-felled with a chain saw and hauled to the landing with a skidder where the logs were either trucked out or milled on site with a portable sawmill. By the 1990s harvest blocks included small clear-cuts with mix of harvest methods, although hand-felling and skidding remained common. It was also fairly common to pile and burn slash on site in larger blocks, or simply spread the slash around the block after harvesting in smaller clear cuts. Regeneration was usually natural, although some planting and fill planting have been noted (Yukon Government 2005). None of the replanted blocks were scarified prior to planting . Historically harvested areas range in size from 1.5ha—12ha and have an average size of 4.6ha (Government of Yukon 2005).

Site selection

The areas considered for inclusion in the study were all in the Boreal Cordillera ecozone[1] and the Yukon Southern Lakes ecoregion[2] (ecoregion 177) (Smith, Meikle and Roots 2004). Candidate sites were chosen from areas surveyed in the 2005 Whitehorse Planning Assessment (WPA). Specific harvest planning areas (HPAs) were flagged as important to the study because they had a variety of historic harvest blocks and were within either 1) high value winter caribou habitat or 2) the Zone of Influence for high value winter caribou habitat (Florkiewicz, Maraj, et al. 2007) and were categorized as pine or mixed pine forest cover types. Historically harvested areas are delineated and described in the WPA Government of Yukon 2005). This study is concerned with harvests completed more than 5 years ago and less than 20 years ago, with retention levels that vary between 5—40%. After assessing the sites and the harvested areas in them, three sites were chosen for the study: Lewes Marsh HPA, Marsh Lake Dump HPA, and Jake's Corner HPA (see Figure 5, Figure 6, and Figure 7 in Appendix 1- Maps of the harvest planning areas (HPAs)).

Plot selection

The three HPAs (see Appendix 1) were scouted for harvest and control treatment types. Harvest plots have a retention level of 5-40% while controls have 100% retention. Harvest plots were selected from the historically harvested areas in each HPA as to obtain a range of sites that were similar in slope, terrain, elevation, vegetation type, and soil characteristics including soil parent material, soil drainage, and soil moisture (Table 1). Control plots, established in a ratio of about one per 1-3 treatment plots, were scouted from the surrounding uncut forest and the same selection criteria were applied. To confirm that sites selected accurately reflected this criteria, these characteristics were measured along with site variables. Control plots in this study had no history of harvest and had a similar stand age to the retention trees in treatment plots. These criteria represent relatively flat, meso-slope conditions in an elevation band that is consistent with pine-dominated vegetation communities.

SLOPE	TERRAIN	ELEVATION	VEGETATION TYPE	SOIL
0—10%	Even—rolling	700—800m	Lodgepole Pine—Spruce forests (open or closed) Stand types: - Pine/Labrador tea —moss - Pine/bearberry - Pine/lichen	Glacial-fluvial or morainal parent material Well to rapid drainage Mesic to sub-mesic soil moisture Thin humus layers Under-developed, sandy soils

Table 1. Criteria for plot selection

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[1] Ecozone is defined as "an area of the earth's surface representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors" (Smith, Meikle and Roots 2004)

[2] Ecoregion is defined as "a part of an ecoprovince [subset of an ecozone] characterized by distinctive physiography and ecological responses to climate as expressed by the development of vegetation, soil, water, fauna, etc." (Smith, Meikle and Roots 2004)

In the Lewes Marsh HPA, 14 treatment and 6 control blocks were established while in the Marsh Lake Dump HPA, 5 treatment and 3 control plots were established and in the smaller Jake's Corner HPA, 3 treatment and 3 control plots were established for a total of 34 plots in our sample. Each of the 34 plots has three subplots laid out 50m apart from mid-point to mid-point along a 150m transect (Figure 1). The point of commencement (POC) for each plot was designated at one end of the harvest block and the bearing for the transect was the nearest cardinal direction to the middle of the plot. Owing to the irregular shape of these historic harvest areas, some transects had to jog to the left or the right of the cardinal point in order to stay in the treatment area.

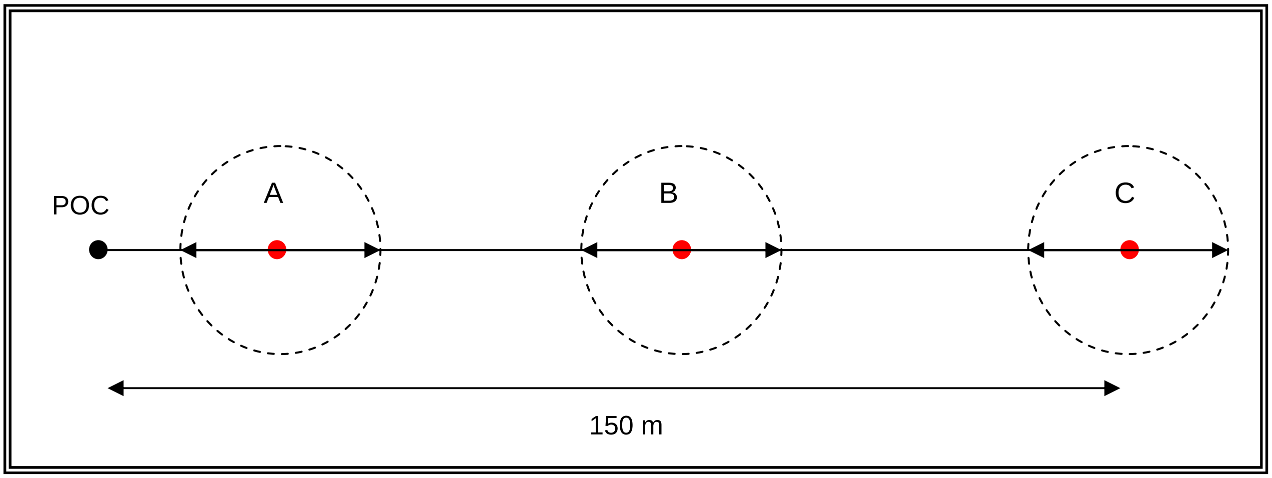

Figure 1. Study plot formation with 3 subplots; each with a 25m transect running in the direction of the plot transect

Lichen and vascular plant abundances

Estimates of vegetation characteristics may differ by sampling method. Many microplots result in more accurate cover estimates but are less likely to sample rare species, while visual estimation over larger plot sizes may capture more species and may perform better in areas with sparse vegetation but are less accurate measures of cover (Lessica, et al. 1991). In order to ensure that vegetation sampling was both accurate and comprehensive, percent cover of terrestrial lichens, bryophytes, shrubs, trees, grasses, woody debris (coarse and fine[3]), and litter were visually estimated across the entire 400m^2 subplot and in 1m^2 microplots embedded in the subplot. Visual estimation was selected because it is efficient, accurate, precise, and sensitive regarding the observation of small and rare species compared with point-frequency and subplot frequency estimation methods, even when considering inter-observer variation (Brakenhielm and Liu 1995).

Four microplots were established per subplot. They were arranged in each cardinal direction at a 5 meter distance from subplot centre. Vascular plants were identified to genus and species using *Flora of the Yukon Territory* (Cody 2000). Unknown species were either identified to genus or grouped into broader taxonomic units as *sp* or *spp*. while a few, deemed important or in large enough abundance,

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[3] Coarse woody debris is defined as having a diameter > 7cm; fine woody debris has a diameter < 7cm

were collected and subsequently identified to species. Caribou terrestrial forage lichens (foliose macro-lichens in the genera *Cladina, Flavocetraria,* and *Cetraria*) were consistently identified to species. Other lichens were identified to genus (*Peltigera*, *Cladina* cups, *Cladina* horns, *Stereocaulon*) because they are not a significant source of lichen forage for caribou (Florkiewicz, Maraj, et al. 2007). Finally, the crustose group was only identified as such, owing the difficulty in identifying this group to species and our focus on caribou terrestrial forage lichens in the study. All lichens were identified using *Lichens of North America* (Brodo, Sharnoff and Sharnoff 2001).

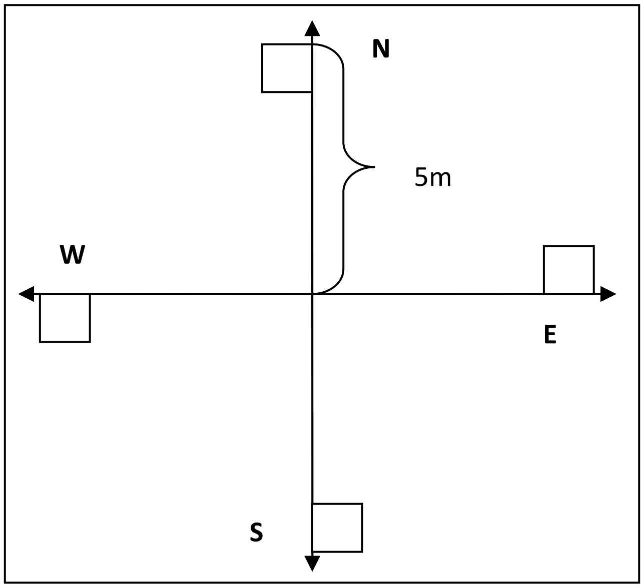
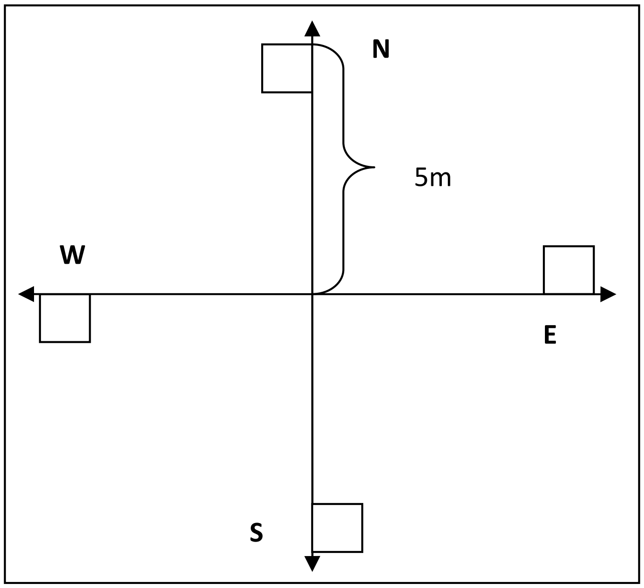


Figure 2. Layout of 1m^2 microplots within each subplot

Guidelines from the B.C. Field Manual for Describing Terrestrial Ecosystems (Province of British Columbia 1998) were used to assist with percent cover estimates. We attempted to ensure that the total cover of plants and other non-vegetation covering the ground was equal to 100%. Coarse woody debris that was raised off the ground and pine needles, which tended to have high cover in many plots, were complicating factors. If large trees, debris piles or multi-stemmed shrubs that comprised a significant amount of ground cover were encountered the quadrat was moved to the 6m mark or if that did not solve the problem, was placed on the other side of the tape.



Although percent cover estimates were made for each species, cover data was grouped into strata according to plant height and function (Table 2). Further groupings were done based on preliminary data analysis using scatter plots to estimate each group's relationship to lichen abundance. For example, woody debris was pulled out of the non-vegetated areas group because the linear relationship between lichen and woody debris was stronger than that of the non-vegetated areas grouped together. Similarly, shrubs (excluding ground shrubs) were grouped together because their linear relationships with lichen were very similar. This preliminary cover analysis was important in teasing out variables for use in multiple regressions.

STRATA	SUB-STRATA	ACRONYM	DESCRIPTION	COMMON SPECIES[4]
Trees	Trees	TR	trunks of trees or stems of medium/tall shrubs	*Pinus contorta, Picea glauca, Salix spp*
Shrubs	Tall Shrubs	TS	woody plants > 2m tall and dbh <7cm	*Shepherdia canadensis, Salix spp., Rosa acicularis, Populus tremuloides, Ledum groenlandicum*
	Medium shrubs	MS	woody plants 0.5 – 2m	
	Low shrubs	LS	woody plants 0.1 – 0.5m	
	Ground shrubs	GS	woody plants <0.1m	*Arctostaphylos uva-ursi, Vaccinium vitis-idaea, Empetrum nigrum, Linnaea borealis*
Forbes		FB	Non-woody vascular plants <15cm tall	*Epilobium angustifolium, Lupinus arcticus, Geocaulon lividum, Mertensia paniculata*
Grasses		GR		*Festuca altaica, F. saximontana, Calamagrostis spp.*
Lichen		LN		*Cladina stellaris, C.mitis, Peltigera spp., Cladonia spp.*
Bryophytes		BR		*Hylocomium splendens, Pleurozium schreberi, Polytrichum spp., Dicranum spp.*
Fungi		FG		Not identified to species
Non-vegetated areas	Litter	LT	Fine organic material not incorporated into the humus layer	n/a
	Coarse woody debris	CWD	Downed woody debris > 7 cm in diameter	n/a
	Fine woody debris	FWD	Downed woody debris <7 cm in diameter	
	Bare ground	BG	No vegetation	n/a
	Rock	ROCK		n/a
	Water	WTR		n/a

Table 2. Strata categories for microplot assessment of cover and common species in each group

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[4] For a full species list, please see Appendix 4- Complete plant list with species codes.

Ecological and stand characteristics

Data was collected using the Yukon Forestry Monitoring Program Field Manual and Monitoring Protocols (2008) (Table 3). Treatment plots use a fixed-radius method for measuring the trees in each 400m^2 subplot. Fixed radius method is when all the trees (>7cm in diameter) in the subplot are measured. Control areas use a variable-radius method, where all trees > 7 cm in diameter that are considered 'in' from the centre of the subplot, using a prism (BAF=3), are measured. Critical distances were taken for trees that were considered borderline, to calculate if they were in or out.

Canopy closure, as an indicator of stand density, was measured with a concave, spherical densitometer. Four measurements were taken, one in each cardinal direction, from the stake at the centre of the subplot. Similar site positioning and the use of a leveling bubble in the densitometer helped to reduce the error associated with this type of crown closure measurement. As well, the same observer measured crown closure in each subplot, across all plots, in order to eliminate the effect of inter-observer variation (Ganey and Block 1994; Laymon 1988).

PROTOCOL	DATA COLLECTED	MODIFICATIONS FROM PROTOCOL
Site Description	Ecoregion, slope, aspect, terrain, elevation, vegetation type	No modifications, measurements taken as outlined in the manual
Forest mensuration	Tree species, dbh, height, age, tree-class, crown-class, dead/dying top, seedling tally, sapling tally, canopy closure	Excluding phase of beetle attack and pathological indicators
Coarse woody debris (CWD)	Species, origin (pre or post-harvest), windthrown (y/n), diameter, decay class, and length of intact piece	Excluding the tilt angle
Fuel Treatment Prescription Compliance and Effective Monitoring Protocol	Stump tally by size class, species and stump height	Only the stump measurement section of the protocol was used
Soil description	See Yukon Forestry Monitoring Program Field Manual and Monitoring Protocols (2008) for full details	No modifications, measurements taken as outlined in the manual

Table 3. Data collection protocols, data collected, and modifications of the protocols for this study

Forest mensuration data (diameter and heights of trees) was used to calculate post-harvest stand volumes. Following Kozak (1995), we calculated total tree volume using Schumacher's Volume Equation:

$$V= aD^bH^c$$

Linearized by logarithmic transformation to:

$\log(V) = b_0 + b_1\log(D) + b_2\log(H)$

where: V = total tree volume
D = diameter at breast height
H = total tree height
b_0, b_1, and b_2 = regression coefficients estimating a, b, and c

Regression coefficients for each tree species were drawn from the Yukon Forest Inventory Compilation System (FIS v.3.0) (Dendron Resource Surveys Inc. 2002) (see Table 4 for values). Since regression coefficients are delineated by ecoregion, these coefficients reflect conditions specific to the "Lake Laberge" ecoregion, now referred to as the Yukon Southern Lakes Region (Smith, Meikle and Roots 2004).

REGRESSION COEFFICIENT[5]	PINE	SPRUCE	ASPEN
b_0	-4.288192771	-4.363512104	-4.406713933
b_1	1.95239	1.77531	1.88989
b_2	0.91923	1.1098	1.04839

Table 4. Regression coefficients for volume calculations (from FIS (Dendron Resource Surveys Inc. 2002)

For fixed radius plots (treatment plots) the tree volumes were then summed over the subplot and multiplied by a plot correction factor of 25 to get the total stand volume in hectares for each subplot. An average was taken to achieve a stand volume for each plot.

To obtain pre-harvest stand volumes, the stand reconstruction protocol used by the Yukon government's Forest Management Branch was used to calculate the original tree volumes from stump measurements (diameter, height, and species) (W. Young, personal communication). This included coefficients from Demaerschalk and Omule (1982) for reconstructing diameter at breast height. The reconstructed tree volumes were added to the tree volumes for treatment plots prior to calculating stand volume for pre-harvest stands.

To calculate stand volume for the variable radius plots (control plots), the method follows Avery and Burkhart (1983). Total tree volumes are calculated similarly to those of fixed-radius plots, but in order to obtain stand volumes, we must first standardize the plot size for the trees. We used critical distances to obtain tree factors for each tree, which we could then use to multiply the tree volumes to obtain standardized plot areas per tree. The total tree volumes were then summed over the subplot and averaged over the plot to obtain stand volumes. A plot correction factor is not needed for variable radius plots as this is incorporated into the tree factor (Avery and Burkhart 1983).

The Coarse Woody Debris Assessment in the CWD/Fuel Calculator (Ember Research Services Ltd. 1997) was used to obtain volume, weight, and piece of CWD per hectare.

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[5] b_0, b_1, and b_2 are equal to a, b, and c respectively in the Yukon FIS system; the only change is that $b_0=\log(a)$

Data analysis

There were many variables that could potentially be used in the analysis. Screening variables included cleaning data, averaging across subplots to gain plot-level values, analyzing and normalizing data through square root, arc-sine, and logarithmic transformations, and plotting data against lichen abundance to see if there were any noticeable trends. When comparing the effectiveness of the microplot versus subplot data sets in the analysis, it was found that the two were not significantly different and only the microplot data set would be needed. Using microplot data means that percent cover estimates are more accurate, but that some rare species may be missed. Given that the focus is on harvest effect on lichen and not on species richness or abundance, losing some rare species is not an issue.

Multiple regression is useful in exploring the relationship between a dependent variable (lichen abundance) and several independent variables (measured in the study area) in order to ascertain which variables have a direct, predictive relationship with lichen. These relationships are central to understanding how forest harvesting may impact lichen abundance. The number of variables should be lower than 10 in order to keep the data interpretation manageable and reduce the probability of a Type II error, as Type II error increases with the number of variables included (Kleinbaum, Kupper and Muller 1988). Thus, potential regression variables were first plotted against lichen abundance in a scatter plot to test their potential for significance in the regression. Once the data was transformed and the assumptions of multivariate normality were met, a standard multiple regression was run using SAS 9.2 (for windows) on the variables that showed a relationship to lichen abundance at the $\alpha=0.05$ level. Statistical regression techniques were used to compare statistically significant variables ($\alpha=0.05$) with intuitive significant ones in order to derive a final standard multiple regression equation that made intuitive sense and had a solid statistical basis.

MANOVA tests were employed to determine if there were any significant differences between treatments types (harvest and control). Cover variables used in the multiple regression and other environmental variables which are highlighted in the literature as having an influence on terrestrial lichen, but which were not significant in the regression, were assessed together as dependent variables in the MANOVA ($\alpha=0.05$; H_0: $\bar{\mu}_t = \bar{\mu}_c$, H_1: $\bar{\mu}_t \neq \bar{\mu}_c$). When SAS performs a MANOVA, ANOVA is used to look specifically at differences in individual variables between harvest and control ($\alpha=0.05$; H_0: $\mu_t = \mu_c$, H_1: $\mu_t \neq \mu_c$). MANOVA often renders results similar to ANOVA but running the variables together allows for correlations between variables to be considered both within a treatment type and between treatment types, which allows us to test for overall type effect. As well, running the variables together avoids inflated Type I error due to multiple ANOVA tests on correlated dependent variables (Tabachnick and Fidell 2001). Finally, correlation analysis was also completed for all of the variables used. This analysis was used to corroborate the findings from the regression and the MANOVA and make some of the relationships between less significant variables more explicit. Correlations were considered significant if they had a p-value<0.05 ($\alpha=0.05$).

Results

Characteristics of the sample plots

Measurements of site and soil characteristics confirmed that the sites had similar slope, terrain, elevation, vegetation type, stand age, soil parent material, soil drainage, moisture and nutrients (see Appendix 2, Table 11 and Table 13 for reporting on basic site and soil information). Between the three HPAs, there were small differences in soil characteristics, but generally all soils were moderately-well to rapidly drained, sandy, sub-mesic to mesotrophic with pH ≥5 and ≤ 7, classified as Eutric Brunisols. The Canadian System of Soil Classification (Soil Classification Working Group 1998) defines brunisolic soils as forest soils that are well to imperfectly drained, have a Bm horizon that has a stronger chrome and redder hue than underlying material, and can be mildly affected by gleying. Eutric soils of this type have a moderately high degree of base saturation (pH ≥ 5.5) and lack a well-developed mineral-organic surface horizon. In the Eutric Brunisols in the study area, small clay accumulations were present, usually as clay lenses where some deposition has occurred. As well, some soils were affected by seepage, although none were strongly gleyed. Organic layers, on average, were thin (<5cm), but were significantly thicker in controls than in harvest plots (T-test, α=0.05, p=0.03). In addition, T-tests on tree species confirmed that the treatment types in the analysis were pine-dominated stands in open (<50% tree cover) or closed (≥ 50% tree cover), mixed Lodgepole pine—Spruce forests (average pine- 71 m^3/ha; average spruce- 28 m^3/ha; α=0.05, p=0.003). Canopy closure in control and harvest treatments differed significantly in t-tests as well (57% vs. 25%; α=0.05, p<0.0001).

Selection and treatment of variables

Only the percent cover estimates from the microplots were tested for use in the regression analysis. The dependent variable in the regression was lichen abundance (including all species of lichen). Forage lichen abundance was the preferred variable, but it was not used as it did not meet the assumptions of normality (even after transformation) and did not yield results that were significantly different to the lichen abundance variable. This situation was also established in the winter habitat assessment for the Southern Lakes caribou recovery program (Florkiewicz, Loewen, et al. 2006). Feather moss abundance and other bryophyte abundance were both tested in the regression analysis, although not together. CWD and FWD abundance were grouped together as woody debris abundance in order to reduce the number of variables and because the two variables had very similar relationships to other variables, including lichen abundance. Ground shrubs were similarly tested and grouped to reduce the number of variables. Due to the low diversity in grasses and because some were only identified to genus, grasses were also grouped together in the analysis. Shrubs were first divided into tall, medium, and low, but initial scatter plots of these groupings showed little relationship to lichen abundance and other groups. As one variable, shrubs showed a similar lack of relationship to other variables. As a group, forbs showed a negative relationship to lichen abundance in initial scatter plots, but testing of individual forbs (such as *Epilobium angustifolium*) did not pick up this relationship, so forbs were tested as a group only.

Tree species were grouped together as well, as the effect of tree stem cover was hypothesized to be due to the physical exclusion of lichen where stems were present, and would not vary as a function of species. Cover variables and environmental variables such as canopy closure, stand volume, etc. were averaged across each plot and transformed as necessary. Table 5 shows all of the variables with units and transformations.

VARIABLE	UNIT	TRANSFORM
Lichen abundance	Percent cover (microplot), expressed as an average proportion by plot	Square root
Feather moss abundance	Percent cover (microplot), expressed as an average proportion by plot	Square root
Woody debris ground cover[6]	Percent cover (microplot), expressed as an average proportion by plot	Square root
Ground shrub abundance[7]	Percent cover (microplot), expressed as an average proportion by plot	Not necessary
Grass abundance	Percent cover (microplot), expressed as an average proportion by plot	Square root
Forbs abundance	Percent cover (microplot), expressed as an average proportion by plot	Square root
Shrubs abundance[8]	Percent cover (microplot), expressed as an average proportion by plot	Square root
Tree stem cover	Percent cover (microplot), expressed as an average proportion by plot	Square root
Litter ground cover	Percent cover (microplot), expressed as an average proportion by plot	Square root
Canopy closure (canopy density)	Percent canopy closed, expressed as an average proportion by plot	Square root
Post-harvest stand volume	m^3/ ha	Not necessary
Seedlings	Average tally by plot	Square root
Saplings	Average tally by plot	Log10
Coarse Woody Debris (CWD) volume	m^3/ ha	Square root
CWD piece	Number of CWD pieces/ ha	Square root

Table 5. Study variables with units and transformations

Factors predicting lichen abundance (regression analysis)

Results of the standard multiple regression analysis showed strong negative relationships between predicted lichen abundance (Y') (the dependent variable, DV) and the independent variables (IVs) including: GS (ground shrub), WD (woody debris), FM (Feather moss), TR (trees) and GR (grasses) (n=34;

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[6] Includes fine and coarse woody debris

[7] Includes all ground shrub species, *Arctostaphylos uva-ursi* and *Vaccinium vitis-idea* are also tested separately in some analyses

[8] Includes tall, medium, and low shrubs. Testing on shrubs as separate variables by their size did not yield better results than grouping shrubs together

$\alpha=0.1$; $r^2=0.7528$). The model is reliably different from zero (or what would be expected by chance) ($\alpha=0.05$; $p=<0.0001$). The importance of each independent variable was also assessed statistically using forward, backward, stepwise and r^2 selection method multiple regression techniques to see how each IV affected the prediction equation as it entered and exited it. Of the 15 IVs tested[9], the 5 that remained in the equation all improved the equation when they entered it and reduced the r^2 value of the equation if they were removed. The results of the statistical regressions are consistent with the results from the standard regression regarding the importance of ground shrubs, woody debris, and feather moss. In addition, the statistical regression results suggest that trees and grasses be included in the regression because they strengthened the r^2 value and were significant at the $\alpha=0.1$ level. Increasing the alpha level would have allowed forbs (FB) to also be significant, but the r^2 regression procedure revealed that this would not benefit the goodness of fit of the model. The resulting regression equation is graphed in Figure 3.

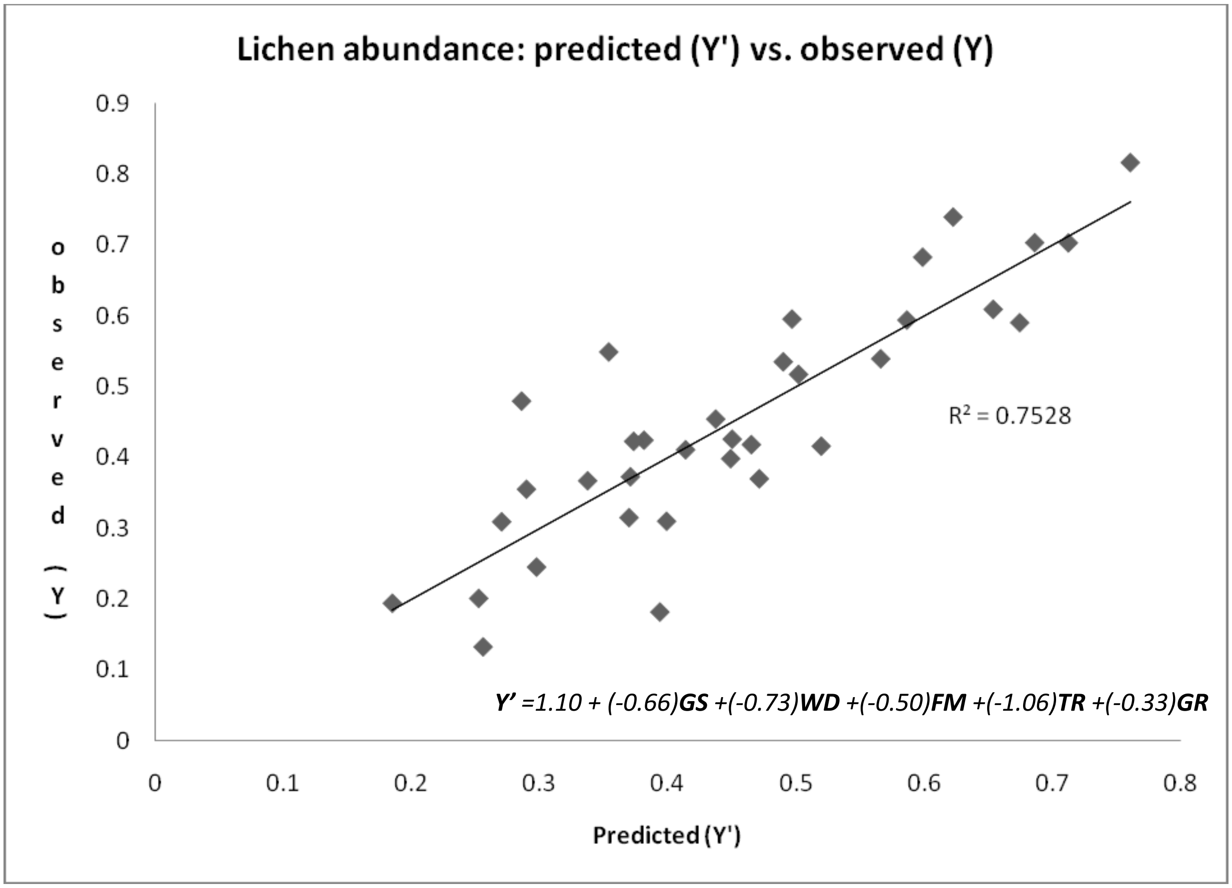

Figure 3. Plot of predicted (Y') vs. observed (Y) lichen abundance.

Y' was generated from the regression equation (bottom right hand side of the graph) using the y-intercept (1.10) plus the five independent variables: GS= ground shrub abundance, WD= woody debris ground cover, FM= feather moss abundance, TR= tree stem ground cover, GR= grass abundance and their concomitant parameter estimates (B values). The goodness of fit is measured by $r^2=0.7528$, where $r^2=1$ is a perfect prediction. Y and Y' are in transformed units square root of the cover expressed as a proportion, $\sqrt{(cover/100)}$.

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[9] Note that while 15 variables were tested, the equation never held more than 8 at a time, as variables that were clearly not statistically significant during trials were not tested in all combinations

The test of normality and scatter plot of the predicted values (see Appendix 3, Table 14 and Figure 8) of lichen and the residuals showed that the following assumptions have been met: a) residuals are normally distributed about the predicted values; b) residuals have a straight-line relationship with predicted values; c) the variances of the residuals about the predicted values are the same for all predicted values (Figure 8). This suggests linearity, normality, and homoscedasticity in the model.

The importance of each of the IVs is measured by the parameter estimate (or regression coefficient), where the estimate for a particular IV represents the change in lichen abundance associated with a one-unit change in the IV, so long as all other IVs are held constant (Tabachnick and Fidell 2001). The assumption is that the IVs are measured without error and since this is not often the case, interpretation of parameter estimates must be approached with some caution. In addition, the parameter estimates only apply to the value of the IV after transformation, so the relationship between the original, untransformed variables in the equation is not directly expressed. All of the variables used a square root transformation except ground shrubs, (which did not require transformation) allowing for easier interpretation of the parameter estimates since all of the variables have been equally transformed. Trees showed the strongest effect on lichen abundance, followed by woody debris, ground shrubs, feather moss, and grass (see Table 6 for values).

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T VALUE	PR > |T|
Intercept	1	1.10181	0.08882	12.4	<.0001
Ground shrub	1	-0.66259	0.16326	-4.06	0.0004
Woody debris	1	-0.73011	0.17647	-4.14	0.0003
Feather moss	1	-0.49603	0.11615	-4.27	0.0002
Trees	1	-1.05521	0.52794	-2	0.0554
Grass (all species)	1	-0.32739	0.18452	-1.77	0.0869

Table 6. Results of standard multiple regression (n=34; α=0.1)

A correlation analysis was completed on the regression variables (DV and IVs) to explore the contingencies, or interactions, between the independent variables in the equation. The Pearson product moment correlation coefficients (see Table 7) reveal that each of the independent variables has a significant negative correlation with lichen using $p<0.05$, $\alpha=0.05$. The strongest negative correlation is between trees and lichen (-0.5524), followed by ground shrub and lichen (-0.5082), woody debris and lichen (-0.4844), and finally feather moss and lichen (-0.3959). Grasses did not have a correlation with lichen, but were negatively correlated with feather moss (-0.57867), suggesting that the inclusion of grasses in the regression may be contingent upon their relationship with feather moss more than their direct relationship with lichen. This violates the assumption of independence amongst the variables, but also highlights an important secondary relationship which is adding to the predictive power of the regression equation. Furthermore, although trees were negatively correlated with lichen, they were also positively correlated with woody debris (0.40317), also suggesting that the inclusion of trees as a variable in the equation may be contingent upon a relationship between variables. Again, although this violates the assumption of independence to some extent, it also highlights another important relationship that contributes to the predictive power of the model. Finally, ground shrub, woody debris, and feather mosses are all uncorrelated to each other and, other than the two relationships discussed above, uncorrelated with grasses and trees.

	LICHEN	GROUND SHRUB	WOODY DEBRIS	FEATHER MOSS	TREE STEMS	GRASSES
LICHEN	1	**-0.5082**	**-0.4844**	**-0.3959**	**-0.5524**	0.04408
		0.0022	0.0037	0.0216	0.0007	0.8045
GROUND SHRUB	-0.5082	1	0.1038	0.03982	0.07798	0.13541
	0.0022		0.5591	0.8231	0.6611	0.4451
WOODY DEBRIS	-0.4844	0.1038	1	-0.22804	**0.40317**	0.07717
	0.0037	0.5591		0.1946	0.0181	0.6644
FEATHER MOSS	-0.39259	0.03982	-0.22804	1	0.24869	**-0.57867**
	0.0216	0.8231	0.1946		0.1561	0.0003
TREE STEMS	-0.5524	0.07798	0.40317	0.24869	1	-0.11435
	0.0007	0.6611	0.0181	0.1561		0.5196
GRASSES	0.04408	0.13541	0.07717	-0.57867	-0.11435	1
	0.8045	0.4451	0.6644	0.0003	0.5196	

Table 7. Pearson product moment correlation coefficients for variables in the multiple regression

Differences between harvest and control treatments (MANOVA)

MANOVA variables include lichen abundance and the IVs from the regression as well as the other abundance variables and environmental variables such as canopy closure, post-harvest stand volume, coarse woody debris (CWD) volume and pieces per hectare, stand age, and tally of seedlings and saplings. The MANOVA results include ANOVA tests for each of the variables (Table 8). When percent cover of forage lichen was tested separately from other lichen, the variable also did not vary significantly between treatment and control. When ground shrubs were divided into species, *Arctostaphylos uva-ursi* and *Vaccinium vitis-idaea* were significantly different between treatment and control. Other species such as *Linnaea borealis* were not significantly different and were left out of the analysis.

MANOVA was used to test whether the variables in Table 8 would vary as a function of treatment when the correlations between variables were considered in the analysis. This tested the overall type effect of the harvest versus the control. The MANOVA revealed that percent cover of feather mosses, grasses, the two ground shrub species, and woody debris, as well as canopy closure, post-harvest stand volume, and number of seedlings all varied as a function of harvest when compared to control and that this variation is greater than what would occur by chance (α=0.05; p=<0.0001; Table 9). Percent cover of lichen, ground shrubs, and trees did not vary significantly between harvest and control.

VARIABLE	TREATMENT TYPE	LSMEAN	STANDARD ERROR	PR > |T|[10]	PR > |T|[11]
Lichen	Control	0.47419859	0.04953311	<.0001	0.5826
	Harvest	0.44000524	0.03658263	<.0001	
Debris	Control	0.30862718	0.02722471	<.0001	0.0023
	Harvest	0.42066197	0.02010678	<.0001	
Grass	Control	0.11543915	0.02929592	0.0004	0.02
	Harvest	0.20461824	0.02163647	<.0001	
Ground shrub	Control	0.20704861	0.02889603	<.0001	0.26
	Harvest	0.24823864	0.02134113	<.0001	
Tree	Control	0.03767836	0.01045079	0.001	0.5509
	Harvest	0.04551007	0.00771842	<.0001	
Canopy closure	Control	0.75065304	0.04620411	<.0001	<.0001
	Harvest	0.47676955	0.034124	<.0001	
Seedlings	Control	7.8112208	0.9157361	<.0001	0.0449
	Harvest	10.1879446	0.6763159	<.0001	
Post-harvest stand volume	Control	188.252776	14.735824	<.0001	<.0001
	Harvest	55.530984	10.883128	<.0001	
Feather moss	Control	0.37417483	0.0452424	<.0001	0.0004
	Harvest	0.15369726	0.03341372	<.0001	
Litter	Control	0.29970445	0.03718749	<.0001	0.6176
	Harvest	0.32301301	0.02746478	<.0001	
CWD	Control	0.14504159	0.02456087	<.0001	0.0147
	Harvest	0.22383494	0.01813941	<.0001	
FWD	Control	0.25911615	0.02656755	<.0001	0.0089
	Harvest	0.35109236	0.01962144	<.0001	
Arctostaphylos uva-ursi	Control	0.16674685	0.03376906	<.0001	0.0011
	Harvest	0.31727069	0.02494010	<.0001	
Vaccinium vitis-idaea	Control	0.26942795	0.03185708	<.0001	0.0161
	Harvest	0.16884521	0.02352801	<.0001	

Table 8. ANOVA results using least-squared (LS) means (α=0.05)

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[10] H_0: LSMEAN=0; α=0.05

[11] H_0: LSMean1=LSMean2; α=0.05

STATISTIC	VALUE	F VALUE	NUM DF	DEN DF	PR>F
Wilks' Lambda	0.28904703	6.56	9	24	<.0001
Pillai's Trace	0.71095297	6.56	9	24	<.0001
Hotelling-Lawley Trace	2.45964459	6.56	9	24	<.0001
Roy's Greatest Root	2.45964459	6.56	9	24	<.0001

Table 9. MANOVA Test Criteria and Exact F Statistics for the Hypothesis of No Overall TYPE Effect

Relationships between variables (correlation analysis)

Correlation analysis on all 18 variables from the MANOVA revealed that there are direct and indirect relationships between lichen abundance and the other variables in the study. Lichen abundance is directly and negatively associated with feather moss, woody debris, ground shrub, and tree variables (see Table 10 for values, significance is measured at +/- |0.4| and/or p-value<0.05), a finding that reflects the relationships highlighted in the multiple regression.

Lichen is also weakly negatively correlated with the number of CWD pieces per hectare, although it was not correlated with CWD volume. This suggests that it is the ground cover of coarse woody debris, and not the volume, that is the main contributing factor to the negative relationship between CWD and lichen. This is corroborated by the negative correlation between percent cover of woody debris and lichen and the positive correlation between the microplot woody debris variable and both CWD volume and pieces per hectare (Table 10).

The correlation analysis also reveals relationships between variables other than lichen abundance. Percent cover of grass is positively correlated with the number of seedlings (0.60568). Furthermore, feather moss, canopy closure, and stand volume are positively correlated with each other (Table 10) and negatively correlated with seedlings and grass (Table 10). Woody debris is negatively correlated to canopy closure and stand volume and positively correlated to trees, confirming the ANOVA result that woody debris is significantly higher (on average) in the harvest areas than in the control areas with high canopy closure and stand volume. Finally, ground shrubs, although important in determining lichen abundance in the regression analysis, did not have any other significant correlations (Table 10).

Similarly, forbs were not an important predictive variable in the regression analysis, although ground cover of forbs was negatively correlated with lichen abundance in the correlation analysis (-0.48623). Forbs were also positively correlated with coarse woody debris and negatively correlated with saplings. Saplings were otherwise not an important variable and were not associated with lichen abundance.

	LICHEN	FM	DEBRIS	ARCT	VACC	GRASS	TREE	CC	POSTVOL	SEED	SAP	CWDV	CWDP	LITT	FORB
LICHEN	1	**-0.39259**	**-0.4844**	-0.11284	0.26703	0.04408	**-0.5524**	-0.07018	-0.04185	0.10585	0.22753	-0.25749	**-0.33801**	-0.17599	**-0.48623**
		0.0216	0.0037	0.5252	0.1268	0.8045	0.0007	0.6933	0.8142	0.5513	0.1956	0.1415	0.0506	0.3194	0.0036
FEATHER MOSS		1	-0.22804	**-0.41862**	0.29015	**-0.57867**	0.24869	**0.68646**	**0.68689**	**-0.43215**	-0.04154	0.08875	0.06931	-0.20773	0.3071
			0.1946	0.0137	0.096	0.0003	0.1561	<.0001	<.0001	0.0107	0.8155	0.6177	0.6969	0.2384	0.0773
WOODY DEBRIS			1	0.0368	-0.28517	0.07717	**0.40317**	**-0.40563**	**-0.37469**	-0.02646	-0.23523	**0.54607**	**0.54442**	0.0413	0.14971
				0.8363	0.1021	0.6644	0.0181	0.0173	0.029	0.8819	0.1805	0.0008	0.0009	0.8166	0.3981
KINNI-KINNICK				1	-0.31581	**0.60247**	-0.13383	**-0.38126**	**-0.48719**	**0.49167**	-0.00233	-0.21227	-0.00994	0.1701	-0.17429
					0.0688	0.0002	0.4505	0.0261	0.0035	0.0031	0.9896	0.2281	0.9555	0.3361	0.3242
LINGON-BERRY					1	-0.20717	-0.2731	**0.43957**	**0.51596**	-0.14543	-0.26297	0.03975	-0.22983	**-0.51663**	0.06172
						0.2398	0.1181	0.0093	0.0018	0.4118	0.1329	0.8234	0.191	0.0018	0.7288
GRASS						1	-0.11435	**-0.57969**	**-0.58127**	**0.60568**	0.1621	-0.20766	-0.11551	0.17674	-0.24809
							0.5196	0.0003	0.0003	0.0001	0.3597	0.2386	0.5154	0.3173	0.1572
TREE STEMS							1	-0.13011	-0.08222	-0.19048	-0.04586	0.12674	0.252	0.29921	0.16094
								0.4633	0.6439	0.2806	0.7968	0.4751	0.1505	0.0856	0.3632
CANOPY CLOSURE								1	**0.85747**	**-0.36887**	0.0302	-0.04773	-0.13203	-0.11209	0.16742
									<.0001	0.0318	0.8654	0.7887	0.4567	0.528	0.3439
PST STND VOLUME									1	**-0.45458**	-0.11199	-0.00166	-0.13743	-0.20797	0.05725
										0.0069	0.5283	0.9926	0.4383	0.2379	0.7478
SEED-LINGS										1	**0.42689**	-0.21378	-0.18672	0.26423	-0.21171
											0.0118	0.2247	0.2904	0.131	0.2294
SAP-LINGS											1	-0.23512	-0.00991	0.22079	**-0.35661**
												0.1807	0.9556	0.2096	0.0384
CWD VOLUME												1	**0.76556**	-0.04435	**0.42979**
													<.0001	0.8033	0.0112
CWD PIECES													1	0.06785	**0.33991**
														0.703	0.0492
LITTER														1	0.0237
															0.8942
FORBS															1

Table 10. **Pearson Product Moment Correlation Coefficients: significant at +/- |0.4| and/or prob > |r| under H0: Rho=0; α=0.05. P-values are below the correlation coefficient for each combination of variables.**

Discussion

The literature suggests that terrestrial lichens are more abundant in open than in closed stands (Botting and Fredeen 2006; Pharo and Vitt 2000). However, in this study and in others, canopy closure and other environmental variables, such as soil characteristics, have been shown to be weak predictors of lichen abundance while ground layer dynamics have played a more direct role (Pharo and Vitt 2000; Webb 1998). Therefore, the effects of canopy closure in our study may not be directly affecting lichen abundances, but the results suggest that there are indirect ways in which the closure of the stand can influence lichen, especially regarding ground layer dynamics. Our results concur with Sulyma and Coxson (2001) and Cornelissen et al. (2001) that competitive interactions at the ground layer are linked to environmental variables such as canopy closure and stand volumes which, in turn, govern light availability and moisture at the micro-site level. Figure 4 illustrates that the drivers of decline in lichen abundance in the study area are not the treatment types (harvest and control), but the changes in the abundances of vascular plants wrought by the treatments, as well as the increase in abundance of direct physical barriers to lichen. The regression analysis reveals that the variables predicting lichen abundance are those which directly interact with lichen at the micro-site level (indicated by the predictive relationship boundary in Figure 4). These ground-layer interactions include negative relationships between lichen abundance and each of feather moss, ground shrubs, grasses, woody debris and tree stem ground cover. Insights into the positive and negative effects of retention harvesting on lichen abundances are inferred indirectly through the relationship of lichen with these ground layer variables and the relationships between these ground layer variables and other factors in the study.

Miege, et al. (2001), in a study on the effects of harvest on lichen diversity in British Columbia, concluded that elevated slash deposits and increased solar radiation as a result of logging are two factors that are likely to contribute to localized reduction in lichen abundance under a partial cutting regime. The analysis in this study confirms these observations and suggests ways in which these factors affect lichen, especially in the presence of understory competitors. We find that removal of the forest canopy under a retention harvesting regime has four major impacts on the understory vegetation. First, opening up the canopy and disturbing the ground cover and soil constitutes a stand-level disturbance that pushes back the successional stage of the stand from a mature, closed-canopy forest to an open, early seral 'pioneering' forest stand. Concomitantly, harvesting increases the direct solar radiation hitting the understory. Thirdly, tree removal increases the chances of more severe drying events (Miege, Goward, et al. 2001; Sulyma and Wawryszyn 2001), indicated by changes in plant community composition between harvest and control plots. Indeed, the control and harvest plots in the study represent statistically significant treatment types that are differentiated primarily by crown closure and stand volume according to the MANOVA analysis. Control plots had higher canopy closure, greater stand volume, and greater ground cover of feather moss and ground shrubs, such as *V.vitis-idaea*, indicative of mature seral stage stand conditions (Beaudry, et al. 1999). Harvested plots had lower crown closure, lower stand volume, more seedlings, and greater ground cover of woody debris, grasses, and ground shrubs such as *A.uva-ursi*, indicating that harvested plots were of a younger seral

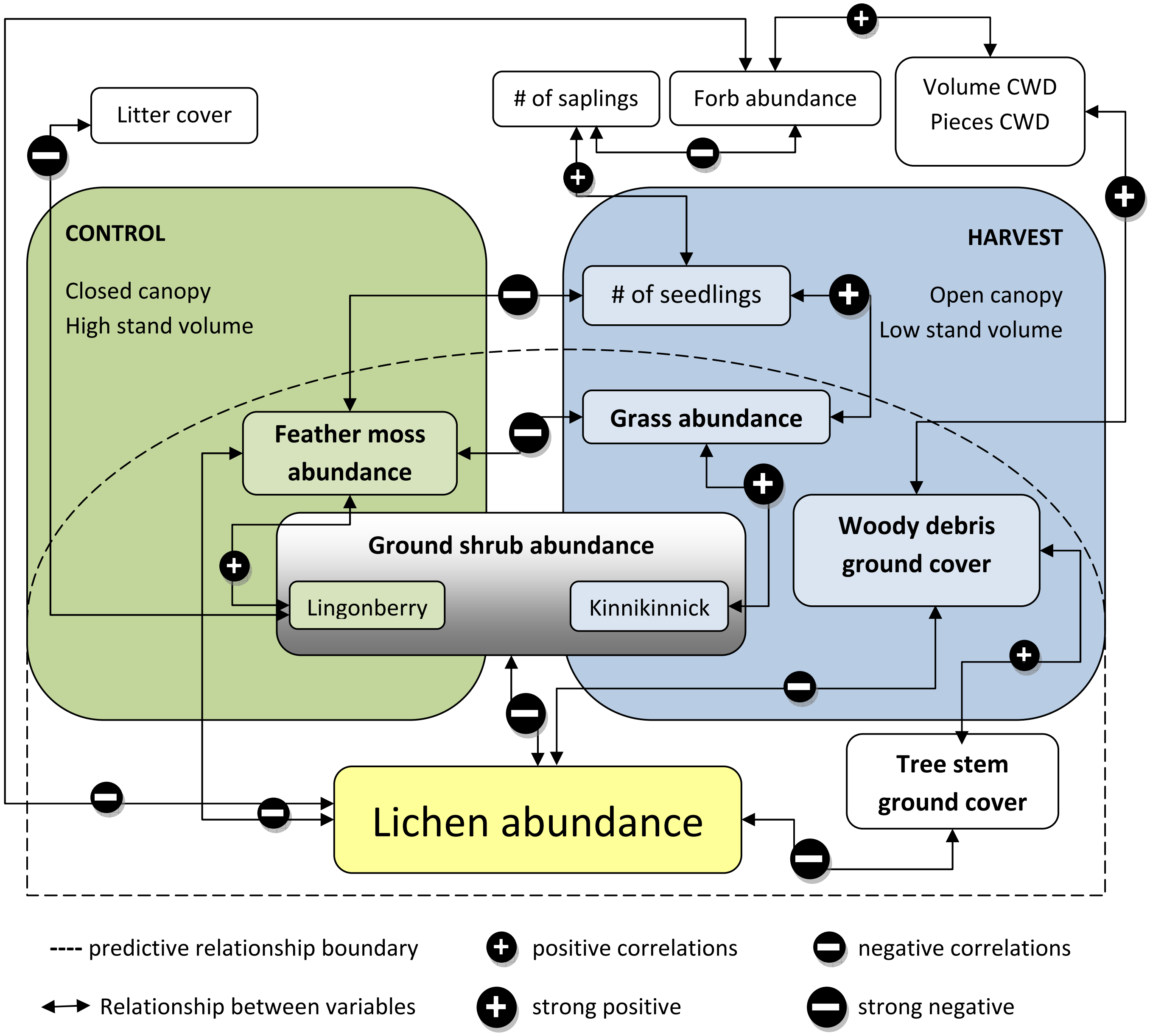

Figure 4. Summary of interactions between lichen abundance and predictive and non-predictive ground cover variables in the presence of control and harvest treatment types.

Variables within the predictive relationship boundary have a direct effect on lichen; the strength and nature of which is indicated by the relationship arrows between the variables. As well, variables that are significantly different between harvest and control plots are represented within one or the other of those categories and coloured similarly to show positive membership (indicated by a higher mean value on the variable for the associated treatment type). Variables outside of the predictive relationship boundary are not part of the regression equation, but may either be significantly correlated with another variable or significantly different between treatment and control. Those variables which are not different between treatment types and are not part of the regression equation are only represented if their relationship to another variable helps explain the statistical results. Measured characteristics that differentiate the treatments types are canopy closure and stand volume. Ground cover variables that are members of that treatment type have significant positive correlations with these characteristics as a requirement of membership.

stage with more direct solar radiation and less available moisture. Finally, the treatment of logging residuals after harvest has physical and chemical effects on the composition of understory species. Harvested plots had higher mean woody debris, which is strongly negatively associated with lichen abundance in the regression model. The presence of woody debris is a physical barrier to lichen growth and also has the potential to increase the plant-available nitrogen in the soil.

One simple conclusion might be that tree removal would have a positive impact on lichen. In a study of boreal forests in northern Quebec, researchers showed that lichens are liable to maintain dominance in open-canopy forests in the absence of disturbance (Morneau and Payette 1989), suggesting that retention harvesting, in theory, could lead to greater lichen abundances by maintaining open canopy forests. In our study, the tree stem cover variable had the strongest negative influence on lichen abundance in the regression, even though the tree ground cover variable represented a small fraction of the total percent cover. The presence of a tree on the forest floor is a physical barrier for lichen and represents complete exclusion of lichen cover from the area covered by the tree stem (tree bases were not large enough to accommodate lichen colonization). However, it is difficult to draw inferences directly between tree removal and increased lichen abundances because the interaction between these variables is complicated by establishment regimes, dispersal success and competition from persistent understory species.

This study concurs with other studies that have stated that closure of the tree canopy as the forest ages and attendant greater shading of the forest floor are major factors controlling the shift from lichen mats to feather moss mats in northern forests (Kershaw 1978; Coxson and Marsh 2001; Sulyma and Coxson 2001). The regression analysis highlighted the negative relationship between feather moss (predominantly *H. splendens* and *P. schreberi*) and lichen, particularly under mature seral stage stand conditions (closed canopy, high stand volume) where there is more humidity and more shade under which feather moss can out-compete lichens. Other studies have shown that feather mosses such as *H. splendens* and *P. schreberi* can dominate the ground cover in old growth forests (Botting and Fredeen 2006) but decline rapidly or disappear following harvest— likely because they cannot tolerate exposure to drier microclimate conditions (Bråkenhielm and Liu 1998; Williston and Cichowski 2006; Pharo and Vitt 2000). However, despite a potential reduction in feather moss competition after harvest, there isn't a significant difference between lichen abundances in control and harvest treatment types because there are direct negative relationships between lichen and other forest floor components in both harvested and unharvested areas. More specifically, ground shrub cover, which was negatively related to lichen abundance, did not vary significantly as a function of the treatment type and was not correlated with any other variables in the correlation analysis. In relation to other forest floor components, this suggests that ground shrubs, as a functional vegetative group, grow reasonably well under different shade and edaphic conditions and may be a competitor of lichen before and after tree-removal. This possibly aids in keeping lichen abundances similar between treatment types. Further analysis of the species of ground shrub found in the study area showed that *A. uva-ursi* was positively correlated with grass and seedlings and negatively correlated with crown closure and post-harvest stand volume. *A. uva-ursi* is a strong competitor of terrestrial lichen in open stand conditions, such as after retention harvesting, because it has a faster growth rate and rapidly expands its ground cover through radial spreading (Williston and Cichowski 2006). In closed forests, *V. vitis-idaea* (Lingonberry) may be a strong ground shrub competitor of lichen. *V. vitis-idaea* was positively correlated with crown closure and post-harvest stand volume as well as being weakly positively correlated with feather moss and has been shown to decline rapidly after clear cutting (Bråkenhielm and Liu 1998).

These findings suggest that as well as an overall negative relationship to lichen, there may be different ground shrubs species that compete with lichen under different forest stand conditions. This has important implications for management because our ability to predict what species will be lichen competitors during the post-harvest recolonization stage of lichen development will enhance the success of forest management strategies that aim to maintain and enhance lichen abundances. For example, *A. uva-ursi* can persist or pioneer after disturbance and is indicative of dry, nutrient poor sites (Beaudry, et al. 1999; Williston and Cichowski 2006). If it is present on a site prior to disturbance from harvesting, it may likely persist and expand in abundance after harvesting, especially if conditions are suitably dry. Controlling this shrub, perhaps through targeted manual removals in lichen seeding areas, may increase the success of forage lichen persistence and growth after harvesting.

Finally, the relationship between lichen and harvesting depends substantially on the treatment of logging residuals. Woody debris has a negative, predictive relationship to lichen and is higher in harvest plots, indicating that this variable is predominantly measuring logging slash. First, as a physical barrier to terrestrial lichen growth, woody debris is harmful immediately after harvest until the debris has sufficiently decomposed because lichen are poorly adapted to survival under low lights levels and with little ventilation (Miege, Goward, et al. 2001; Miege, Armleder, et al. 2001). Secondly, woody debris does not favor forage lichens. Bråkenhielm and Liu (1998) reported that in their study of the long-term effects of harvest intensity (particularly in regards to logging residues) on vegetation dynamics in Sweden, reindeer lichens thrived particularly well on sites without slash 20 years after harvest. In the same study, pioneer lichens, such as *Cladonia*, developed best on plots where slash was evenly spread across the plot and were abundant after 20 years post-harvest. This suggests that slash is harming lichen species typically associated with later seral stage stands and creating an environment that favors early successional lichen species instead. This has major implications for ground cover management in forest operations that aim to maintain or enhance reindeer lichen, as it is possible that the negative effects on *Cladina* spp. may be minimized during harvest by controlling the amount and placement of slash.

In addition to the potential effects of woody debris on lichen successional patterns, understanding the long-term effects of logging residues on forage lichens requires an appreciation of the effect that woody debris has on available soil nitrogen. Studies have shown that the amount of debris left on the site after harvest can influence the state of soil nutrient resources, although the effect depends on soil conditions (Thiffault, et al. 2006; Perrson 1981; Olsson and Staaf 1995). In nutrient-poor soils such as those typical of the study area, leaving woody debris onsite can minimize the reduction in nutrients typically associated with tree removal and provide shelter from environmental extremes (Bråkenhielm and Liu 1998). Bråkenhielm and Liu (1998) suggest that managers leave the debris in the forest and spread it around evenly in order to retain nutrients and conserve biodiversity because logging slash has a net positive benefit to sites with poor soils. However, as mentioned before, this would not favor the increase in forage lichen abundances in harvested areas. It is increasingly apparent that there is a trade-off between the negative physical effects of woody debris on reindeer lichens, and the positive chemical effects of debris on long-term site productivity and forest growth (Olsson and Staaf 1995). When the focus is on reindeer lichen, forest managers may find it prudent to minimize logging residues, possibly by practicing whole tree harvesting (WTH) in order to protect reindeer lichen colonies from being burdened with slash cover, because studies have shown that WTH can significantly reduce plant available nitrogen post-harvest (Olsson and Staaf 1995). A slash management regime that could concomitantly minimize the negative physical effects of slash and the nutrient reduction effects of harvesting would be an ideal regime for forestry in the study area.

One potential candidate is branch and stem harvesting (BSH), in which the tree is harvested as it would be under stem-only harvesting (conventional harvesting method) but the branches are removed from the site once sufficient time had passed for the needles to fall off. The result would be that the needles are left on the ground to sink into the bottom layer and promote site productivity while the most physically constricting debris (coarse woody debris) is removed. Olsson and Staaf (1995) reported that BSH had a pronounced positive effect on plant-available nitrogen but negligible physical effects. However, the direct effect of needle debris on lichen is still a matter for further research, and results from their study showed a negative effect on lichens under the BSH regime despite a minimal negative physical effect on other understory vegetation. Negative effects of litter accumulation were also reported in Cornelissen et al. (2001), although their analysis was not focused on needle litter. Other studies have also tested the effects of needle litter on lichens, finding in one study that *C. stellaris* recovered from being covered in needle litter and bark fragments after 3-8 years (Kauppi 1990). In another study in British Columbia, lichens appeared to recover in 1-2 years (Williston and Cichowski 2006). In our study, litter was not correlated with lichen or forage lichen in particular and was not significant in either the regression or MANOVA analyses. In the correlation analysis, it was negatively associated with the abundance of *V. vitis-idaea* (Lingonberry) (see Figure 4). These results suggest that leaving needle litter on the ground may not impact lichen negatively beyond the first few years after harvest, and may actually help control potential ground shrub competitors. Further analysis of litter is necessary, including better measurement techniques for litter such as using litterfall traps to sample litter and derive litterfall loading (in Kg/ha/day) (Coxson and Marsh 2001) as well as ground cover.

It is difficult to test species response to particular harvesting and slash management regimes in this study because the experiment was not specifically designed to test the effects of slash, although some causal relationships have been cautiously surmised from the negative relationship between woody debris and lichen. Given that the harvesting was generally small-scale hand-felling/skidding operations, the impacts from logging were considered to be similar across all harvest plots. However, slash management included spreading slash around or piling and burning slash piles, and possibly other regimes as well, making it difficult to infer a similar pattern of species response to slash management in the harvest plots. In this regard, more targeted and active research is needed to test species response to both physical and chemical effects of slash.

Furthermore, the results do reflect a strong response to tree removal across species and vegetative types, and this is helpful in developing future studies. Time since harvest in the study area was 5-20 years ago, which is a window of time that has been identified in other studies as a good period in which to measure the long-term impact of slash on the development of plant communities. Approximately 5-6 years after harvest, the physical effects of slash decline considerably as the coarse woody debris decomposes while it may take 20 years for the nutrient effects to decline (Olsson and Staaf 1995). For example, Brakenhielm and Liu (1998) measured the long-term effects on vegetation 20 years after harvesting and Olsson and Staaf (1995) measured 8 years and 16 years after harvest to test the influence of harvest intensity of logging residues on ground vegetation. This is largely because the most pronounced vegetation changes occur not only as a result of the cutting, but also due to the subsequent successional changes measured over the course of the first 20 years, after which the nutrient effects of slash are expected to decline considerably (Olsson and Staaf 1995). Given the success of this study in revealing tangible relationships between debris and lichen, a similar time frame for testing would be assumed to be effective in a long-term slash management experiment.

In addition, although not measured directly in the study, nutrient-mediated effects from wood debris are suggested through the presence and abundance of indicator plants (Kellner and Marshagen 1991; Perrson 1981). Vascular plant abundances are better explained by environmental variables than lichen or bryophyte abundances (Pharo and Vitt 2000) and can provide valuable indications of the influence of nutrients on ground layer plant community composition after harvest. Both of the treatment types had poor to medium[12] nutrient regimes with sub-mesic soil moisture conditions. They were sandy, well-drained soils that support a predominance of ericaceous shrubs, bryophytes such as *H. splendens* and *P. schreberi*, and lichens in the genera *Cladina* and *Cladonia*— indicating low nitrogen availability (Dirkse and Martakis 1992; Lahde and Nieppola 1987). After harvest, pioneering and early seral stage competitors can move in quickly and capitalize on nitrogen released from harvest and site preparation more rapidly than slow growing lichen (Kellner and Marshagen 1991). In a study of lichen chronosequences in northern British Columbia, *Epilobium angustifolium* was found to be invading sites where logging residues had been piled or mixed with surface soils (Coxson and Marsh 2001). Furthermore, in fertilization tests in Sweden, *E. angustifolium* was found to be a good indicator of disturbance and nitrogen availability (Kellner and Marshagen 1991; Olsson and Staaf 1995) and was present up to 10 years after harvesting (Bråkenhielm and Liu 1998). In this study, *E. angustifolium* was present in high abundance on many harvest sites in the study and forbs, in general, were negatively related to lichen abundance in the correlation analysis. In another example, grass was a negative predictor of lichen abundance in the regression and was significantly higher in the harvest plots than the controls. Common grass species found in the study area, including *Festuca altaica* and *F. saximontana*, are pioneering species that invade areas of disturbance (Beaudry, et al. 1999; Johnson, et al. 1995). Consequently, under common post-harvest conditions, forbs and grasses could quickly capitalize on the available nitrogen and out-compete lichen for colonization and growth in freshly disturbed areas.

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[12] For detailed descriptions of the soil classifications, see the Yukon Forestry Monitoring Protocol Program, Field Manual and Monitoring Protocols (Government of Yukon 2008)

Recommendations for management and further research

Maintenance versus recruitment

It is recommended that maintaining, as best possible, the pre-harvest lichen patches in key microsites throughout harvesting and site preparation treatments is preferable to recruitment treatments than to attempt to mimic fire disturbance (e.g. by broadcast burning during site preparation) in order to create a natural succession process beneficial to lichens. Periodic fires recycle soil nutrients, increase plant productivity, and maintain ecosystem diversity (Klein 1982), however, lichen colonies lost during the fire are not likely to begin to flourish again until 50+ years post-harvest (Sulyma and Wawryszyn 2001; Klein 1982). The benefit of maintenance, especially in a retention harvest scheme, is that forest managers can foster forage lichen abundances in stands that are <20 years old when typically, the same levels of abundance would be associated with stands that are 70—140 years old (Sulyma 2001; Harris 1996). Forage lichen persistence after harvesting would also be more successful if harvesting is done on a winter snow pack, thereby minimizing disturbance to the pre-existing lichen mat and to the soil (Coxson and Marsh 2001; Government of Yukon 2008). In addition, avoiding severe site-preparation techniques such as broadcast burning and disc trenching is recommended, as these practices have deleterious effects on lichen abundance and re-growth (Adamczewski, Florkiewicz and Loewen 2003). The drawback is that a maintenance system of lichen management may be more time-consuming and expensive than conventional practices while the recruitment approach relies heavily on fire as a site preparation tool to create desired conditions, which may be cheaper and easier to accommodate under present forest practices.

Harvest intensity and treatment of logging residues

The results in this study correspond with other research on logging debris where it has been demonstrated that woody debris negatively impacts forage lichens both physically and chemically (Sulyma 2001; Bråkenhielm and Liu 1998; Olsson and Staaf 1995). Harvesting regimes that take the whole tree (Whole tree harvesting or WTH) leave less woody debris on the ground. If the debris were left behind, as with stem-only harvesting (SOH), it would be an immediate impediment to lichen growth as well as providing a long-term nutrient source that would likely favour higher plants. However, WTH is not an ideal method as it deprives the site of much needed nutrients in nitrogen-limited ecosystems such as those in the study area. Therefore, an important question in the treatment of logging residues in the context of lichen management is what kinds of harvest regimes offer the optimal solution between restricting physical barriers and enhancing site productivity? Branch and stem harvesting (BSH) is one alternative where only the needles are left on the ground, providing nutrients for the future forest, while the physical impediment of the coarse woody debris is removed and the post-harvest nutrient-flush is limited, possibly reducing the efficacy of lichen competitors. A cutting practice such as this may be congruent with the goals of a maintenance system of lichen management, but further research is needed to test lichen response. In studies on the effectiveness of this method in Sweden (e.g. Olsson and Staaf, 1995), the result on lichen abundances is still negative, although other studies have shown that negative impacts to lichen are immediate but not far reaching and suggest lichen may recover in <5 years (Kauppi 1990; Williston and Cichowski 2006). One final point is that the absence of woody debris onsite following BSH may reduce the need for scarification during site preparation, thereby further reducing the disturbance to lichen mats and mineral soils. More research is needed to test the usefulness of branch and stem harvesting in the study area.

High level of retention and small patch size

A pilot project in the Itcha-Ilgachuz area of the west Chilcotin Plateau, British Columbia tested the response of lichens (abundance and diversity) to different retention levels and patterns (Miege, Armleder, et al. 2001). They used cutting regimes comprised of different retention levels and patterns of cut, including: (a) group selection (groups of trees are removed, leaving small circular openings in a 70% retention block), (b) clearcut with residual groups of 10-13 trees (with 30% retention); and (c) clearcut with large islands of trees left intact (with 30% retention). Furthermore, the treatments with 30% retention also had a 30% cover of slash. The results suggest that shrubs, grounds shrubs, and herbs predominate in all cutting regimes by 2 years post-harvest, while bryophytes were much reduced in the cut areas under both 30% retention regimes. As well, lichen diversity was not significantly different between cut and uncut forest but the time frame of the study (2 years) may not be long enough to capture successional shifts. Forage lichen abundances were significantly lower in the 30% retention regimes as compared to uncut forest, while the 70% retention with group selection block had lichen abundances that were not significantly different from the uncut controls. In regards to slash, the increase in slash cover responded directly to the decrease in forage lichens. These results must be approached with caution, as the sample sizes are quite small and the replication is not truly independent; however, it serves as an excellent guide for further studies.

A 30% area removal using group selection in 15m diameter circular openings has been shown in preliminary trials, to approximate the conditions in an uncut forest and produce no discernable difference in lichen abundances, mortality rates, and diversity (Miege, Armleder, et al. 2001). This is attributed to lower slash and more tree cover for lichen protection. This represents an interesting scenario for further testing under a maintenance system for lichen management and using branch and stem harvesting. Other treatments in the study did not yield promising results. Cuts with 70% volume or area removal, with retention in islands or small patches of trees have a negative impact on lichen abundances and increase the rate of mortality, although diversity is much the same (Miege, Armleder, et al. 2001). Controls in that study had a 60% tree cover, while 70% volume removal left a tree cover of 12% and the 70% area removal left 43% and 3% in residual forest and patch cuts respectively. The 30% removal left a tree cover of 31% in forest and 2% in patches on the block. This last set of values is very similar those of the mean control and harvest tree covers[13] in our study (32% and 8% respectively),

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[13] It is important to note that tree cover is a different measure than canopy closure. The former is a visual estimate of the proportion of the forest floor covered by the vertical projection of the tree crowns while the latter is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings, Brown and Sheil 1999). See Appendix 5- Canopy closure versus canopy cover, for more details.

indicating that the dominance of the site by trees in our harvest and control treatment types is similar to the 30% removal/ group selection technique used by Miege, Armleder, et al. (2001).

Enhancing the growth of forage lichens immediately post-harvest

Two approaches that may be used simultaneously to enhance lichen growth and recolonization, specifically for forage lichens under a maintenance system, are physical removal of known ground shrub competitors (e.g. *Arctostaphylos uva-ursi*) and tall forbs, and seeding of cut-blocks with forage lichen thallus fragments harvested from surrounding lichen colonies (e.g. Phillips 2009). Disturbance from forest harvesting may favor the establishment of lichen via thallus fragments as opposed to spore dispersal because the disturbances from machinery creates and distributes thallus fragments from crushed lichen across the site as they move around (Sulyma 2001; Harris 1996). However, a seeding scheme may also be necessary to ensure that forage lichen, and not lichen species associated with earlier seral stages (such as *Cladonia* spp.) recolonize the plot. One possible source of thallus fragments is the site itself. With careful planning, lichen colonies that have a high risk of being destroyed could be harvested and their thallus fragments spread out over the site during seeding. This would provide managers with a locally habituated lichen source, which may be imporant considering how affected lichen are affected by ambient moisture conditions under which they have flourished (Kranner, et al. 2008).

Water and nutrients are the most easily manipulated abiotic factors determining the structure and species composition of a plant community (Kellner and Marshagen 1991). In a potential ground cover management regime, the manipulation of these factors is, to a certain degree, a function of tree removal and slash management. The elimination of water and nutrients as growth limiting factors is not desirable, as this would lead to a successional pathway dominated by tall and fast-growing species such as *E. angustifolium* (Kellner and Marshagen 1991; Perrson 1981). If harvest and slash management do not sufficiently manipulate water and nutrients for lichen establishment, manual or mechanical control of shrubs and forbs may be necessary to increase the success of a seeding scheme, since both of these groups of competitors present serious barriers to lichen re-establishment immediately post-harvest, especially if there is large flush of plant-available nitrogen over the first 10 years. Manual or mechanical control may be expensive, and many treatments over the early post-harvest years may be necessary. To control costs, it may make sense to only employ control techniques on more mesic sites, where the competition from other vegetation is anticipated to be much more detrimental to lichen management success.

In addition, the retention of trees must provide enough shade to reduce the severity of drying events that can dessicate forage lichen colonies (Sulyma 2001; Miege, Armleder, et al. 2001). Thallus fragments have the best chance of survival and growth with some protection from the sun, but too much cover may promote competition from other plants, such as feather mosses. Sulyma (2001) suggested that trees planted on a clearcut site would sufficiently shade lichen, but it would take time until the seedlings were tall enough to provide enough shade to minimize drought and extreme temperatures. The proper level of retention and pattern of cut may accelerate this process, although the level of disturbance to the forest floor (including slash) must be minimized (Miege, Armleder, et al. 2001).

Level of retention

The level of retention is an important factor in the success of lichen management. The relationship between lichen cover and canopy closure may be non-linear and marked by a threshold after which the negative respone of terrestrial lichens to canopy closure may increase rapidly (Pharo and Vitt 2000). At low but increasing levels of canopy closure, terrestrial forage lichens, such as *C. mitis,* benefit from the protection of the tree canopy against extreme temperatures and drought (Harris 1996) while competition from feather moss is much reduced due to substantial mortality of these bryophytes under open canopy conditions (Pharo and Vitt 2000). Although terrestrial lichens can withstand the drying events, they grow better and more rapidly with a low-moderate cover of trees (Enns 1990) and some, including *C. mitis* may benefit from moderate levels of disturbance from harvesting (Ahti 1961). However, after a certain threshold of canopy closure is reached, the transition of the forest floor from lichen dominated communities to feather moss dominated communities may proceed rapidly and with extreme deleterious effects on forage lichen (Sulyma and Coxson 2001). Understanding what the value of this threshold is in the Southern Lakes region would greatly inform harvest practices. For example, if Phase 2 of the project were to test the high retention/ small patch size hypothesis, it would be critical for the retention level to be high enough to benefit lichen but below the critical threshold for crown closure and feather moss establishment. Historically, typical retention levels in the study area are between 10—40% (Government of Yukon 2005). Pharo and Vitt (2001) assert that a marked increase in lichen cover with canopy openings between 0—43% is possible. It is recommended that further studies regarding retention levels focus on testing the hypothesis that canopy closures > 40% will have a substantial negative effect on lichen.

Use of the regression model as a predictive tool

The results of the regression model indicate that the interactions between forest floor components are what drive lichen abundances in the study area. One application of this work would be to create a model of establishment regimes following harvest constructed using pre-harvest forest-floor structure and species assemblages information as well environmental variables and coefficients for dispersal success. This could potentially guide forest managers through a ground cover management process that would allow them to tailor their harvest treatments in order to achieve post-harvest conditions that will maximize or optimize lichen regeneration and growth. The ground shrub, feather moss, and woody debris variables would be suitable for a predictive model because the cover of each of these variables could be managed and manipulated during the harvesting process. Of course, much more information would need to be added to such a model before it could reliably guide forest management decision-making, but the relationships in this study provide a solid basis for exploring this idea. For example, feather moss could be treated during harvesting by selecting harvest patches that coincide with feather moss mats while large lichen colonies are left in retention areas. Post-harvest competition could be modeled on the pre-harvest presence and abundance of ground shrub species that are known to be persistent and pioneering after disturbance. A recent study experimented with seeding lichen thallus fragments after harvesting and found that it was effective in encouraging lichen recolonization (Phillips 2009). If this were to become practice in Yukon, forest managers may increase the success of such post-harvest treatments by identifying the ground shrub species most likely to compete with lichen and targeting a treatment to reduce their abundances. For example, if patches of *A. uva-ursi* are present in a forested area prior to harvest, the expansion and growth of the shrub under different retention levels could be estimated after which, in anticipation of some level of competition, forest managers could assess the need (area and amount) for 'seeding' the harvested area with lichen thallus fragments.

Key points for Phase 2: active adaptive management

Passive adaptive management is a snap shot of historical practices, not a cohesive forest harvesting protocol. The harvest techniques sampled have been employed with varying effect, creating uncertainty in our model. This makes the data harder to interpret and underlines the need for active experimental design in Phase 2. Furthermore, we did not test cause and effect in this study, only relationships. Causality was inferred in some instances due to the information from other studies but, as a rule, these inferences should be tested in Phase 2. With guidance from the results of Phase 1, Phase 2 should focus on testing retention levels and patterns of harvesting as well as harvest intensities (such as branch and stem harvesting versus whole tree harvesting). Ideally, Phase 2 results would be similar to those found in the Phase 1 regression analysis, in order to confirm (or, if dissimilar, deny) the validity of the tests on historically harvested areas. The scope of Phase 2 should also be expanded to include variables such as lichen mortality, species richness and diversity, and more accurate tests for soil moisture and nutrients. The relationship between soil moisture, humidity, canopy cover and lichen abundances have been broadly discussed in this report, but more in-depth measurements are needed to understand how canopy removal affects evapotranspiration and what implications this has for lichen and lichen competitors. In addition, litter was not a significant variable, but this could be because of the metrics used. A more appropriate measure would be dry biomass of litter from litter fall traps set up in the plots. Finally, hemispherical photography may be more appropriate than using a densiometer to measure canopy closure because the densiometer cannot incorporate the effect of the low angle of the sun at high latitudes. This is especially important when looking at small forest gaps situation, such as under retention harvesting, where the zenith angle may result in very little sun actually reaching the forest floor (Miege, Goward, et al. 2001).

The scope of study excluded temporal factors and the effects of natural disturbance but these factors are important to determining patterns of succession, which are integral to understanding how lichen can benefit from canopy removal over the long term and across the landscape. Understanding the dynamics involved will require an active adaptive management scheme that includes active removals and long-term monitoring of permanent plots. Short term studies will only capture immediate effects of tree removal (e.g. Miege, Armleder, et al. 2001). It is important to consider a long-term study when the goal is to capture the effects of succession (e.g. Brakenhielm and Liu (1998) tested richness, evenness, and diversity over a 20 year period).

Finally, it is difficult to make broad assertions and management decisions based solely on the results of Phase 1. With an active adaptive management phase, experimentation can expand and test the ideas outlined in this report and develop more meaningful and scientifically-defensible information for forest management decision-making across the region.

Conclusions

This study concurs with the conclusions of Sulyma and Coxson (2001) that for lichen abundance to be maintained or enhanced after harvesting, forest managers must create a post-harvest environment that precludes competitive displacement by other plants, such as those that would otherwise benefit from disturbance and nutrient-release faster than slow-growing, stress-tolerant terrestrial lichens. Selecting the right environmental characteristics is not sufficient for managing lichen. This study has shown that linking terrestrial lichen abundance to the abundance of vascular plants and physical barriers is an important consideration for forecasting the effects of retention harvesting on post-harvest plant communities, although active experimentation (e.g. through retention harvesting) is necessary to confirm these relationships. Many management recommendations have been suggested that are designed to make harvesting practices complement lichen management (caribou management) and vice-versa; however, care must be taken that the effects of stand level manipulations are considered not just at the operational-level, but are inclusive of landscape level trends in lichen abundance and diversity (Sulyma and Coxson 2001) and are flexible enough to adapt to the inherent spatial and temporal heterogeneity of the forest landscape. Further research and trials are advised to test management recommendations outlined in this study, with emphasis on confirming microsite relationships revealed in the regression analysis, strengthening the assessment of site characteristics such as soil moisture and litter deposition, and including temporal and broader-scale variables in the analysis.

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Personal Communication

Kirk Price, Forest Management Analyst, Forest Management Branch, Department of Energy, Mines and Resources, Government of Yukon

Will Young, Forest Management Branch, Department of Energy, Mines and Resources, Government of Yukon

Appendix 1- Maps of the harvest planning areas (HPAs)

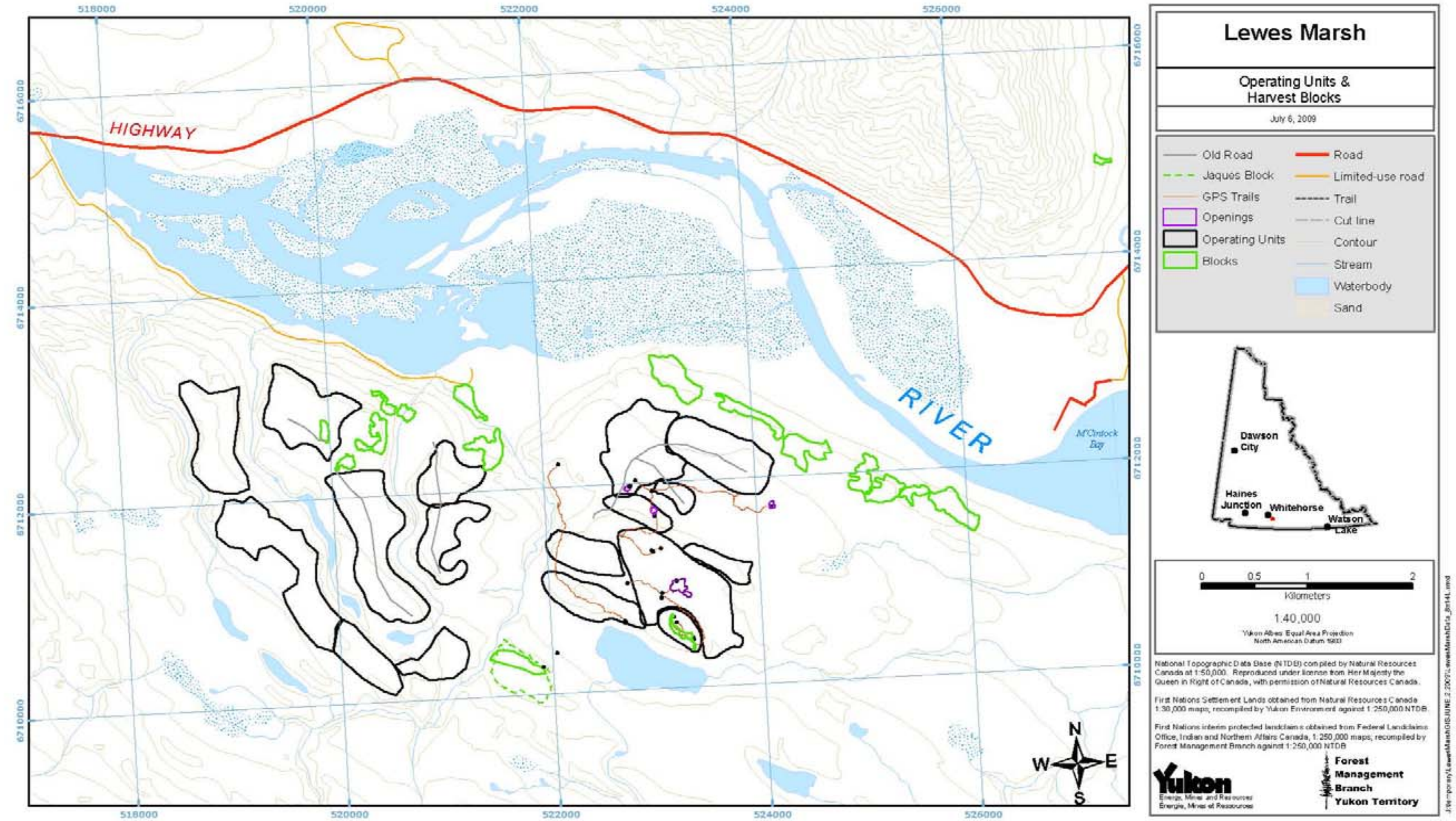


Figure 5. Map of Lewes Marsh Harvest Planning Area with historically harvested areas in green

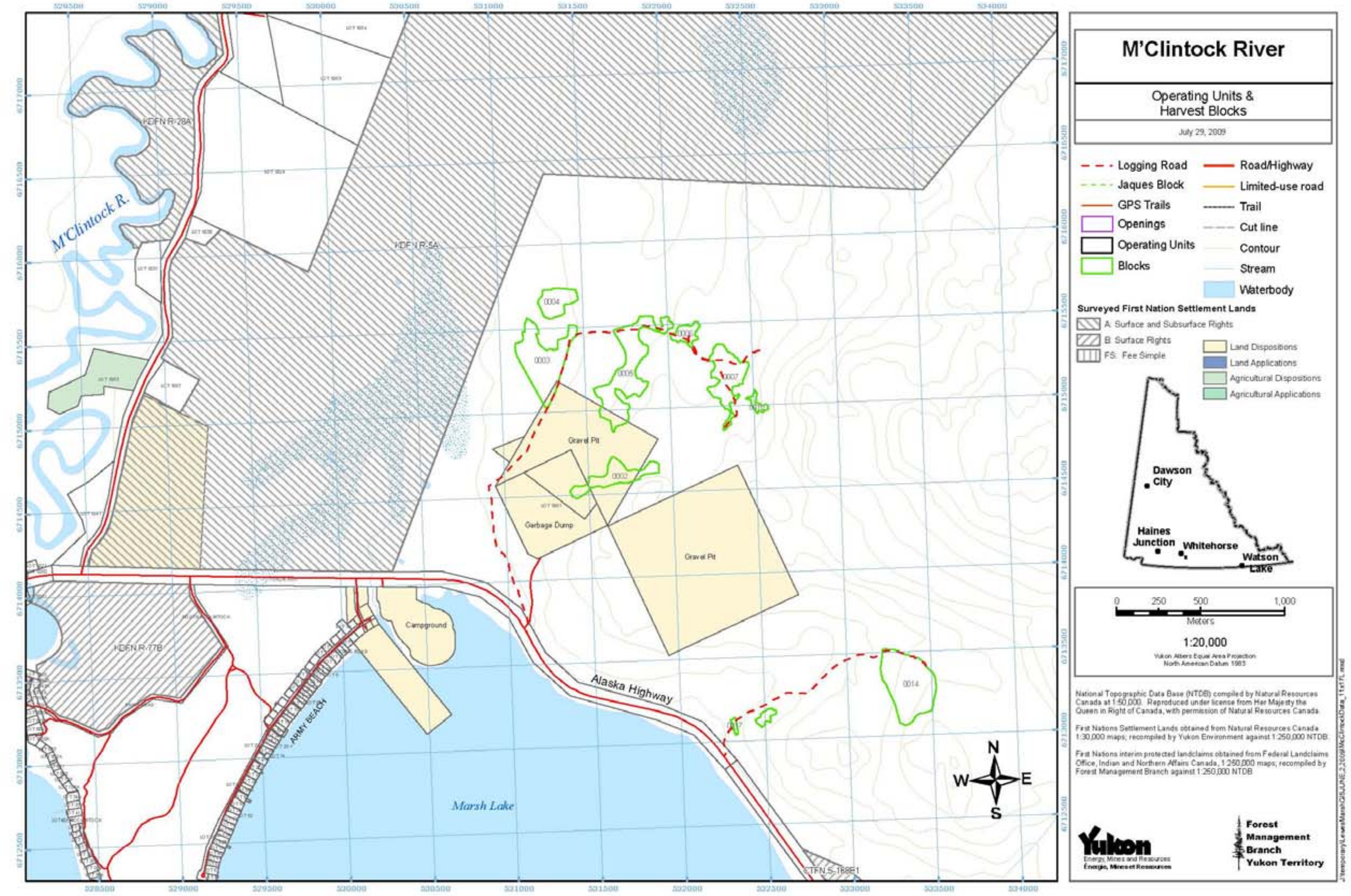
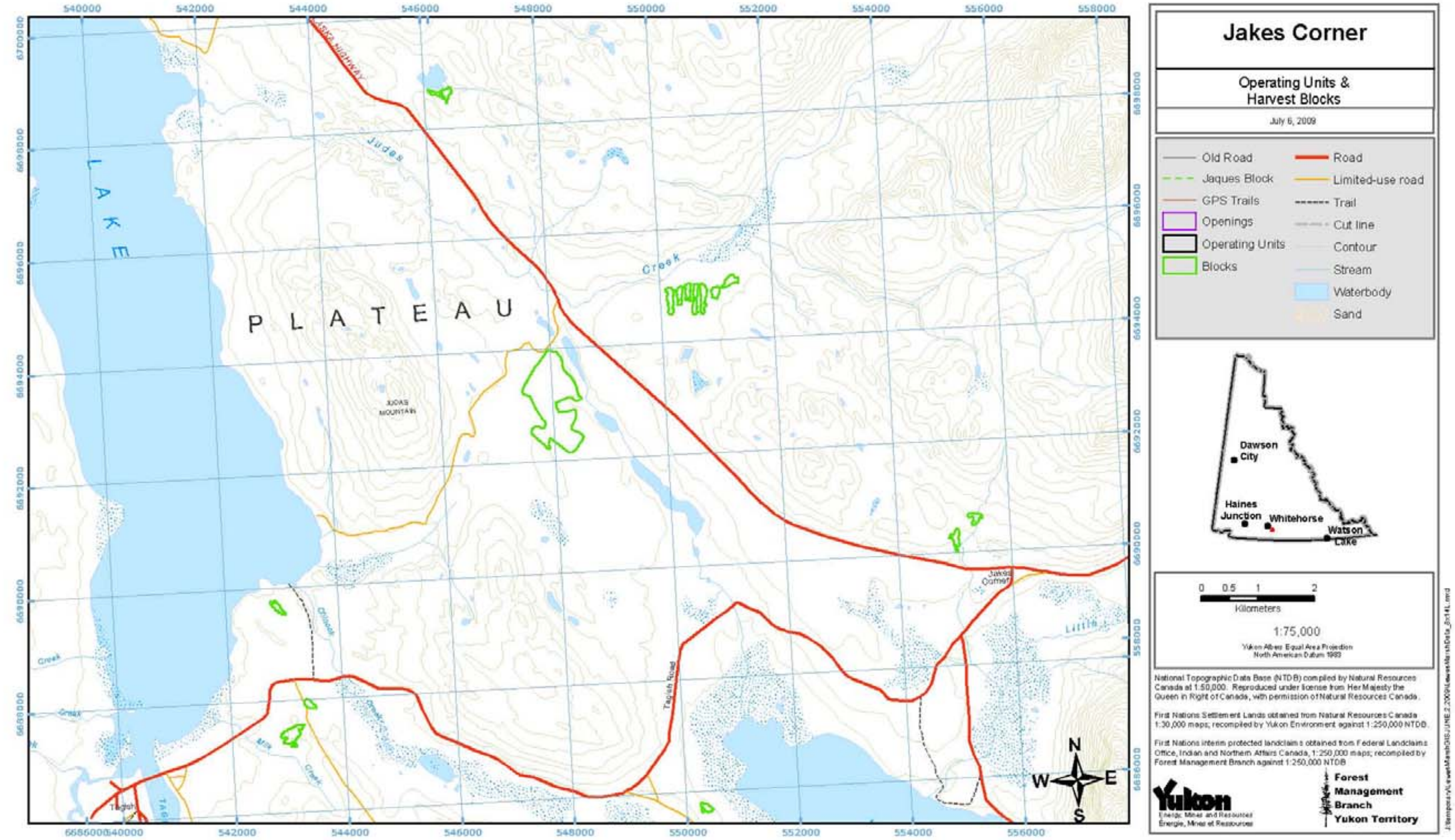


Figure 6. Map of the Marsh Lake Dump (M'Clintock River) Harvest Planning Area with historically harvested areas in green



National Topographic Data Base (NTDB) compiled by Natural Resources Canada at 1:50,000. Reproduced under license from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada.

First Nations Settlement Lands obtained from Natural Resources Canada 1:30,000 maps; recompiled by Yukon Environment against 1:250,000 NTDB.

First Nations interim protected landclaims obtained from Federal Landclaims Office, Indian and Northern Affairs Canada, 1:250,000 maps; recompiled by Forest Management Branch against 1:250,000 NTDB.

Figure 7. Map of Jakes Corner Harvest Planning Area with historically harvested areas in green

Appendix 2- Basic site data

Table 11. BASIC SITE CHARACTERISTICS

PLOT	SLOPE (dgr)	ASPECT	ELEVATION (m)	SITE POSITION	TERRAIN	VEG TYPE	STAND AGE (years)	CANOPY CLOSURE (%)	POST HARVEST TREE VOLUMES (m^3/ha)	
									PINE	SPRUCE
1	5	S	767	Middle Slope	EVEN	V21[14]	151	47	41	47
2	3	S	760	Lower Slope	ROLLING	V21	166	50	64	14
3	5	NE	760	Upper Slope	EVEN	V14[15]	159	72	187	17
4	4	S	798	Upper Slope	Even	V14	187	73	143	43
5	0	FLAT	794	Level	Even	V14	171	75	97	54
6	2	FLAT	798	Middle Slope	Even	V14	213	74	137	56
7	0	FLAT	815	Level	Rolling	V21	89	4	3	4
8	3	NE	803	Middle Slope	Rolling	V21	115	9	5	2
9	1	FLAT	788	Crest	Even	V21	128	20	8	4
10	1	FLAT	805	Middle Slope	Even	V14	120	85	249	0
11	1	FLAT	765	Level	Even	V21	101	21	18	9
12	3	N	760	Level	Even	V21	133	15	34	3
13	1	FLAT	760	Level	Even	V14	109	52	115	0
14	6	NE	718	Middle Slope	Even	V21	120	10	7	6
15	5	NE	705	Middle Slope	Even	V21	188	10	2	27
16	4	NE	706	Lower Slope	Rolling	V21	120	37	51	8
17	1	N	717	Lower Slope	Rolling	V21	92	17	11	12
18	2	N	729	Middle Slope	Even	V14	115	60	278	0
19	1	NE	721	Level	Even	V21	110	18	11	20

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[14] V21 refers to an open lodgepole pine- spruce forest classification under the Yukon Ecosystem Classification Key to treed vegetation types (Government of Yukon 2008)

[15] V14 refers to a closed lodgepole pine - spruce forest classification under the Yukon Ecosystem Classification Key to treed vegetation types (Government of Yukon 2008)

20	0	FLAT	728	Level	Even	V14	143	69	68	99
21	2	FLAT	757	Level	Even	V21	128	24	16	39
22	3	E	760	Middle Slope	Even	V21	139	27	41	11
23	2	N	754	Lower Slope	Even	V14	122	50	164	8
24	4	W	721	Middle Slope	Even	V21	104	31	24	30
25	3	W	719	Lower Slope	Even	V14	122	61	87	80
26	0	FLAT	717	Crest	Rolling	V21	135	20	21	45
27	2	W	705	Lower Slope	Even	V21	140	28	0	60
28	1	S	728	Middle Slope	Even	V21	149	35	0	113
29	0	FLAT	769	Level	Even	V21	116	15	50	1
30	0	FLAT	764	Level	Even	V21	117	9	11	16
31	0	FLAT	768	Level	Even	V21	127	7	9	2
32	0	FLAT	781	Lower Slope	Even	V14	147	60	105	122
33	0	FLAT	777	Level	Even	V21	138	35	251	0
34	0	FLAT	762	Lower Slope	Rolling	V21	125	37	104	12

Table 12. PRE AND POST HARVEST STAND CHARACTERISTICS

PLOT	PRE-HARVEST					POST-HARVEST				
	Average DBH	Average ht	Stems/ha	BA/ha	Stand Vol.	Average DBH	Average ht	Stems/ha	BA/ha	Stand Vol.
1	21	15	525	19	139	20	15	392	14	96
2	14	11	883	16	97	14	11	725	13	84
3	15	14	250	30	204	15	14	250	30	204
4	17	14	1142	31	238	17	14	1008	27	200
5	17	14	1017	27	200	17	15	800	21	163
6	19	14	242	29	193	19	14	242	29	193
7	16	13	367	9	65	14	10	92	1	8
8	15	12	325	6	42	12	10	100	1	7
9	17	13	383	11	83	12	10	175	2	12
10	14	14	283	34	249	14	14	283	34	249
11	14	13	458	9	56	13	12	317	4	28
12	16	13	217	10	65	15	12	150	6	40
13	24	15	217	16	115	24	15	142	16	115
14	14	12	425	8	47	12	10	225	3	14
15	19	16	417	13	97	18	15	258	4	31
16	19	16	367	13	109	17	15	233	8	63
17	20	15	325	12	88	18	14	208	4	32
18	15	17	292	33	278	15	17	258	33	278
19	18	13	333	11	80	15	11	258	6	33
20	18	16	317	24	174	18	16	258	24	174
21	19	16	350	14	106	18	15	258	8	60
22	18	14	400	11	77	17	14	333	8	56
23	18	18	142	20	172	18	18	125	20	172
24	23	16	267	13	99	21	15	217	8	61
25	25	20	158	19	166	25	20	133	19	166
26	17	14	617	14	104	16	13	542	10	72
27	16	14	442	13	93	16	14	383	10	66
28	26	20	167	14	113	26	20	142	14	113
29	17	13	408	10	69	17	13	283	8	54

30	14	11	358	7	42	15	11	225	5	30
31	11	10	392	4	22	10	9	317	2	11
32	19	16	258	31	228	19	16	258	31	228
33	13	15	217	32	251	13	15	217	32	251
34	19	16	113	15	116	19	16	113	15	116

Table 13. BASIC SOIL CHARACTERISTICS

PLOT	MOISTURE	NUTRIENTS	pH	DRAINAGE	MATERIAL	HUMUS FORM	THICKNESS (CM)	CLASSIFICATION
1	SUB-MESIC	MEDIUM	5.5	WELL	MORAINAL	MORMODOR	5	EUTRIC BRUNISOL
2	SUB-MESIC	MEDIUM	5.5	WELL	MORAINAL	MORMODOR	1.5	EUTRIC BRUNISOL
3	SUB-MESIC	MEDIUM	5.5	WELL	MORAINAL	MORMODOR	1.5	EUTRIC BRUNISOL
4	SUB-MESIC	MEDIUM	5.5	WELL	MORAINAL	MORMODOR	2.5	EUTRIC BRUNISOL
5	SUB-MESIC	MEDIUM	5.5	WELL	MORAINAL	MORMODOR	2.5	EUTRIC BRUNISOL
6	SUB-MESIC	MEDIUM	5.5	WELL	MORAINAL	MORMODOR	3	EUTRIC BRUNISOL
7	SUB-XERIC	POOR-MED	6.5	WELL	MORAINAL	MORMODOR	2	EUTRIC BRUNISOL
8	SUB-XERIC	POOR-MED	6.5	RAPID-WELL	MORAINAL	HEMIMOR	3.5	EUTRIC BRUNISOL
9	SUB-MESIC	MEDIUM	6.5	WELL	MORAINAL	HEMIMOR	3	EUTRIC BRUNISOL
10	MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	HEMIMOR	6	EUTRIC BRUNISOL
11	SUB-MESIC	MEDIUM	6.5	RAPID	GLAC-FLUV	MORMODOR	2.5	EUTRIC BRUNISOL
12	SUB-MESIC	MEDIUM	6.5	WELL	GLAC-FLUV	HEMIMOR	5	EUTRIC BRUNISOL
13	SUB-MESIC	MEDIUM	6.5	WELL	GLAC-FLUV	HEMIMOR	4	EUTRIC BRUNISOL
14	SUB-MESIC	MEDIUM	6.5	WELL	GLAC-FLUV	MORMODOR	3.5	EUTRIC BRUNISOL
15	SUB-MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	MORMODOR	4	GLEYED EUTRIC BRUNISOL
16	SUB-MESIC	MEDIUM	6.5	WELL	GLAC-FLUV	LIGNOMOR	9	GLEYED EUTRIC BRUNISOL
17	MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	LIGNOMODOR	6	GLEYED EUTRIC BRUNISOL
18	MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	LIGNOMOR	7	GLEYED EUTRIC BRUNISOL
19	MESIC	MEDIUM	7.5	MOD-WELL	GLAC-FLUV	LIGNOMOR	6	GLEYED EUTRIC BRUNISOL
20	MESIC	MEDIUM	5.5	MOD-WELL	GLAC-FLUV	LIGNOMOR	5	GLEYED EUTRIC BRUNISOL
21	SUB-MESIC	MEDIUM	5.5	WELL	GLAC-FLUV	LIGNOMODOR	3	EUTRIC BRUNISOL
22	MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	LIGNOMOR	7.5	GLEYED EUTRIC BRUNISOL
23	MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	MORMODOR	3.5	GLEYED EUTRIC BRUNISOL
24	MESIC	MEDIUM	6.5	WELL	GLAC-FLUV	MORMODOR	2	GLEYED EUTRIC BRUNISOL
25	MESIC	MEDIUM	6.5	MOD-WELL	GLAC-FLUV	MORMODOR	2	GLEYED EUTRIC BRUNISOL
26	MESIC	MEDIUM	6.5	WELL	GLAC-FLUV	MORMODOR	3	GLEYED EUTRIC BRUNISOL

27	MESIC	MEDIUM	5.5	WELL	GLAC-FLUV	MORMODOR	3	GLEYED EUTRIC BRUNISOL
28	MESIC	MEDIUM	6.5	RAPID	GLAC-FLUV	MORMODOR	3	GLEYED EUTRIC BRUNISOL
29	SUB-MESIC	MEDIUM	5.5	RAPID	GLAC-FLUV	MORMODOR	1.5	GLEYED EUTRIC BRUNISOL
30	SUB-MESIC	MEDIUM	7	RAPID	GLAC-FLUV	HEMIMOR	6.5	EUTRIC BRUNISOL
31	SUB-MESIC	MEDIUM	5	WELL	GLAC-FLUV	MORMODOR	1	EUTRIC BRUNISOL
32	MESIC	MEDIUM	7	MOD-WELL	GLAC-FLUV	HEMIMOR	2.5	EUTRIC BRUNISOL
33	SUB-MESIC	MEDIUM	5	RAPID	GLAC-FLUV	HEMIMOR	5.5	EUTRIC BRUNISOL
34	SUB-MESIC	MEDIUM	5.5	RAPID	GLAC-FLUV	HEMIMOR	4	EUTRIC BRUNISOL

Appendix 3- Supplementary statistical results

TEST	STATISTICS		P-VALUE	
Shapiro-Wilk	W	0.976232	Pr < W	0.6512
Kolmogorov-Smirnov	D	0.082296	Pr > D	>0.1500
Cramer-von Mises	W-Sq	0.037937	Pr > W-Sq	>0.2500
Anderson-Darling	A-Sq	0.296132	Pr > A-Sq	>0.2500

Table 14. Test for Normality on lichen residual (from SAS output)

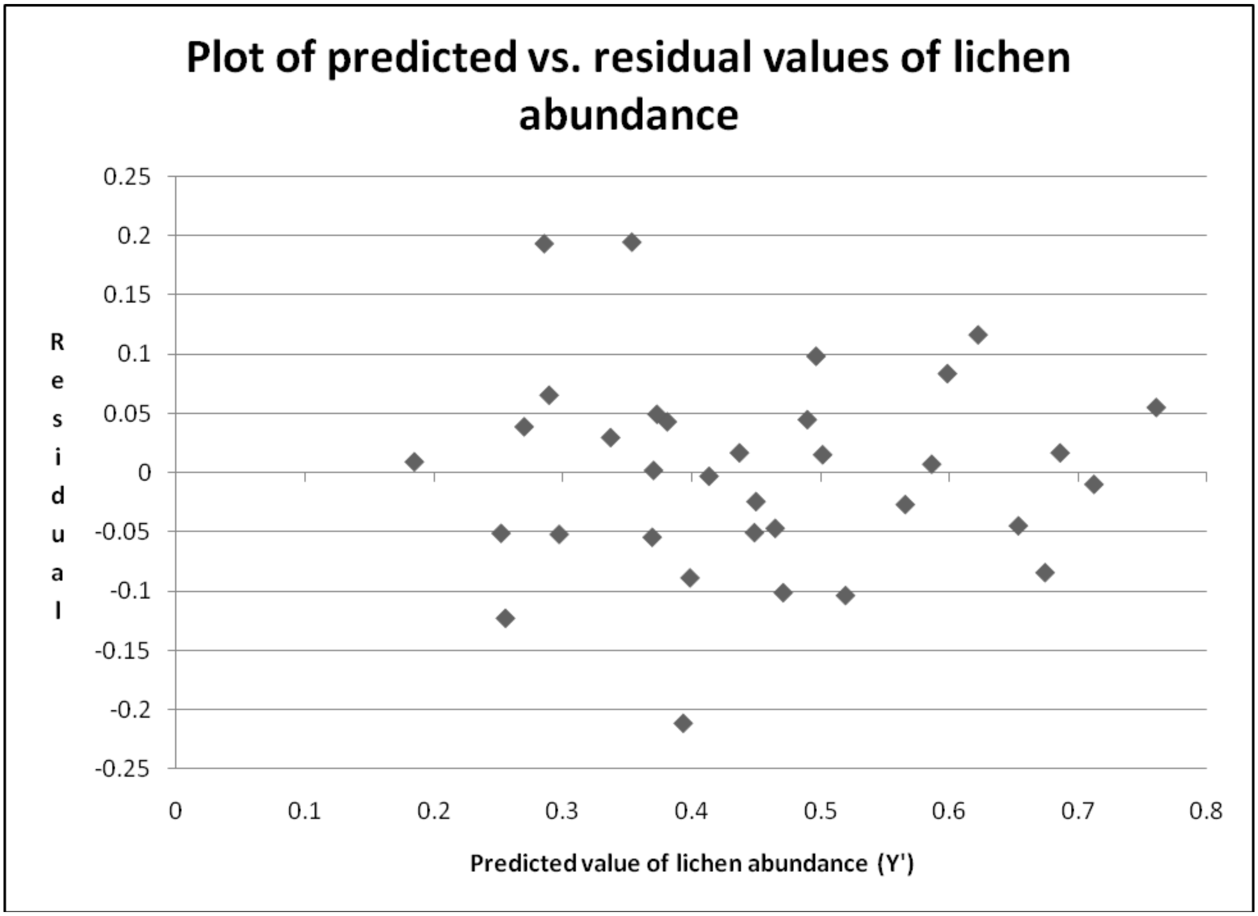


Figure 8. Plot of residual value of lichen versus predicted values.

Appendix 4- Complete plant list with species codes

TT- TALL TREES	LATIN NAME	COMMON NAME
PICE GLAU	*Picea glauca*	White spruce
PICE MARI	*Picea mariana*	Black spruce
PINU CONT	*Pinus contorta*	Lodgepole pine

LT- LOW TREES	LATIN NAME	COMMON NAME
BETU OCCI	*Betula occidentalis*	Water birch
PICC GLAU	*Picea glauca*	White spruce
PINU CONT	*Pinus contorta*	Lodgepole pine

TR – TRUNKS OF TREES OR STEMS OF MEDIUM/TALL SHRUBS	LATIN NAME	COMMON NAME
PICC GLAU	*Picea glauca*	White spruce
PINU CONT	*Pinus contorta*	Lodgepole pine
SALI GLAU	*Salix glauca*	Northern willow, grayleaf willow
SALI SCOU	*Salix scouleriana*	Scouler’s willow
SALI SPP	*Salix spp.*	(unidentified at species level)

TS – TALL SHRUB (>2M)	LATIN NAME	COMMON NAME
ABIE LASI	*Abies lasiocarpa*	Sub-alpine fir
POPU TREM	*Populus tremuloides*	Trembling aspen
SALI SCOU	*Salix scouleriana*	Scouler’s willow
SALI SPP	*Salix spp.*	(unidentified at species level)

MS – MEDIUM SHRUB (0.5 – 2M)	LATIN NAME	COMMON NAME
PICE GLAU	*Picea glauca*	White spruce
PINU CONT	*Pinus contorta*	Lodgepole pine
POPU TREM	*Populus tremuloides*	Trembling aspen
SHEP CANA	*Sheperdia Canadensis*	Soap berry
SALI BEBB	*Salix bebbiana*	Beaked willow
SALI SPP	*Willow spp.*	(unidentified)
SALI GLAU	*Salix glauca*	Northern willow, grayleaf willow

LS – LOW SHRUB (0.1 – 0.5M)	LATIN NAME	COMMON NAME
ABIE LASI	*Abies lasiocarpa*	Sub-alpine fir
JUNI HORI	*Juniperus horizontalis*	Creeping juniper
LEDU GROE	*Ledum groenlandicum*	Labrador tea
OXYC MICR	*Oxycoccus microcarpus*	Small cranberry
PICE GLAU	*Picea glauca*	White spruce
PINU CONT	*Pinus contorta*	Lodgepole pine
POPU BALS	*Populus balsamifera*	Balsam poplar
POPU TREM	*Populus tremuloides*	Trembling aspen
ROSA ACIC	*Rosa acicularis*	Prickly wild rose
RUBU IDAE	*Rubus idaeus*	Wild red raspberry
SALI BEBB	*Salix bebbiana*	Beaked willow
SALI MYRT	*Salix myrtillifolia*	Blueberry willow
SALI PLAN	*Salix planifolia*	Tea-leaved willow
SALI SPP	*Willow spp.*	(unidentified)
SHEP CANA	*Sheperdia canadensis*	Soap berry
VACC OXYC	*Vaccinium oxycoccus*	Small cranberry
VACC ULIG	*Vaccinium uliginosum*	Bog bilberry
VIBU EDUL	*Viburnum edule*	Low bush cranberry

GS – GROUND SHRUB (<0.1M)	LATIN NAME	COMMON NAME
ARCT RUBR	*Arctostaphylos rubra*	Red bearberry
ARCT UVA-	*Arctostaphylos uva-ursi*	Kinnikinnick; bearberry
EMPE NIGR	*Empetrum nigrum*	Crowberry
LINN BORE	*Linnaea borealis*	Twinflower
PICE GLAU	*Picea glauca*	White spruce
VACC VITI	*Vaccinium vitis-idaea*	Lingonberry

GR – GRAMINOIDS	LATIN NAME	COMMON NAME
CALA SPP	*Calamagrostis spp.*	(unidentified)
CARE CONC	*Carex concinna*	Low northern sedge
(CARE CAPI)	*should be: Carex concinna*	Low northern sedge
BROM SPP	*Bromus spp*	(unidentified)
BROM PUMP	*Bromus pumpellianus*	Pumpelly's brome grass
FEST ALTA	*Festuca altaica*	Altai fescue
FEST SAXI	*Festuca saximontana*	Rocky mountain fescue
GRAM SPP	*Graminoid species*	(unidentified)
POA PALU	*Poa palustris*	Fowl bluegrass
TRIS SPIC	*Trisetum spicatum*	Spike trisetum; narrow false oats

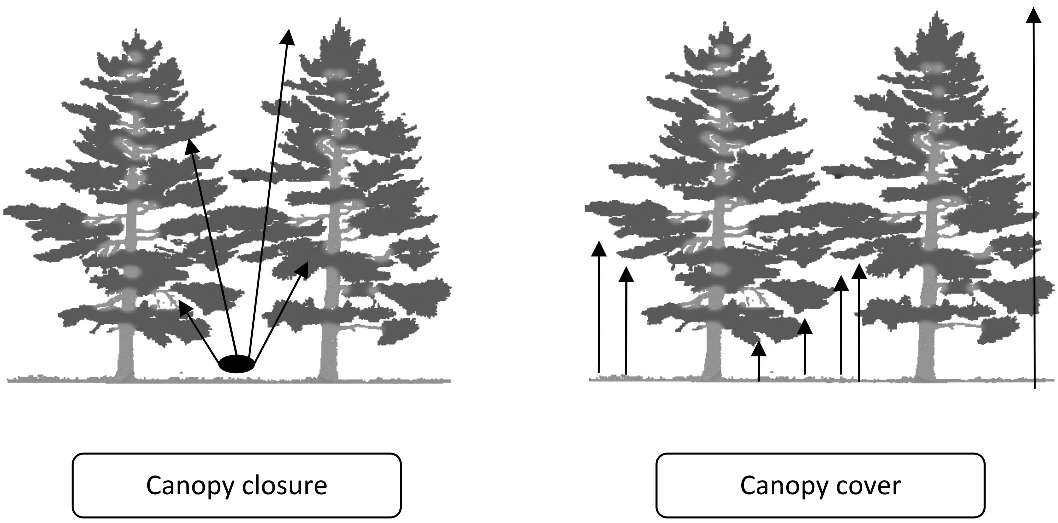
FB – FORBS	**LATIN NAME**	**COMMON NAME**
ACHE MILL	*Acillea millefolium*	Common yarrow; milfoil
ANEM MULT	*Anemone multifida= Pulsatilla patens ssp. Multifida*	Cut-leaf anemone
ANEM PARV	*Anemone parviflora*	Small wood anemone; northern anemone
ANTE SPP	*Antennaria spp.*	Pussytoes
ARNI CORD	*Arnica cordifolia*	Heartleaf arnica
ARNI SPP	*Arnica species*	(unidentified)
ASTE SIBI	*Aster sibiricus*	Arctic aster
CORN CANA	*Cornus canadensis*	Bunchberry
DELP GLAU	*Delphinium glaucum*	Tall larkspur
EPIL ANGU	*Epilobium angustifolium*	Fireweed
EQUI SCIR	*Equisetum scirpoides*	Dwarf scouring-rush
FRAG VIRG	*Fragaria virginiana*	Smooth wild strawberry
GALI BORE	*Galium boreale*	Northern bedstraw
GENT PROP	*Gentianella propinqua*	Four-parted Gentian
GEOC LIVI	*Geocaulon lividum*	Northern comandra, Northern bastard toadflax
HEDY ALPI	*Hedysarum alpinum*	Alpine sweet-vetch
LUPI ARCT	*Lupinus arcticus*	Arctic lupine
MERT PANI	*Mertensia paniculata*	Northern bluebell
OXYT SPP	*Oxytropis species*	Locoweed species
PEDI LABR	*Pedicularis labradorica*	Labrador Lousewort
PETA FRIG	*Petasites frigidus*	Arctic coltsfoot
PLAT HYPE	*Platanthera hyperborea*	Northern green bog-orchid
POLE PULC	*Polemonium pulcherrimum*	Jacob's ladder
PULS PATE	*Pulsatilla patens*	Prairie crocus; Pasqueflower
(PULS LUDO)	*Pulsatilla ludoviciana*	= P.patens
(ANEM PATE)	*Anemone patens*	= P.patens
PYRO SPP	*Pyrola spp.*	Wintergreen spp.
PYRO SECU	*Pyrola secunda*	One-sided wintergreen
(ORTH SECU)	*Orthilia secunda; same as Pyrola secunda*	One-sided wintergreen
PYRO ASAR	*Pyrola asarifolia*	Pink wintergreen
PYRO UNIF	*Pyrola uniflora*	One-flowered wintergreen; Single delight
(MONE UNIF)	*Moneses uniflora*	One-flowered wintergreen; Single delight
PYRO GRAN	*Pyrola grandifolia*	Large flowered wintergreen
RUBU ARCT	*Rubus arcticus ssp. acaulis* *(also rubus acaulis)*	Dwarf raspberry, Dwarf nagoonberry, stemless raspberry

SOLI SIMP	Solidago simplex	Rand’s goldenrod
ZYGA ELEG	Zygadenus elegans	Mtn deathcamas, elegant camas, white camas

BR – BRYOPHYTES	**LATIN NAME**	**COMMON NAME**
AULA TURG	*Aulacomnium turgidum*	Turgid aulacomnium moss
BRYO SPP	*Bryophyte species*	(unidentified)
DICR SPP	*Dicranum spp.*	Broom mosses
HYLO SPLE	*Hylocomium splendens*	Step moss
LEPI REPT	*Lepidozia reptans*	Little hands liverwort
PLEU SCHR	*Pleurozium schreberi*	Red-stemmed feather moss
POLY SPP	*Polytrichum species*	(unidentified)
(POLY JUNI)	*Polytrichum juniperinum*	Juniper Haircap
PTIL CRIS	*Ptilium crista-castrensis*	Knight’s plume
PTIL CILI	*Ptilidium ciliare*	

LN – LICHENS	**LATIN NAME**	**COMMON NAME**
CETR ISLA	*Cetraria islandica*	
CLAD CUPS	*Cladonia cups*	
(CLAD GRAC)	*Cladonia gracilis*	
(CLAD VERT)	*Cladonia verticillata*	Closely resembles C.gracilis
(CLAD SULP)	*Cladonia sulphurina*	
(CLAD BORE)	*Cladonia borealis*	
CLAD HORNS	*Cladonia horns*	
(CLAD AMAU)	*Cladonia amaurocraea*	Closely resembles C.uncialis
(CLAD CARI)	*Cladonia cariosa*	
(CLAD CORN)	*Cladonia cornuta*	
(CLAD SCAB)	*Cladonia scabriscula*	
CLAD MITI	*Cladina mitis*	
CLAD RANG	*Cladina rangiferina*	
CLAD STEL	*Cladina stellaris*	
CLAD UNCI	*Cladonia uncialis*	
CRUS TOSE	*Crustose and squamulose lichens*	(unidentified)
DACT ARCT	*Dactylina arctica*	Dead man’s fingers
FLAV NIVA	*Flavocetraria nivalis*	
FLAV CUCU	*Flavocetraria cucullata*	
(CETR CUCU)	*Cetraria cucullata*	Flavocetraria cucullata
NEPH ARCT	*Nephroma arcticum*	Green kidney
PELT SPP	*Peltigera spp.*	
STER SPP	*Stereocaulum spp.*	

Appendix 5- Canopy closure versus canopy cover



Canopy closure

Canopy cover

Figure 9. Canopy closure versus canopy cover (adapted from Jennings, Brown and Sheil 1999).

Canopy closure takes hemispherical measurements of the obstruction of the sky by tree canopy from a single point while canopy cover measures the proportion of the forest floor covered by the canopy and is gauged from various points in the subplot.

This study makes reference to both canopy closure and canopy cover in the analysis. Canopy closure, also called canopy density, is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings, Brown and Sheil 1999). Canopy cover is the proportion of the forest floor covered by the vertical projection of the tree crowns (Jennings, Brown and Sheil 1999). Our study measured both of these variables. Closure was measured with a spherical densitometer from a set point while cover was measured visually from various points in the subplot. Figure 9 illustrates the difference between the two measurements. Many studies have used the terms interchangeably. For example, Pharo and Vitt (2000) use canopy density and canopy cover interchangeably when their methods reflect canopy closure measurements only. The mean canopy closure over an area of forest is not necessarily correlated with the mean cover over the same area. The difference is that canopy closure is related to the light regime and microclimate and will be linked to survival and plant growth at the point of measurement while canopy cover reflects the dominance of a site by trees (Jennings, Brown and Sheil 1999). The study relies on canopy closure to a large degree but we have used tree cover values on p.29 to compare results with those found in Miege, Armleder, et al. (2001).