Lewes Marsh Caribou Lichen

Research and Monitoring Phase 2

Report on 2017 Post-Harvest Shrub Assessments.

Prepared for the Yukon Government

Forest Management Branch

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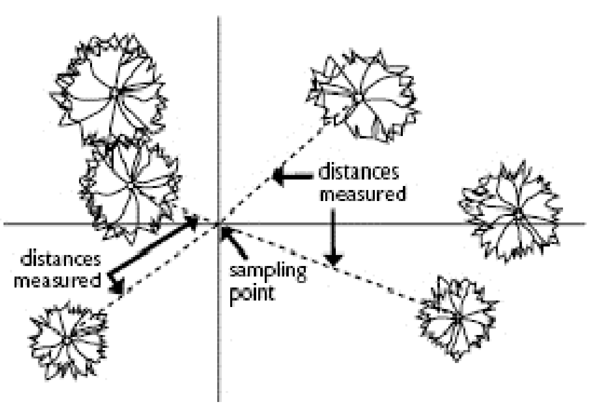

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1.0 Summary.

Harvesting trials for the Lewes Marsh Caribou Lichen Research and Monitoring study were established in the winter of 2014/15 and 2015/16. Nine experimental treatment units, each 3 ha in size, were laid out in three blocks, each block containing three different treatment units. The blocks were separated from each other by a 100 m buffer. Within each block, treatment units were randomly assigned to one of three treatments: high-retention logging (one-third basal area removal), low-retention logging (two-thirds basal area removal), or no harvesting (control). Post-harvest assessments in 2016 found that mean canopy openness of the control, one-third, and two-thirds basal area removal treatments was 38.7, 50.1, and 62.9% respectively. This raises the questions of whether or not increased forest floor light availability will trigger greater establishment and growth of shrub species used as ungulate forage, predominantly willow (*Salix spp.*) on this site. This is a key question for wildlife managers, as the value of enhancing ground lichen cover for caribou by partial cutting would be negated if growth responses on the part of the shrub community change predator-prey dynamics on the site, from apparent competition triggered by wolf-moose interactions. Measurements in summer 2017 found that crown area and the number of stems were greatest in the two-thirds removal treatments, followed by the control, and one-thirds removal treatments. The height of established willows was greatest in old clumps in the control plots. A vigorous resprouting response was seen in many willow clumps in the two-thirds removal treatment, especially where existing mature stems had been knocked to the ground during harvesting or broken off at the soil surface, for instance, on skid trails. A lesser response was observed in the one-thirds removal treatment. Continued monitoring of shrub response at the time of the next site reassessment (planned for 2020/2021) will be critical to evaluating the overall quality of the site for caribou habitat.

2.0 Introduction.

2.1 Factors Controlling Lichen Development in Boreal Forests.

Numerous studies have documented the successional development of terrestrial lichens in fire-origin stands. Zouaoui *et al*. (2014) found that the time elapsed since the last fire was the best explanatory variable for the abundance of terrestrial lichens in black spruce (*Picea mariana*) forests, while Johnson (1981) found that forage lichen cover reached maximum values between 150 to 250 years after stand origin. Johnson noted that feather moss mats dominated many of the old forest stands, especially in sites with greater canopy closure. Coxson and Marsh (2001) found that older pine-lichen woodlands in north-central B.C. showed a gradual transition from a *Cladina* dominated forest floor cover to feather moss mat dominated forest-floor surfaces. Many of the *Cladina* lichen mats in their mature to old stands were found growing embedded within feathermoss mats, which were slowly infiltrating and covering the lichen thalli.

This pattern of lichen decline is very similar to that observed in the open needle-leaf mixed spruce and pine lichen forests in the Lewes Marsh area south of Whitehorse. Sulyma and Coxson (2001) found that terrestrial lichen mats were strongly associated with forest floor microsites with greater canopy exposure, while feather mosses dominated shaded microsites. Similar conclusions were reached by Jonsson Čabrajić *et al*. (2010) in northern Scandinavian forests, where optimal terrestrial lichen growth was found only in stands with less than 60% canopy cover. Haughian and Burton (2015) confirmed these opposing habitat preferences of terrestrial lichens and feather mosses, demonstrating that terrestrial lichens responded positively to warmer microsites with greater light availability, while feather mosses preferred cooler shaded microsites. Stevenson and Coxson (2015) suggested that forest management practices such as stand thinning could, under some circumstances, be used to slow or even halt this loss of terrestrial forage lichens in mature to old forest stands, prolonging the period of terrestrial lichen forage availability.

2.2 Apparent Competition for Caribou – The Role of Browse Shrubs.

One of the key emerging concepts explaining the decline of many North American caribou herds has been the role of apparent competition from other ungulates, such as moose (Cumming *et al*. 1996, Hervieux 2016, Wittmer *et al.* 2005). This competition is based not on direct use of the same food resource or habitat; rather it is mediated by predator-prey dynamics. In British Columbia, this has often been triggered by the introduction of clear-cut logging within and adjacent to caribou ranges. This leads to greater availability of early seral shrub species, such as willow and alder. As a result, regional moose populations climb within 15 to 20 years after logging, supporting, in turn, increased populations of predators such as wolves. Caribou become a secondary casualty of these landscape level changes, facing higher mortality as an incidental prey resource for expanding wolf populations. This scenario has played out in mountain caribou herds across British Columbia. A text-book case was the Telkwa herd south of Smithers, which fell from some 300 animals in the late 1960's to less than 20 animals by 2016 (Grant 2017), notwithstanding attempts to reintroduce animals in 1997 and 1998. Grant (2017) documents the rapid decline of caribou populations in the first decades after logging, driven by increasing availability of early seral vegetation and the resultant climb in abundance of moose and wolf populations. Short-term solutions to the rise of apparent competition and associated collapse of caribou populations have looked at both sides of the moose-wolf interaction, some attempting to reduce moose populations by increasing hunting pressure (Serrouya *et al.* 2017), other implementing wolf cull programs (Hervieux *et al.* 2014), yet others introducing maternal pens to safeguard caribou from predation in the critical late winter-early spring period (Boutin and Merrill 2016). These solutions have had mixed success, but all will require continued management interventions for many decades, until the primary driving factor, the abundance of early seral vegetation, declines in regional landscapes.

2.3 Caribou Habitat in the Southern Lakes Region.

The winter range of the Carcross caribou herd is located in the Southern Lakes Region in south central Yukon Territory, and a portion of adjacent British Columbia. In many woodland caribou (*Rangifer tarandus caribou*) ranges managers have adopted a strategy of intensively developing large blocks of habitat within a short period so that other larger areas could be left undisturbed (Racey *et al*. 1991, Smith *et al*. 2000, McNay 2011). That strategy may not be appropriate for the Carcross caribou winter range (Florkiewicz *et al*. 2007) for several reasons. The Carcross caribou winter range is close to centres of human habitation; linear developments, and rural residential areas. Small scale agriculture and forestry activities are common throughout the area as well. The best lichen-producing habitats are dispersed and are over-represented within the zone of human influence, and access to lichens may ultimately become a limiting factor for this herd (Florkiewicz *et al*. 2007). Timber harvesting operations in the area are small in scale, and have included commercial firewood cutting operations and selective removal of trees for local building projects. Historically harvested areas ranged from 1.5 ha to 12 ha (Gough 2010).

2.4 The Lewes Marsh Caribou Lichen Research and Monitoring Program.

In response to these issues the Yukon Forest Management Branch and Environment Yukon jointly initiated a program of research aimed at identifying how forest harvest practices can minimize impacts on terrestrial forage lichens in the winter range. The project was designed as a multi-phase adaptive management study, described by Ogden *et al*. (2009) as focussing on the relationship between variable retention harvesting systems and abundance of terrestrial forage lichens. As part of Phase 1 a literature review was prepared on factors affecting the abundance of terrestrial lichens in managed forests, including the effects of variable retention harvesting (Gough 2009). The field component of Phase 1 was a retrospective study of the relationship between levels of retention and lichen abundance in historic harvesting blocks in the Lewes Marsh area (Gough 2010).

Phase 2 harvesting trials for the Lewes Marsh Caribou Lichen Research and Monitoring study were established in the winter of 2014/15 and 2015/16 as described in Coxson (2017). Mean canopy openness in control, one-third, and two-thirds basal area removal treatments were 38.7, 50.1, and 62.9% respectively (Coxson 2017). Initial post-harvest assessments noted a trend of declining feather-moss mat abundance, which suggests increasing future habitat availability for terrestrial lichens. A major recommendation of the 2017 assessment report was that additional monitoring protocols be put in place to assess changes in forage shrub (primarily willows and alders) abundance in the Lewes Marsh trial (Coxson 2017). These recommendations were implemented during the summer 2017 field season, with point-quarter methods used to assess forage shrub abundance along sampling lines in the Lewes Marsh Caribou Lichen Research and Monitoring study. This provides critical baseline data for assessing the success of the partial-cutting treatments in restoring/extending late successional caribou habitat characteristics.

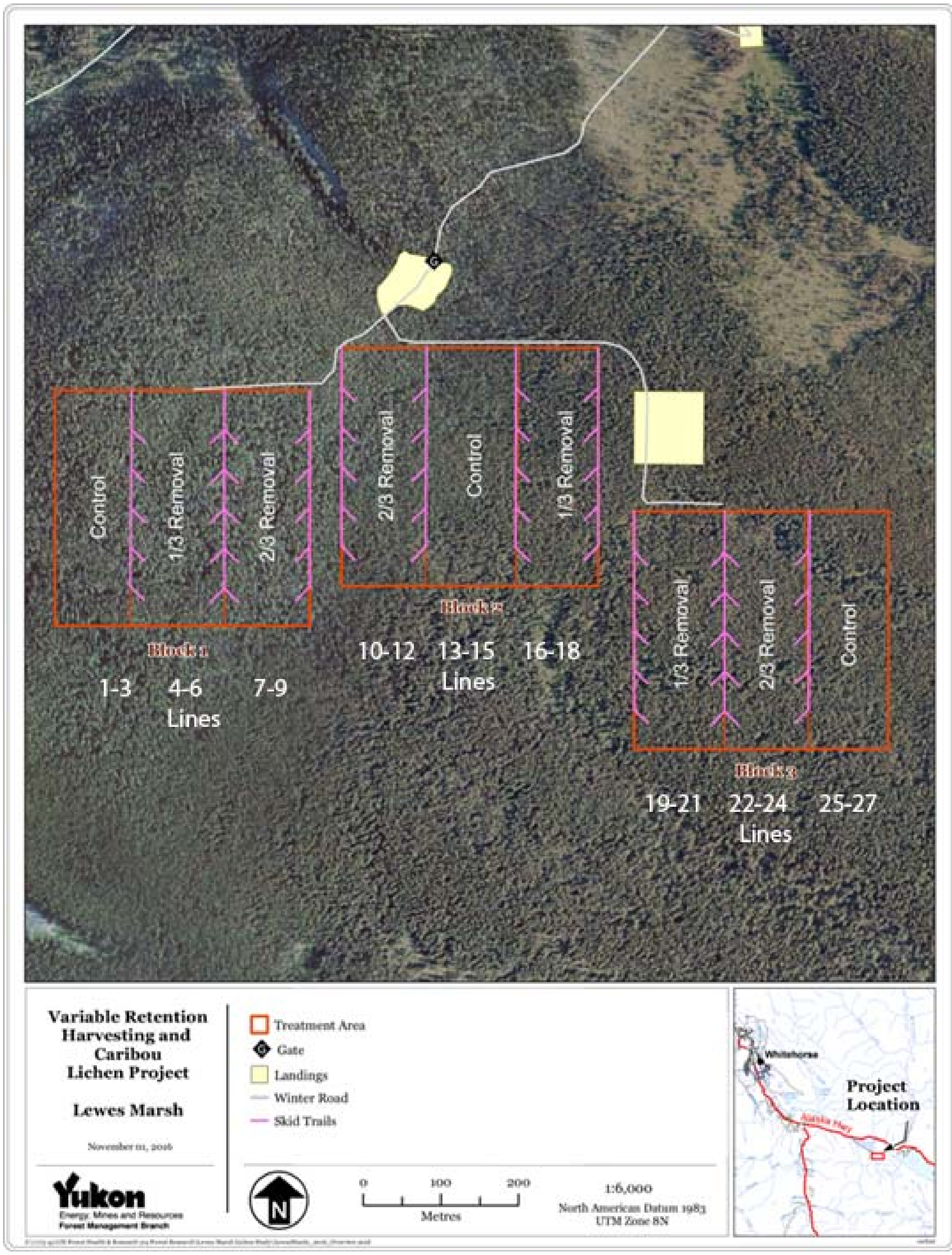

Figure 1. Location and layout of the sampling lines, treatment units, and level of tree removal (one-third basal area removal, two-thirds basal area removal, and control) at the Lewes Marsh study area.

3.0 Methods.

The experimental design within the Lewes Marsh Caribou Lichen Research and Monitoring study is described more fully by Coxson (2017). In brief, the intent of the harvesting prescriptions was to create stands with dispersed retention of the existing tree canopy at two different levels of openness. Over time, the result will be a two-storied or multi-storied stand. Three levels of retention were implemented:

- High retention – one-third basal area removal using a mark-to-cut single-tree selection system, with trees marked for removal.

- Low retention – two-thirds basal area removal using a mark-to-leave single-tree selection system, with trees marked for retention.

- Control – no modification to stand structure.

Nine experimental treatment units, each 3 ha in size, were laid out during the winter of 2014 and 2015 (see outline of treatment units in Fig. 1). The treatment units were set out in three blocks, each block containing three treatment units. The blocks were separated from each other by a 100 m buffer. Within each block, each treatment unit was randomly assigned to one of the three treatments.

Assessments of shrub abundance were conducted using the point-quarter sampling method of Mueller-Dombois and Ellenberg (1974). Shrub sampling points were established at 20 m intervals along the north-south permanent sampling lines in the nine treatment blocks (Fig. 1). At each of the 20 m interval points along the permanent transect lines the distance to the nearest shrub clump was measured within each of the 4 quarters as shown in Fig. 2. Additional measurements taken on each of the shrub clumps located in each quadrat were diameter of canopy coverage, the number of stems, and the height of the highest branch. A height of 1 m was established as the minimum size for measuring a shrub clump. Only forage shrubs were measured. In the Lewes Marsh site these consisted of willows (*Salix bebbiana* and *Salix scouleriana*) and green alder (*Alnus viridis*) (Gould 2010). Measurements were not taken on ground cover shrubs such as soapberry (*Shepherdia canadensis*), or dwarf shrubs such as bearberry (*Arctostaphylos spp.*), as these were included in prior quadrat based cover assessments (Coxson 2017). In total 540 point-quarter measurements were taken in 2017; all but one was on willows (*Salix spp.*), thus our analysis was confined to this genus. A preliminary investigation of differences between treatment blocks was obtained by conducting Bonferroni t-tests on crown area measurements (Table 1). The primary focus of future statistical analysis (after the next re-measurement of plots in 2020-2021) will be that of time series analysis within individual treatment blocks.

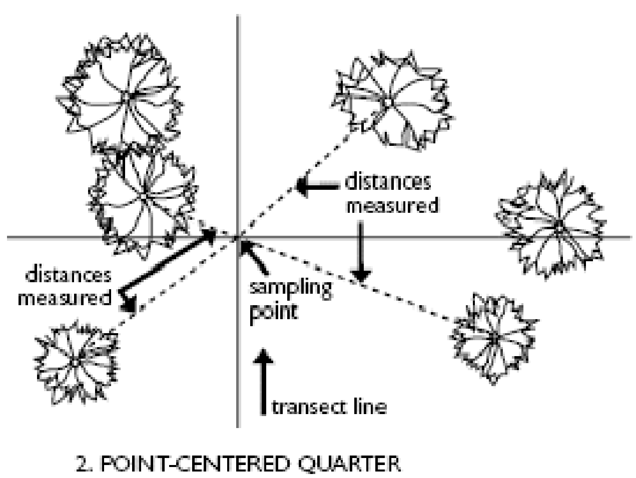

Figure 2. Layout of point-quarter sampling method. The transect line runs from south to north along each plot line (from University of Idaho 2011).

Table 1. Probability values (p) for Bonferroni t-tests between treatment groups for shrub crown area measurements.

Treatment	Control	One-thirds	Two-thirds
Control	---	---	---
One-thirds	0.096	---	---
Two-thirds	0.908	0.506	---

4.0 Results and Discussion.

The point-quarter sampling method used in the present study provides a highly repeatable means of obtaining measurements of density and basal area for trees and shrubs (Mueller-Dombois and Ellenberg 1974, Elzinga *et al.* 1998). In a comparison of sampling methods Cottam and Curtis (1956) found that the point-quarter method gave the least variable results and was less subject to bias. Point-quarter sampling has been widely used in ecological assessments, from California Chaparral (Jacobsen and Davis 2004) to Alaskan shrub communities (Oldemeyer and Regelin 1980). Although point-quarter sampling can overestimate basal area compared to direct assessments of all known individuals (Mark and Essler 1970), this is a bias that is found mainly in stands with very uneven age-classes, where large stemmed individuals disproportionately influence measurements. The coefficient of variation in point-quarter centred quadrat measurements in Alaska was between 16 and 21% (Oldemeyer and Regelin 1980), well below that of direct quadrat based measurements (16-56%). One factor which can diminish the accuracy (essentially reducing replication) of point-quarter shrub measurements is when individual shrub clumps are detected from multiple sampling lines (Mueller-Dombois and Ellenberg 1974). This occurred very infrequently in the current data set, mainly on lines 25-27, where shrub abundances were lower.

Figure 3. Established willow clumps in the control sites were comprised predominantly of older large upright stems and decaying snags. (photo Sept. 2011).

Figure 4. Left: Willow clumps disturbed by harvesting, here in the two-thirds removal plot, showed vigorous resprouting of new stems. Right: Vigorous growth of adventitious sprouts was seen on willow stems (Salix spp.) knocked to the ground by harvesting (photo July 2017).

The mature pine forests in the Lewes Marsh site contained scattered willow clumps. In control plots these consisted largely of upright older large stems and decaying snags (Fig. 3). Where established shrub clumps were disturbed during harvesting a vigorous resprouting of willow shoots was seen (Fig. 4). With one exception, as noted below, the abundance and distribution of shrubs in the study area reflects their pre-existing occupancy in the landscape (Figs. 5-7). The size of pre-existing willow clumps was largest in the westernmost parts of the study area (lines 1-3), declining in both crown area and height in the lines nearer the eastern block boundaries (lines 25-27) (Figs. 5 and 6). Within control plots the number of stems and the height of those stems showed opposing patterns (Fig. 6), again reflecting the fewer large stems found near the eastern boundary of the study area. The one notable exception to these patterns was the relatively high cover and density of shrubs along sampling lines 7 to 9. These sampling lines not only had the highest removal levels (two-thirds) of our treatments, but line 7 was also an area where the initial harvesting effort was conducted at a higher intensity than planned, with over 70% canopy openness found along much of line 7, compared to average canopy openness nearer 60% for most of the two-thirds removal treatments, and 50% in the one-third removal treatment (Coxson 2017). Many of the willow clumps along line 7 were knocked over or broken in this initial harvesting period, leading to vigorous resprouting (Fig. 4). These differences between sampling lines, however, were not statistically significant in comparisons using Bonferroni t-tests (Table 1). The value of the study design, however, lays in the ability to support time series statistical assessments within treatment blocks at the next sampling interval (see Recommendations).

The greater crown area and number of stems along lines 7 to 9 are still likely a response from pre-existing shrub clumps. Much as they would after fire, willow clumps respond strongly to mechanical disturbance and the greater light and increased soil temperature found in open areas. Increasingly, forest ecologists are realizing that shrub communities are persistent spatial elements in the understory of forest stands, resprouting in the same location over the course of multiple disturbance events (Bond and Midgley 2001, Lertzman *et al*. 1996). These concepts apply equally well to boreal forests (Chapin III 2006), subject to the intensity of stand-initiating fires, which on occasion can burn through soil organic horizons and below-ground root remnants (Bergeron 1991, De Grandpre *et al*. 1993, Rowe and Scotter 1973).

Although willows are a preferred browse species for caribou (Denryter 2017), when they are abundant in caribou winter range they can trigger apparent competition. This occurs when other ungulate species browsing on the same shrub communities support predator populations, for whom caribou are now an incidental prey species (Cumming *et* al. 1996, Hervieux 2016, Wittmer *et al.* 2005). There is no clearly defined threshold at which increased shrub availability will trigger apparent competition for caribou from other ungulates, however, these interactions have been widely accepted as an important factor in global declines of caribou and reindeer (Vors and Boyce 2009). The response of shrub communities to increasing canopy openness in the Lewes marsh selective harvest treatment is thus an important variable for continued monitoring.

The level of tree removal in selective harvesting treatments is a key variable in understanding the response of understory shrubs (Bose *et al*. 2014). The goal of the Lewes Marsh Caribou Lichen Research and Monitoring selective harvest treatments was to achieve a level of canopy thinning which promoted the growth of forest floor caribou forage lichens at the expense of feather moss mats, while minimizing the growth response of understory shrubs. At the present time there is no correlation between shrub abundance and canopy openness in the Lewes marsh plots (Fig. 8). Although Mallik (2003) notes that Ericaceous shrubs can respond vigorously to forest harvesting (clear-cutting or selective cutting), these conclusions were drawn from a temperate rainforest ecosystem on Vancouver Island. The best evidence for an intermediate response to selective harvesting comes from the study of Miège *et al*. (2001), with follow-up measurements provided by Waterhouse *et al*. (2011). This study took place in the Chilcotin plateau of central-interior British Columbia. Terrestrial lichen cover initially declined in partial-cut harvesting treatments; however, 8 years after harvesting, terrestrial lichen cover had recovered with little exclusion from understory shrubs. Bryophyte cover also declined significantly in the partial-cuts, but did not recover; supporting the hypothesis that reduced canopy cover differentially favoured terrestrial lichen mats. It would have been interesting to see if the trends towards recovery of lichen mats without a significant response from understory shrubs had continued in the Waterhouse study, however, the mountain pine beetle outbreak led to widespread defoliation of remaining trees, with a concomitant increase in abundance of understory shrubs (Waterhouse *et al*. 2011).

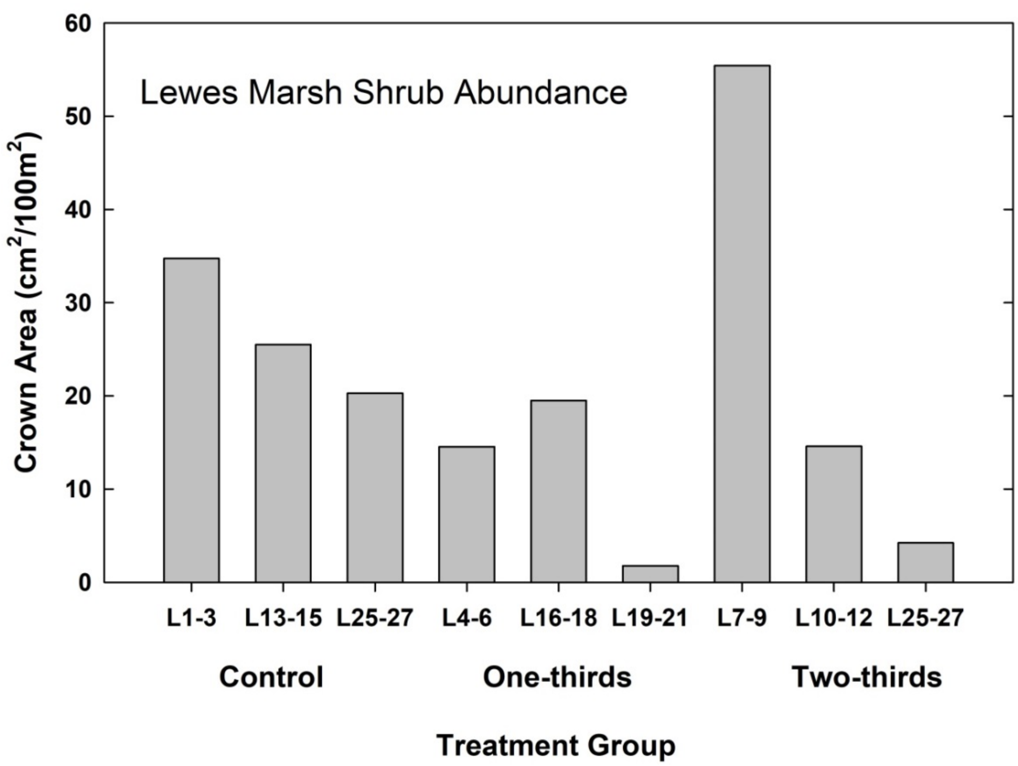

Figure 5. Mean crown area by treatment line ($cm^2/100m^2$) for shrubs in the Control, One-thirds removal, and Two-thirds removal treatment areas at Lewes Marsh.

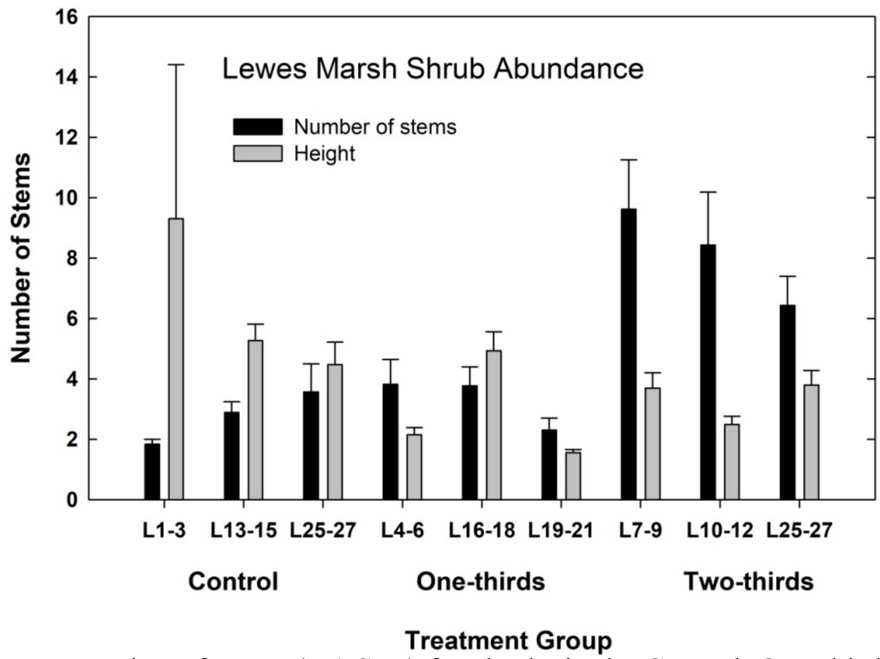

Figure 6. Mean number of stems (+ 1 S.E.) for shrubs in the Control, One-thirds removal, and Two-thirds removal treatment areas at Lewes Marsh.

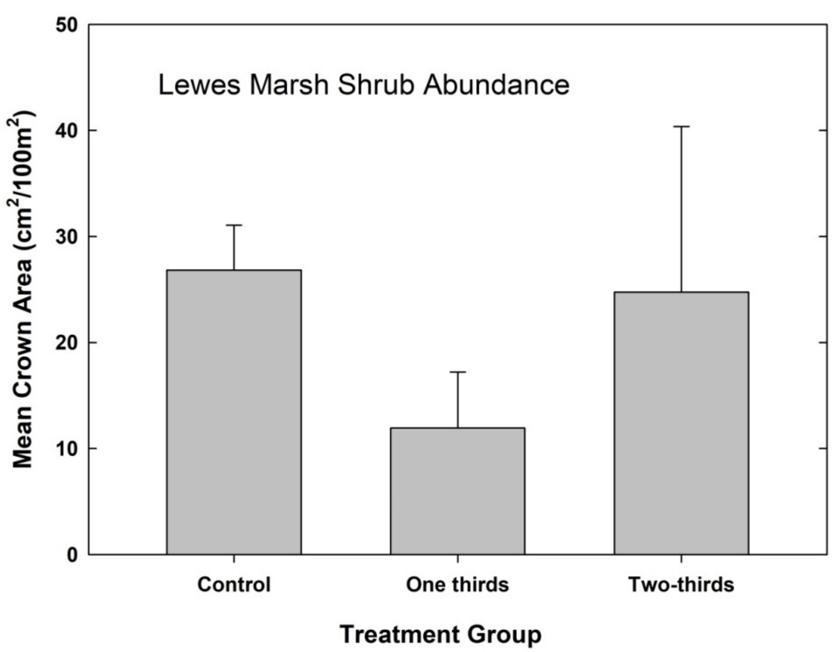

Figure 7. Mean crown area ($cm^2/100m^2$) for shrubs in the Control, One-thirds removal, and Two-thirds removal treatment areas at Lewes Marsh.

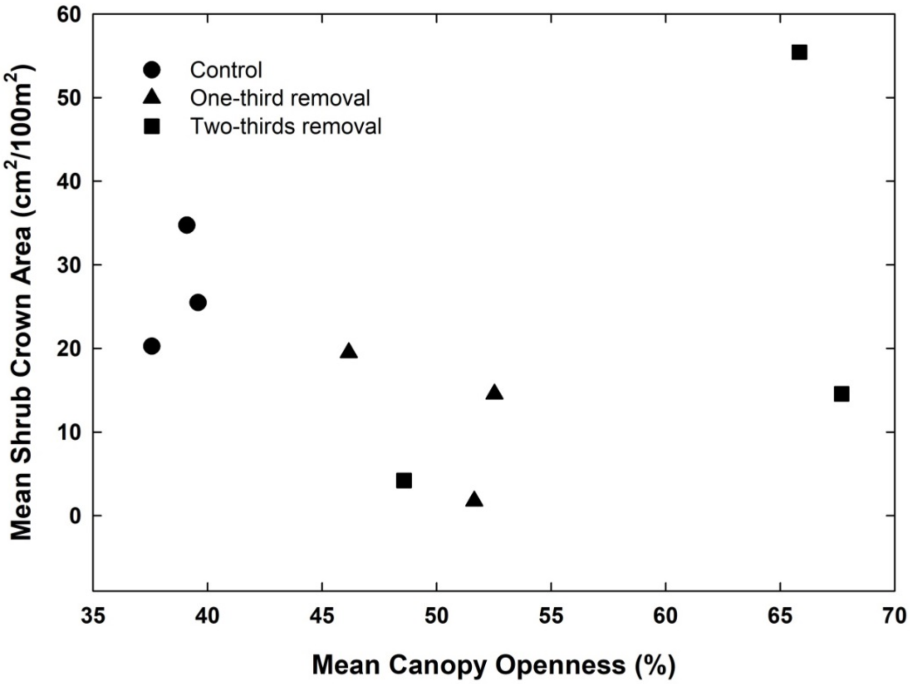

Figure 8. Mean crown area ($cm^2/100m^2$) as a function of canopy openness (%) for shrubs in the Control, One-thirds removal, and Two-thirds removal treatment areas at Lewes Marsh.

5.0 Recommendations.

The evaluation of forage shrub species in the Lewes Marsh selective harvest treatments is a key part in the determination of the suitability of treatment blocks as future caribou habitat. It is recommended that point-quarter shrub assessments be continued in the next major reassessment of terrestrial lichen communities and understory vegetation, currently planned for 2020/2021, five years after harvesting, with time series analysis conducted on data obtained from within each treatment block to determine response of forage shrub communities.

6.0 Literature Cited.

Bergeron, Y. 1991. The influence of island and mainland lakeshore landscapes on boreal forest fire regimes. Ecology 72: 1980-1992.

Bond, W.J., and J.J.Midgley. 2001. Ecology of sprouting in woody plants: the persistence niche. Trends in Ecology & Evolution. 16: 45-51.

Bose, A.K., B.D. Harvey, S. Brais, M. Beaudet, and A. Leduc. 2014. Constraints to partial cutting in the boreal forest of Canada in the context of natural disturbance-based management: a review. Forestry 87: 11–28.

Boutin, S., and E. Merrill. 2016. A Review of population-based management of Southern Mountain caribou in BC. Columbia Mountains Institute. March 2016. http://cmiae.org/wp-content/uploads/Mountain-Caribou-review-final.pdf

Chapin III, F.S., C.L. Fastie, L.A. Viereck, R.O. Ott, P.C. Adams, D. Mann, K. Van Cleve, and J.F. Johnstone. 2006. Successional Processes in the Alaskan Boreal Forest. Chapter 7 In: Alaska's Changing Boreal Forest. edited by F.S. Chapin, M.W. Oswood, K. van Cleve, L,A. Viereck, and D,L. Verbyla. Oxford University Press. 353 pages.

Cottam, G., And J. T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Coxson, D. 2017. Lewes Marsh Caribou Lichen Research and Monitoring Phase 2. Report on 2016 post-harvest assessments. Prepared for the Yukon Government Forest Management Branch. Unpublished Report. University of Northern British Columbia, Ecosystem Science and Management Program, March, 2017.

Coxson, D. S., and J. Marsh. 2001. Lichen chronosequences (post-fire and post-harvest) in lodgepole pine (*Pinus contorta*) forests of northern-interior British Columbia. Canadian Journal of Botany 79: 1449-1464.

Cumming, H.G., D.B. Beange, and G. Lavoie. 1996. Habitat partitioning between woodland caribou and moose in Ontario: the potential role of shared predation risk. Rangifer 16: 81-94.

De Grandpré, L.D., D. Gagnon and Y. Bergeron. 1993. Changes in the Understory of Canadian Southern Boreal Forest after Fire. Journal of Vegetation Science 4: 803-810.

Denryter, K., R. Cook, G. John, and K. L. Parker. 2017. Straight from the caribou's mouth: detailed observations of tame caribou reveal new insights into summer-autumn diets. Canadian Journal of Zoology 95: 81-94.

Elzinga, C.L., D.W. Salzer and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Technical Reference 1730-1. Bureau of Land Management. Denver, Colorado. USDI, BLM

Florkiewicz, R., R. Maraj, T. Hegel and M. Waterreus. 2007. The effects of human land use on the winter habitat of the recovering Carcross woodland caribou herd in suburban Yukon Territory, Canada. Rangifer Special Issue 17:181-197.

Gough, A. 2009. Sawmill Creek/Lewes Marsh Timber Harvest and Caribou Management Study Phase 1 – Passive adaptive management: Literature review. Unpublished report prepared for Forest Management Branch, Government of Yukon. 29 pp.

Gough, A. 2010. Effects of historical timber harvesting practices on caribou forage lichen abundance near Marsh Lake, Yukon: Phase 1 final report. Unpublished report prepared for Forest Management Branch, Government of Yukon. 56 pp.

Grant, L.V. 2017. Spatial factors influencing northern Mountain Caribou (*Rangifer tarandus*) survival and distribution in the Telkwa range. M.Sc. Thesis, Natural Resources and Environmental Studies (Biology). University Of Northern British Columbia. April 2017.

Haughian, S. R., and P. J. Burton. 2015. Microhabitat associations of lichens, feathermosses, and vascular plants in a caribou winter range, and their implications for understory development. Botany 93: 221-231.

Hervieux D. 2016. Predator management and species at risk in Alberta. PeerJ Preprints 4:e2344v1 https://doi.org/10.7287/peerj.preprints.2344v1

Hervieux, D., M. Hebblewhite, D. Stepnisky, M. Bacon, and S. Boutin. 2014. Managing wolves (*Canis lupus*) to recover threatened woodland caribou (*Rangifer tarandus caribou*) in Alberta. Canadian Journal of Zoology 92: 1029-1037.

Jacobsen, A.L., and S.D. Davis. 2004. Fire frequency impacts non-sprouting chaparral shrubs in the Santa Monica Mountains of southern California. Proceedings 10th MEDECOS Conference, April 25 – May 1, 2004, Rhodes, Greece, Arianoutsou & Papanastasis (eds). Millpress, Rotterdam, ISBN 90 5966 016 1

Johnson, E. A. 1981. Vegetation Organization and Dynamics of Lichen Woodland Communities in the Northwest Territories, Canada. Ecology. 62: 200-215.

Jonsson Čabrajić, A. V., J. Moen, and K. Palmqvist. 2010. Predicting growth of mat-forming lichens on a landscape scale – comparing models with different complexities. Ecography 33: 949-960.

Lertzman, K.P., G.D. Sutherland, A. Inselberg and S.C. Saunders. 1996. Canopy Gaps and the Landscape Mosaic in a Coastal Temperate Rain Forest. Ecology 77: 1254-1270.

Mallik, A.U. 2003. Conifer regeneration problems in boreal and temperate forests with ericaceous understory: Role of disturbance, seedbed limitation, and keystone species change. Critical Reviews in Plant Sciences 22: 341–366.

Mark, A.F., and A. E. Esler. 1970. An assessment of the point-centred quarter method of plotless sampling in some New Zealand forests. Proceedings New Zealand Ecological Society 17: 106-110.

McNay, R.S. 2011. Silviculture options for use in ranges designated for the conservation of northern caribou in British Columbia. BC Journal of Ecosystems and Management 12(2):55-73.

Miège, D., T. Goward, M. Waterhouse, and H. Armleder. 2001. Impact of partial cutting on lichen diversity in lodgepole pine forests on the Chilcotin Plateau in British Columbia. British Columbia Ministry of Forests, Research Branch, Working Paper 55,Victoria, British Columbia, Canada.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons. New York. 547 pages.

Ogden, A., K. Price, J. Ryder, V. Loewen. 2009. Draft Study Design, Lewes Marsh Monitoring Program. Version 5. Forest Management Branch, Government of Yukon, Whitehorse, YT. 35 pp.

Oldemeyer, J.L., and W.L. Regelin. 1980. Comparison of 9 Methods for Estimating Density of Shrubs and Saplings in Alaska. The Journal of Wildlife Management 44: 662-666.

Racey, G.D., K. Abraham, W.R. Darby, H.R. Timmerman, and Q. Day. 1991. Can woodland caribou and the forest industry coexist: the Ontario scene. Rangifer Special Issue 7:108-115.

Rowe, J.S., and G.W.Scotter. 1973. Fire in the boreal forest. Quaternary Research 3: 444-464.

Serrouya R, McLellan BN, van Oort H, Mowat G, Boutin S. 2017. Experimental moose reduction lowers wolf density and stops decline of endangered caribou. PeerJ 5:e3736 https://doi.org/10.7717/peerj.3736

Smith, K. G., E.J. Ficht, D. Hobson, T.C. Sorensen, and D. Hervieux. 2000. Winter distribution of woodland caribou in relation to clearcut logging in west-central Alberta. Canadian Journal of Zoology 78: 1433-1440.

Stevenson, S.K., and D.S. Coxson. 2015. Can partial-cut harvesting be used to manage terrestrial lichen habitat? A review of recent evidence. Rangifer Vol 35: 11-25.

Sulyma, R. and D.S. Coxson. 2001. Microsite displacement of terrestrial lichens by feather moss mats in late seral pine-lichen woodlands of north-central British Columbia. The Bryologist 104:505-516.

University of Idaho. 2011. Principles of Vegetation Measurement & Assessment and Ecological Monitoring & Analysis. College of Natural Resources http://www.webpages.uidaho.edu/veg_measure/

Vors, L.S., and M.S. Boyce. 2009. Global declines of caribou and reindeer. Global Change Biology 15: 2626–2633.

Waterhouse, M. J., H. M. Armleder, and A. F. L. Nemec. 2011. Terrestrial lichen response to partial cutting in lodgepole pine forests on caribou winter range in west-central British Columbia. Rangifer 19: 119-134.

Wittmer, H.U., A.R.E. Sinclair, and B.N. McLellan. 2005. The role of predation in the decline and extirpation of woodland caribou. Oecologia 144:257-267.

Zouaoui, S., C. Boudreault, P. Drapeau and Y. Bergeron. 2014. Influence of Time since Fire and Micro-Habitat Availability on Terricolous Lichen Communities in Black Spruce (*Picea mariana*) Boreal Forests. Forests 5: 2793-2809.