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Review

Using Partial-cut Harvesting to Conserve Terrestrial Lichens in Managed Landscapes

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Abstract

The development of terrestrial lichen communities used as forage by woodland caribou (*Rangifer tarandus*) in boreal and sub-boreal forests is strongly linked to changes in canopy structure and associated changes in canopy microclimate that occur during stand succession. Additionally, substrate type and proximity to propagule sources can have a major influence on lichen establishment. Increasingly, the development of lichen communities now occurs within managed landscapes where the scale and intensity of disturbance events can be very different from those that historically shaped lichen community development. Nonetheless, our knowledge of factors that previously mediated the establishment and development of lichen communities may provide important clues to understanding the success of terrestrial lichens in managed landscapes, and help guide forest managers in designing practices that promote conservation of woodland caribou habitat. Evidence from recent harvesting trials suggests that partial-cut harvesting may be a silvicultural system that can provide forest managers with tools for conserving terrestrial forage lichens in caribou winter range. Best practices and limitations on the use of partial-cut harvesting techniques to conserve terrestrial lichen communities are reviewed, including a consideration of secondary impacts on caribou from factors such as the construction of forestry access roads and disposal of logging debris and slash.

Key Words: Caribou Management, *Cladina*, *Cladonia*, Partial-cut Harvesting, *Stereocaulun*.

INTRODUCTION

The management of boreal woodland caribou (*Rangifer tarandus*) populations has become increasingly challenging in recent years, with cumulative impacts from habitat loss, anthropogenic disturbance, and changing predator-prey dynamics, interacting to bring many herds into a state of decline (Boutin *et al.* 2012; Bradley and Neufeld 2012; Dyer *et al.* 2002). Although these issues are often inter-related, the retention of suitable foraging habitats remains a major concern for many populations. Caribou diet in the summer and fall can be diverse; however, winter habitat for most populations consists mainly of terrestrial and/or arboreal

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forage lichens (Johnson *et al.* 2000; Thompson *et al.* 2015). Loss of access to winter forage can be a result of the direct loss of habitat, for instance after logging, or stem from indirect causes when disturbance results in the abandonment or depopulation of core habitats (Polfus *et al.* 2011). Compounding these considerations is the changing nature of northern ecosystems where lichen communities themselves may be particularly susceptible to climate change (Bjerke *et al.* 2013; Cornelissen *et al.* 2001; Gustine *et al.* 2014).

Clearly, the best solution for the long-term conservation of caribou would be the maintenance of large regional landscapes free from anthropogenic influence. However, in many areas, this is no longer an option. We must instead take steps that reduce the rate of habitat loss and habitat change (Environment Canada 2012; Johnson *et al.* 2015; Proulx 2015). In landscapes where industrial forestry is a major influence on caribou habitat and predator-prey dynamics, the adoption of alternative forest harvesting techniques, i.e., moving away from clear-cutting as the dominant forest harvesting paradigm, may favour the conservation of caribou populations. Recent examples of the application of partial-cut harvesting approaches are reviewed here and placed in context of our understanding of factors that promote the development of terrestrial lichens.

CARIBOU HABITAT SELECTION

Although caribou are generally thought to prefer mature forests with a high cover of terrestrial lichens, relatively few studies have examined the thresholds of terrestrial lichen cover at which caribou select habitat. Collins *et al.* (2011) noted that caribou in the Nelchina herd in Alaska, during a period of shifting range occupancy in the early 1990s, generally selected new habitats with

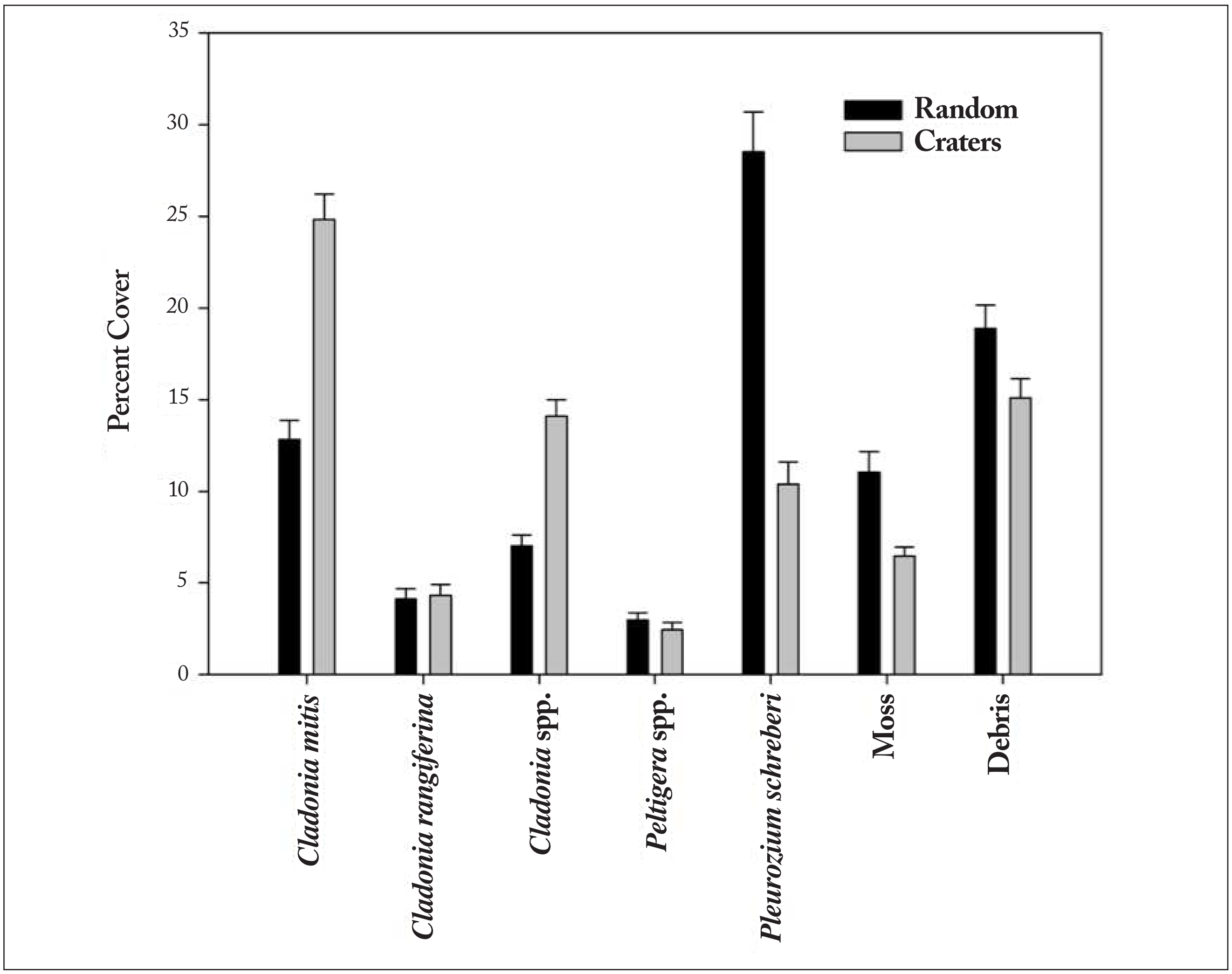

Figure 1. Mean percent cover (+ 1 SE) of the lichens *Cladonia mitis, C. rangiferina, Cladonia* morphotype lichens (squamulose species in *Cladonia* subgenus *Cladonia*, labelled as *Cladonia* spp.), *Peltigera* spp., the pleurocarpous moss *Pleurozium schreberi*, acrocarpous moss species (labelled as Moss), and forest floor debris at random (n = 255) and caribou cratered (n = 206) sites in forested locations within the winter range of woodland caribou in central-interior BC. Adapted from Johnson *et al.* (2000).

greater than 20% terrestrial lichen cover. In a detailed study on winter habitat choice in valley-bottom forests of north-central British Columbia (BC), Johnson *et al.* (2000) found that in sites where caribou dug craters through the snow to access terrestrial lichens, the cover of *Cladinia mitis* ranged from between 22 to 28 % (the range of values from ±95% confidence intervals around sample means); this compared to average *C. mitis* cover values of between 10 and 16% in randomly chosen plots in the same region (Figure 1). In contrast, the feather moss *Pleurozium schreberi*, whose average cover in the study landscape was between 20 and 25%, had cover value between 7 and 15% in foraging craters (Figure 1).

The selection of habitats by caribou for their forage values, however, must be weighed against avoidance behaviours, especially for habitats that pose greater predation risk. In one of the few studies that examined landscape response of caribou populations to the outcome of a forest management plan that preserved large blocks of mature forest connected by habitat corridors in eastern Quebec, Courtois *et al.* (2008) found that caribou avoided open habitats (clear-cuts and burns) as well as mixed and deciduous stands. Habitat use was concentrated into remaining forested sites, with corridors used in proportion to their abundance. Although caribou numbers were maintained after logging in the study area, Courtois *et al.* speculated that their future viability may be strongly influenced by interactions with moose (*Alces alces*), wolves (*Canis lupus*), and bears (*Ursus* spp.) as early seral habitats develop in the clear-cuts.

DEVELOPMENT OF TERRESTRIAL FORAGE LICHENS

A common theme in studies of successional development in fire-origin boreal forest stands is the greater abundance of terrestrial lichen mats in mature and old forest stands. Zouaoui *et al.* (2014) found that the time elapsed since the last fire was the best explanatory variable for the abundance of terricolous lichens in eastern Canadian black spruce (*Picea mariana*) forests and concluded that the maintenance of late-successional terricolous lichens will require landscape-level management strategies that conserve old forest stands. Likewise, Johnson (1981) found that cover of *Cladonia rangiferina* and *C. mitis* reached maximum values between 150 and 250 years after stand origin in the Northwest Territories; however, Johnson noted that feather moss mats dominated in some old forest stands in sites with canopy closure and/or with greater nutrient availability. Maikawa and Kershaw (1976) similarly documented a transition from *Stereocaulon*-dominated lichen woodlands to a feather-moss dominated forest floor surfaces as canopy closure occurred in stands older than 130 years in the Abitau-Dunvegan Lakes area of the Northwest Territories.

The association of terrestrial lichen cover with stand structural characteristic was also noted by Coxson and Marsh (2001) in the Omineca region of central-interior BC where they found that older pine-lichen woodlands showed a gradual transition from *Cladina* morphotype (*Cladonia* subgenus *Cladina*) lichen-dominated forest-floor surfaces to feather moss (acrocarpous mosses)-dominated forest-floor surfaces (Figure 2). This change was accompanied by increasing canopy closure in old stands. In contrast, acrocarpous mosses and *Cladonia* morphotype lichens (squamulose species in *Cladonia* subgenus *Cladonia*) were most abundant (standing biomass) in the 0-50 year age class.

Sulyma and Coxson (2001), also working in the Omineca region of BC, found that terrestrial lichen mats were strongly associated with forest floor microsites with greater canopy exposure, while feather mosses dominated the more shaded microsites. This can be seen in microsite plots of the forest floor surface, where *Cladina* morphotype lichens occupy canopy gaps, while feather-moss mats occupy sites with a higher level of shading (Figure 3). Where leaf area index exceeded 2.0, Sulyma and Coxson found that the forest floor surface was largely covered with litter. Similar conclusions were reached for northern Scandinavian boreal forest stands by Jonsson Čabrajić *et al.* (2010), who found that optimal terrestrial lichen growth occurred in stands with less than 60% canopy cover. They noted that many forest stands in northern Scandinavian landscapes are now too dense to support terrestrial lichen growth.

Haughian and Burton (2015) confirmed these opposing microsite preferences of terrestrial lichen mats and feather mosses, demonstrating that terrestrial lichens responded positively to warmer microsites with greater light availability, while feather mosses preferred cooler more shaded microsites. They found that the understory composition within lodgepole pine (*Pinus contorta*) stands was strongly associated with canopy characteristics, although microsites with fine soil textures and high nutrient availability were more often associated with feather mosses and vascular plant-dominated forest floor communities. Pharo and Vitt (2000), similarly, working in montane forests in Alberta where terrestrial lichens are an important food source for caribou, found that the 10% most open microsites, when compared to the 10% most shaded microsites, had much higher terrestrial lichen cover. However, they cautioned that terrestrial lichen cover in site with intermediate canopy exposure often showed a poor relationship with canopy cover, and suggested that other factors, especially dispersal and establishment limits were equally important.

It should be noted that forage lichens for caribou are not confined exclusively to old forests. Skatter *et al.* (2014) documented terrestrial lichen mat development between 20-40 years after fire, as did Coxson and Marsh (2001). This initial phase of forage lichen growth follows post-fire colonization by crustose lichens and squamulose *Cladonia* subgenus *Cladonia* species. This

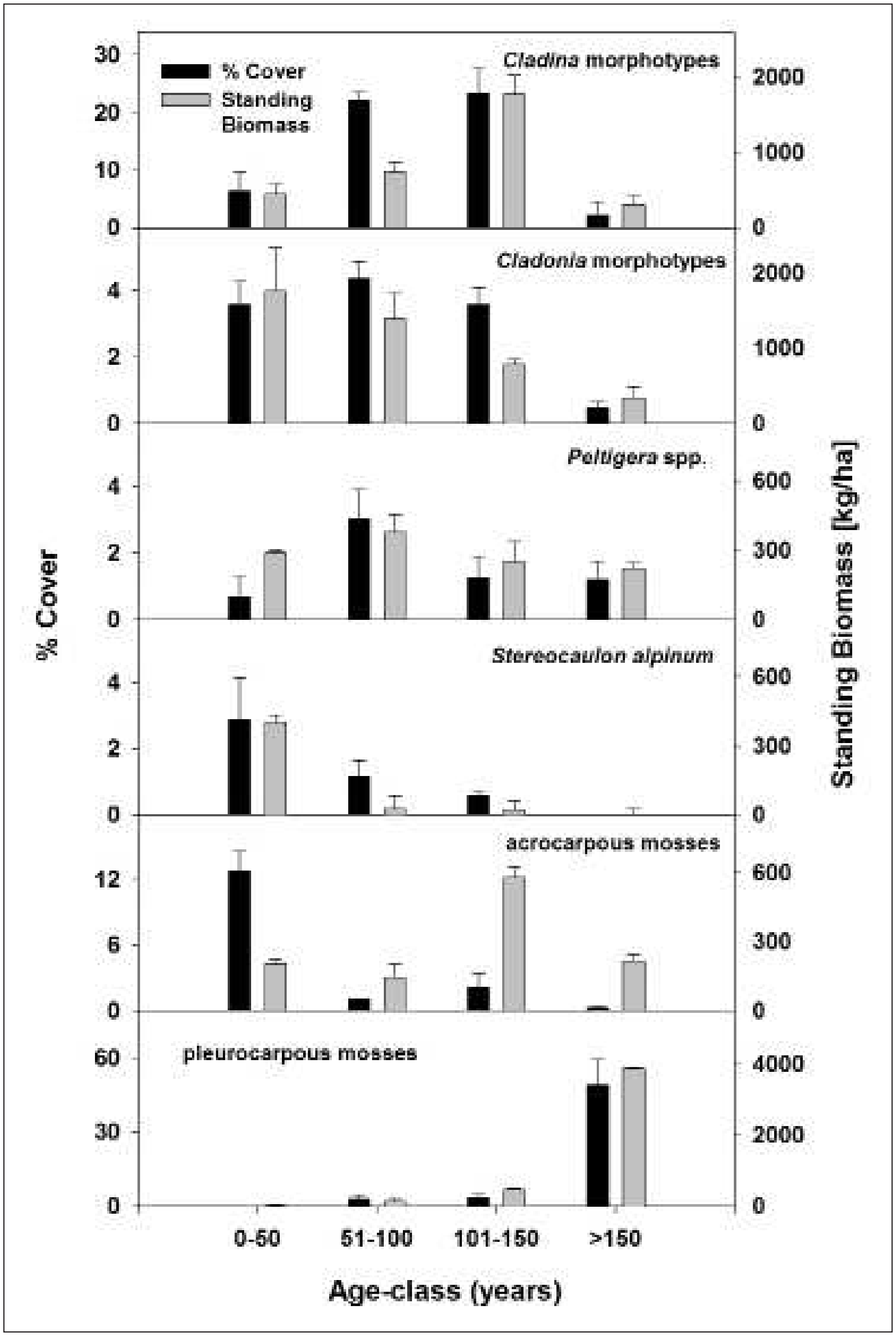

Figure 2. Mean (± 1 SE) percent cover and standing biomass by functional group within 50-year age-class intervals (*n*=4, 4, 5, and 2 stands, respectively) for pine-lichen woodlands in central-interior BC. *Cladonia* subgenus *Cladina*, are referred to as *Cladina* morphotypes, while squamulose species in *Cladonia* subgenus *Cladonia*, are referred to as *Cladonia* morphotypes. Reproduced from Coxson and Marsh (2001).

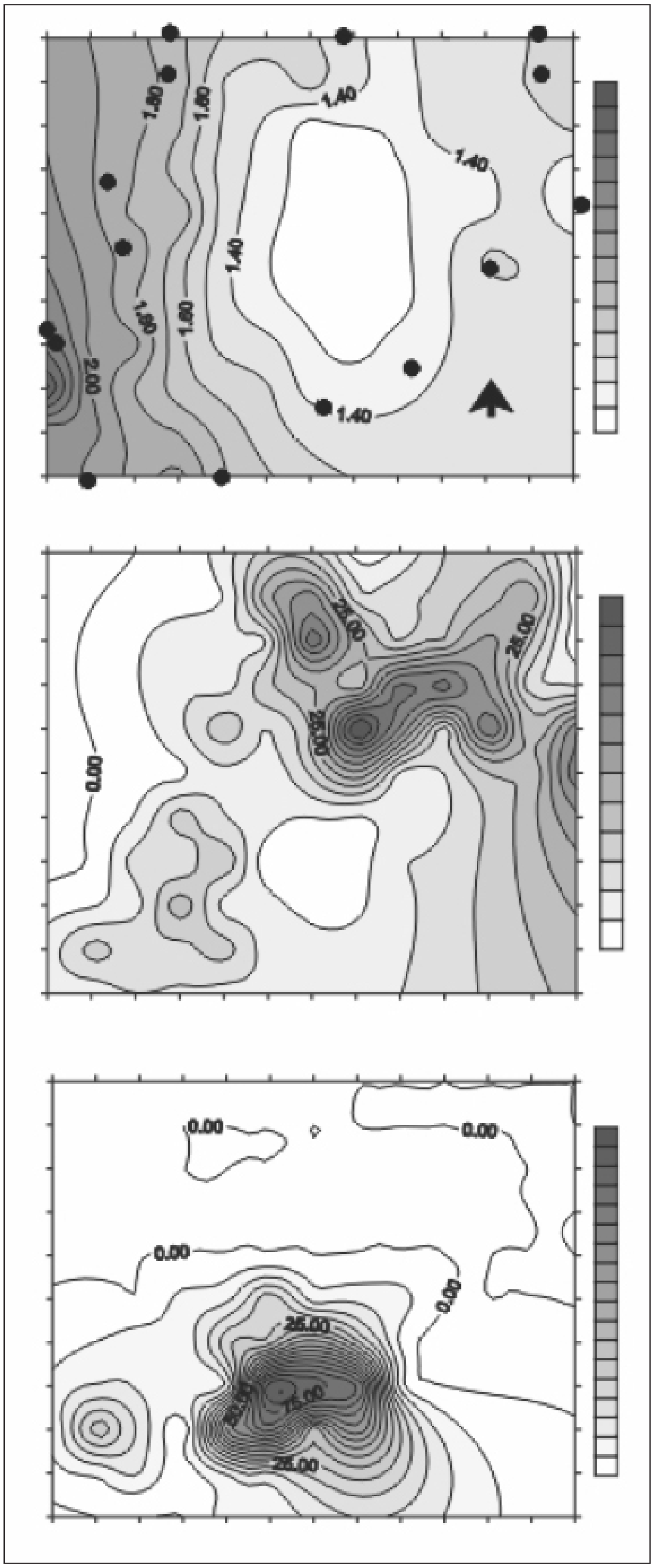

Figure 3. Isopleth plot of forest floor in a representative canopy gap for pine-lichen woodlands in central-interior BC. From top plots of : A) Leaf Area Index, B) percent cover of *Cladina* morphotype lichens, and C) percent cover of feather moss mats. The location of pines within the plot is shown by filled circles in the top plot. The x- and y-axis ticks are at 1-m intervals (12x12 m plots). Reproduced from Sulyma and Coxson (2001).

early period of colonization by forage lichens, however, may be transitional. Regeneration of conifer seedlings after fire typically shades or covers with litter these early developing lichen mats, a trend which is not reversed until self-thinning of trees starts to occur at later stages of stand development (Coxson and Marsh 2001).

This association of caribou forage lichens with mature to old forest stands is reflected in current management guidelines for northern Canada, which use an age threshold of 40 years before habitat is regarded as suitable for woodland caribou after wildfire (Environment Canada 2012). The availability of older boreal forest stands, however, may now be at risk in many areas, both from the changing frequency of fires (Gustine *et al.* 2014), and, in some regions, the addition of logging as a major agent of stand regeneration (Cumming and Beange 1993; Smith *et al.* 2000; Vors and Boyce 2009). Schaefer (2003), for instance, documented a strong association between the decline of the southern limits of caribou occupancy and the expansion of forest harvesting in Ontario boreal forests.

PARTIAL-CUT HARVESTING AND TERRESTRIAL LICHENS

Our knowledge about the development of lichen-rich mid- to late-seral boreal habitats is based largely on studies from fire-origin stands. Less certain is the successional trajectory of boreal forest stands that regenerate after clear-cut logging. The burning of surface organic horizons creates very specific post-fire microclimate and soil physical properties, which in turn have a large influence on colonizing early-successional lichens and mosses (Rouse 1976). Even where the size and shape of clear-cuts is designed to mimic fire-origin stands (DeLong 2007), it is unclear as to whether or not ecological processes in clear-cuts will be the same as those in fire-origin stands.

At a landscape scale, Schroeder and Perera (2002) found that fire-origin stands showed much greater heterogeneity than did stands originating from clear-cut logging. Webb (1998) found that numerous terrestrial lichen fragments persisted after clear-cut logging, with lichen cover gradually increasing in logged sites. The oldest study sites examined by Webb, however, had been logged only 16 years previously, so the long-term development of persisting terrestrial lichen mats in plantations remains uncertain. Coxson and Marsh (2001) similarly found significant retention of terrestrial lichens in winter-logged clear-cuts in the first decade after harvesting, but noted that in microsites where pine regeneration was dense, lichens were excluded by litterfall.

In a retrospective study on lichen recovery in young clear-cuts in west-central Alberta, Snyder and Woodard (1992) found that total cover of retained lichens peaked 20-30 years after harvesting. Where post-harvest silvicultural treatments included herbicide applications, McMullin *et al.* (2013) found a significant decline in forage lichen availability. In one of the few retrospective comparisons of older fire-origin and clear-cut logging-origin stands (70-100 years after stand initiation), Reich *et al.* (2001) found that vascular plant and bryophyte diversity did not differ significantly with type of stand origin, although they did note a greater frequency of aspen (*Populus* spp.) in logging-origin stands. Reich *et al.* (2001), however, did not inventory lichen cover, so the impact of logging on the development of late-successional lichen communities in their stands remains unknown.

An alternative to clear-cut harvesting is provided by partial-cutting harvest systems, where limited thinning of the canopy has the potential to favour lichen growth over that of feather mosses, in effect, reversing the loss of terrestrial lichen cover as canopy closure occurs in older boreal forest stands. Equally important, partial-cutting harvest systems can reduce the magnitude of early seral vegetation response after logging (Frey *et al.* 2003), an important consideration for development of predator-prey interactions with alternate ungulate species such as moose.

Much of our experience on the implementation of partial-cut harvesting systems comes from studies that were designed to maintain or enhance arboreal lichen availability for mountain caribou (Stevenson *et al.* 2001; Coxson and Stevenson 2007). Although these are quite different ecosystems from terrestrial lichen woodlands in boreal forests, the general conclusions from these earlier studies still provide lessons for the design of partial-cut harvesting practices to maintain terrestrial lichen communities.

The 2 types of partial-cut harvesting systems that are most often used for arboreal lichen conservation are single-tree-selection and group-selection harvesting. Both maintain a high degree of site occupancy by existing mature to old trees and can maintain uneven-aged stand structures (Figure 4). Previous experience with partial-cut harvesting trials suggests that several trade-offs must be considered when comparing partial-cut harvesting systems. Group-selection harvesting can confer greater resistance to wind throw among retained trees compared to single-tree selection harvesting, but it can also result in a more vigorous response by understory vegetation and regenerating trees (Huggard *et al.* 1999). When reviewing silvicultural options it is worth noting that group-selection opening sizes are normally chosen to maximize the growth of regenerating tree seedlings (Webster and Lorimer 2002). When managing for terrestrial lichens, however, you want the opposite outcome, i.e., a harvest design that minimizes growth rate response of understory shrubs and trees, while still inducing a positive growth rate response in terrestrial lichens.

Similarly, shelterwood partial-cut harvesting systems are a

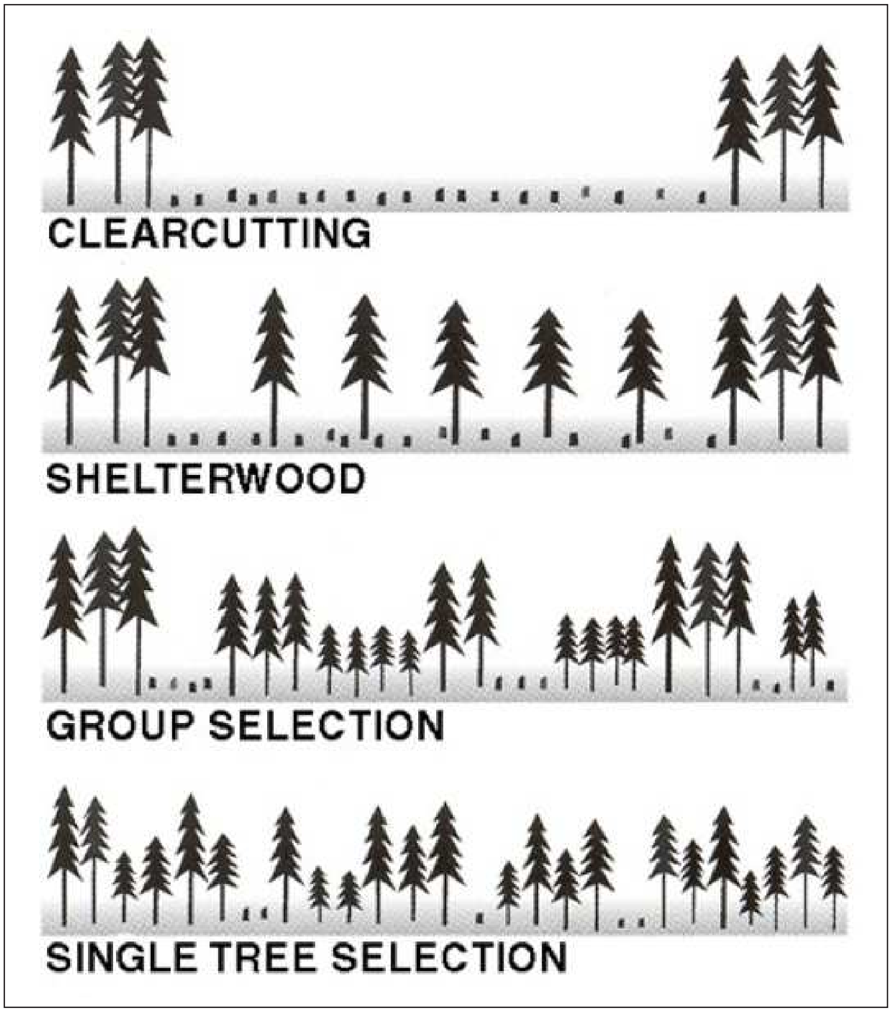

Figure 4. Hypothetical canopy structure after clearcutting, shelterwood, group-selection, and single-tree selection partial cut harvesting.

third design sometimes used to maintain ungulate winter range (Figure 4). The higher levels of tree removal typically seen in shelterwood harvesting systems also run the risk of triggering a growth response from early-seral vascular plants in the understory, to the detriment of retained terrestrial lichens.

Experimental evidence for the enhanced growth of terrestrial lichens after partial or complete removal of canopy cover using single-tree harvesting was provided by Boudreault *et al.* (2013a), who used transplant experiments with 3 terricolous lichen species (*Cladonia* stellaris, *C. mitis*, and *C. rangiferina*) (Figure 5). They observed significantly increased growth rates in both *C. stellaris* and *C. rangiferina* after transplantation to partial-cuts (45-85% canopy removal) and clear-cuts, especially in the second year of their study, which was characterized by cooler wetter conditions. Both *C. mitis* and *C. rangiferina* showed a net loss of carbon in control sites during the second summer of observations, while *C. stellaris*, a species more tolerant of cool wet conditions, showed a small positive carbon gain during their second summer of observations. These observations are consistent with earlier studies of Moser and Nash (1978), who documented negative growth rates in terrestrial lichen mats under cool wet summer growing conditions. These results highlight the importance of multi-year assessments of lichen response to changes in canopy cover.

Interestingly, in the same study sites that were monitored for growth of terrestrial lichen transplants by Boudreault *et al.* (2013a), concurrent transplant experiments with epiphytic lichens showed a contrasting response to cool wet summer conditions, where higher summer growth rates were seen during the year with more precipitation (Boudreault *et al.* 2013b). Further, when the epiphytes *Bryoria nadvornikiana* and *Evernia mesomorpha* were transplanted into partial-cuts, their growth rates were significantly lower than control samples, especially for the old-growth indicator *Bryoria nadvornikiana*. Where caribou populations rely on both terrestrial and arboreal lichens in the same landscape (Johnson *et al.* 2000), these differing patterns of response should be kept in mind when assessing potential benefits of forest canopy thinning.

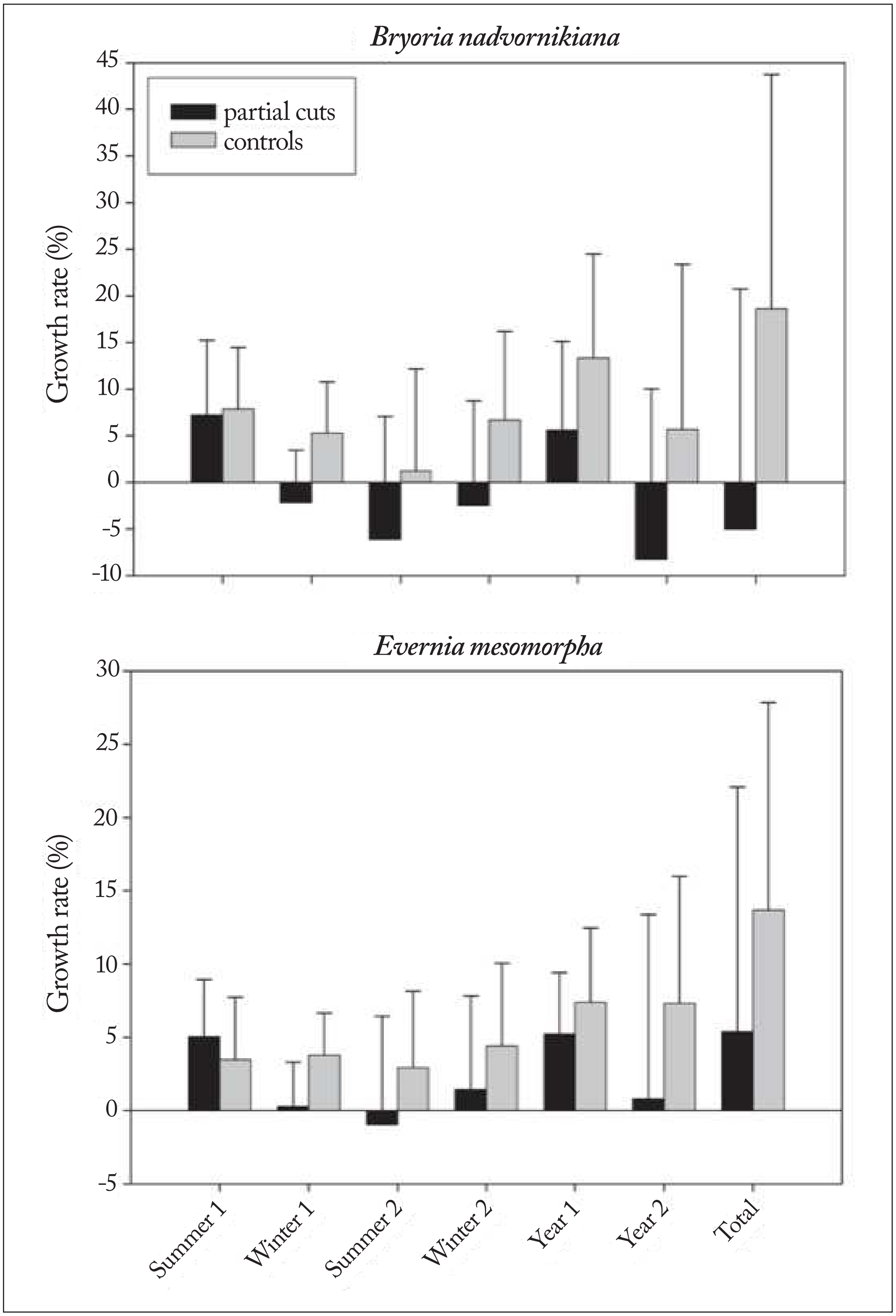

Figure 5. Mean growth rates of *Cladonia stellaris, C. rangiferina*, and *C. mitis* by treatment for each season in black spruce boreal forests of western Québec. Bars are means of growth rates. Error bars are SDs. Growth rate for each period was calculated as the percentage of change in biomass between beginning and end of each measurement interval divided by the number of days within each interval. Summer 1: June 2005 - September 2005, winter 1: September 2005 - May 2006, summer 2: May 2006 - September 2006. Reproduced from Boudreault *et al.* (2013a).

A further factor of importance in the data set of Boudreault *et al.* (2013a) are the very low or even negative growth rates observed during the winter period. Our traditional perception of terrestrial lichen mats in boreal forest environments is that they are snow covered and inactive for most of the winter period (Bonan and Shugart 1989; Kershaw 1978). In many high latitude regions, however, winters in recent decades have seen an increasing proportion of rain versus snow events and an earlier more variable spring snowmelt threshold (Beaubien and Freeland 2000; Shindell *et al.* 1999). These trends towards changes in winter climate pose a risk to terrestrial lichens, which face continued respiratory demands when hydrated and unfrozen during the mid-winter period, but may have insufficient light exposure to compensate for respiratory demands through photosynthetic activity (Bjerke *et al.* 2013). Further, terrestrial lichens may have limited tolerance of repeated freeze-thaw events if they are not covered by a deep winter snowpack (Bjerke 2011).

Relatively few studies have evaluated long-term changes in the cover of terrestrial lichen mats following partial-cut harvesting. One of the comparisons made in the retrospective study of Snyder and Woodard (1992) was between unlogged stands and 20-year-old partial-cut stands. This comparison showed that the abundance of caribou forage lichens was greater in the partial-cuts than in adjacent unlogged stands, which had not been harvested, and also exceeded that of similar aged clear-cuts.

The only replicated study in which the effects of partial-cut harvesting on terrestrial lichen cover were evaluated was described by 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. Harvest treatments included irregular group shelterwood with stem-only harvesting (IGS-SO), IGS with whole tree harvesting (IGS-WT), group selection with stem-only harvesting (GS-SO), and no harvest. Terrestrial lichen cover initially declined in each of the partial-cut harvesting treatments; however, 8 years after harvesting, terrestrial lichen cover had recovered to values from 68% in the IGS-SO up to essentially preharvest levels in the GS-SO treatment. Bryophyte cover also declined significantly in the partial-cuts, but did not recover to the same degree, 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 in the Waterhouse study had continued into the second decade of their study after harvesting; however, the mountain pine beetle (*Dendroctonus ponderosae*) outbreak lead to widespread defoliation of remaining trees in their partial-cut harvesting trials, resulting in a major growth response by understory shrubs (Waterhouse *et al.* 2011).

MAINTAINING CARIBOU HABITAT IN MANAGED FORESTS

Based on experimental studies of terrestrial lichen regeneration in logged and burned areas, partial-cutting may be a valuable tool to maintain caribou habitat. A primary objective of partial-cut harvesting within the winter range of caribou should be that of maintaining or even enhancing terrestrial lichen cover, at least longer than would otherwise be the case as stands age naturally. The thinning of the forest canopy will create brighter and drier conditions at the forest floor surface (i.e., more rapid drying of lichens and mosses after precipitation events), conditions that should favour increased growth of lichens and greater mortality in feather mosses (Kershaw *et al.* 1994). This strategy will be most effective on sites with intermediate levels of soil water retention. On well-drained sites, for instance, lichen woodlands on coarse sands or cobbles, terrestrial lichens can reach quite high cover values and persist without change well into the second century of stand growth. Under these conditions, harvesting is unlikely to enhance terrestrial lichen cover. Similarly, on sites that are quite mesic, there is typically little terrestrial lichen cover present in mature stands, and vegetation response to canopy thinning may predominantly come from understory shrubs, not lichens.

Haughian and Burton (2015) recommended that, where partial-cutting is used to reduce canopy cover to favour growth of terrestrial lichens, managers should consider prescriptions that increase canopy openness to 70% at ground level. They also recommend prescriptions that would reduce LFH (top forest floor organic layer) thickness to less than 5 cm in depth. Although this recommendation would reverse the gradual buildup of organic matter in stands, its implementation may be counterproductive for lichen conservation, in that any disturbance of the forest floor surface will reduce the carry-forward of existing terrestrial lichens into the thinned stand after harvesting. However, in sites that are subject to paludification, this may be a necessary prescription to reduce organic matter buildup and slow increases in the height of the water table (Boudreault *et al.* 2002).

Partial-cutting has been recommended as a prescribed management strategy now in several caribou winter ranges. McNay (2011) proposed that irregular group shelterwood systems be adopted to maintain terrestrial lichen cover in BC's Chilcotin plateau in the Montane Spruce biogeoclimatic zone (Meidinger and Pojar 1991). McNay (2011) recommended that harvest openings not exceed 2-tree lengths in width by 3- or 4-tree lengths in length. Similarly, within the range of the Itcha-Ilgachuz caribou herd in BC's central-interior, partial-cut harvesting is recommended as a management approach for maintaining terrestrial lichen forage values (Armleder and Waterhouse 2008).

Where partial-cut harvesting is conducted to maintain or enhance terrestrial lichen cover, winter harvesting is recommended, so that existing lichen mats are disturbed as little as possible. Retrospective examination of winter-harvested plots in lichen woodlands by Coxson and Marsh (2001) and Gough (2010) confirmed the potential for carry-forward of terrestrial lichens after harvesting. In winter harvest sites examined by Coxson and Marsh (2001), locations where mineral soils had been exposed (landings, roads, some skid trails) were, 10 years after harvesting, overgrown with understory shrubs (Coxson, unpublished data), emphasizing the importance of minimizing soil disturbance. It should be noted that this recommendation for harvesting on a late-winter snowpack may conflict with recommendations to avoid disturbances to caribou during their actual period of occupancy in winter ranges. These conflicting objectives, avoiding disturbance of caribou during logging versus creating potential habitat enhancements over a multi-year time period, will require assessment on a case-by-case basis, depending in-part on the likelihood of encountering caribou and the vulnerability of local populations.

Any harvesting designs that are implemented will have to consider how to deal with slash and logging debris. Optimal carry-forward of existing lichen cover will be obtained by processing whole trees on landings, so that there is minimal burial of lichen mats under logging debris. An alternative strategy, however, may be on-site processing, so that organic residues are spread widely on site. Logging treatments that create windrow type piles, for instance, cut-to-length harvest systems may result in an unacceptably high degree of lichen burial under logging slash. Kranrod (1996) found that the combination of stump-side delimbing, winter harvesting, and no scarification of soils, maintained higher residual terrestrial lichen cover than any other treatment combination. Sulyma (2002) categorizes a range of harvesting prescriptions, including harvesting method, harvesting season, site preparation, and regeneration methods for their potential to maintain terrestrial lichen cover. Of these combinations, he recommended the combination of whole-tree winter harvesting, with no site preparation, and natural regeneration. Cut-to-length methods, when conducted in winter, were rated as good; all the other harvesting methods, when conducted in summer, were ranked poorly.

Perhaps the largest concern relating to the design and implementation of partial-cut harvesting strategies is how to deal with road access issues. Winter harvesting can reduce the footprint of temporary roads within harvest blocks. The construction of haul roads to access logging tracts still raises concerns, however, as discussed above about the negative impacts of roads on caribou populations. Aggressive deactivation of new forestry roads after harvesting is highly recommended. Road access management during harvesting is also important, as caribou avoidance of areas with roads is much higher when roads are in use (Dyer *et al.* 2002). Once roads enter the public domain as access routes for recreational activity, they are much harder to regulate (Mihell and Hunt 2011).

A clear limitation of partial-cut harvesting is the reduced timber volume obtained from a given area of landscape logged, compared to clear-cut harvesting. If partial-cut logging is adopted as a

KEY POINTS

• Terrestrial lichens used by caribou as forage grow best on sites where limitations of climate and/or edaphic factors prevent their being covered by litter or shaded out by competing vascular plants. In boreal forests, lichens woodlands are often limited to low-productivity sites with well-drained soils.

• Canopy closure in mature- to late-successional lichen woodlands can favour the growth and development of feather moss mats over terrestrial forage lichens, as forest floor microclimate becomes cooler and the forest floor surface more shaded.

• Partial-cut harvesting provides a means by which this canopy closure in mature- to late-successional lichen woodlands can be reversed, creating conditions conducive for the growth and development of terrestrial forage lichens.

• The successful use of partial-cut harvesting to enhance terrestrial forage lichen availability for caribou requires that disturbance to the forest floor surface is minimized at time of harvest. Harvesting on a late-winter snowpack is recommended.

• Management of logging debris is critical; terrestrial forage lichens cannot recover if buried under debris. Dispersal of logging debris within stands or processing on landings are both viable approaches.

• If partial-cut harvest openings are too large, enhanced growth of understory shrubs and forbs may have a detrimental long-term impact on terrestrial lichens, negating immediate benefits for terrestrial lichen communities.

• Decommissioning or closure of logging roads after logging is recommended to reduce secondary disturbance impacts on caribou.

• Partial-cut harvesting is a short-term management tool, having the potential to extend terrestrial forage lichen availability by several decades at best. Maintaining landscapes with a broad age-class distribution of lichen woodlands remains critical to insuring future terrestrial forage lichen availability.

• More research is needed on the long-term response of terrestrial lichens to changes in stand structure after partial-cutting. Replicated experimental trials are especially valuable in guiding management recommendations.

management strategy without corresponding reductions in the expected annual allowable cut, then it will likely fail as a strategy for maintaining caribou habitat. Otherwise, a much larger area would have to be logged to obtain the same timber supply, with all of the corresponding issues that entails with respect to road access and disturbance.

Finally, there is no guarantee that natural disturbance events, be they fire or insect outbreaks, will allow managers to meet the goals and objectives of partial-cut harvesting. The partial-cutting trials of Miège *et al.* (2001), which were subsequently defoliated by the mountain pine beetle outbreak in the mid-2000s, provide clear evidence of the limitations of trying to delay the loss of mature- to late-successional stands in landscapes.

Partial-cut harvesting in caribou winter habitat would therefore allow managers to maintain or even enhance the availability of terrestrial lichens in existing mature to old stands. It is a strategy that will be most suited for landscapes where there are few mid-seral stands, and maintaining existing lichen cover in the older stands buys time, as younger stands age and develop greater lichen cover.

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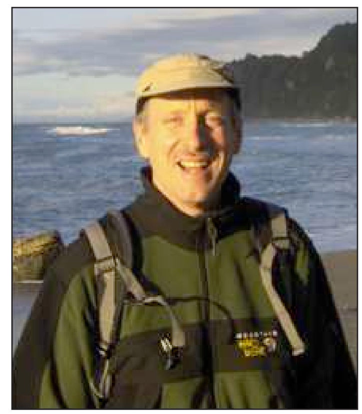

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