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ARCKP

Alberta Regional Caribou Knowledge Partnership

PROJECT REPORT

Alternative Silvicultural Systems and Harvesting Techniques for Caribou Habitat

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Alternative Silvicultural Systems & Harvesting Techniques for Caribou Habitat

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Executive Summary

Introduction

Urgent action is required to reverse caribou population declines that are occurring throughout Alberta and to meet Federal targets for reducing habitat disturbance under the Species at Risk Act. Caribou declines are attributed primarily to anthropogenic habitat alteration, from a range of sources, such as oil and gas exploration and development, commercial forestry, and recreational use.

Forestry in Alberta is a multi-billion-dollar industry and a crucial employer in many rural communities, directly employing 17,500 people and supporting another 23,900 jobs. With 38% of Alberta's green (forested) zone within caribou range and over half of boreal caribou range and nearly one third of Southern Mountain caribou range under Forest Management Agreement or other major forestry tenure, opportunities to allow for a successful working landscape in these areas are vital.

Almost all forestry in Alberta uses a clearcut with retention silviculture system, which causes near-term loss of caribou habitat and often increases the effect of apparent competition, the pathway through which conversion of forest to early seral stages leads to increased predation rates on caribou. This project identifies and reviews alternative silvicultural systems, harvesting and regeneration techniques for their potential to reduce negative impacts on caribou, while still allowing for timber harvest.

Methods

This report uses a literature review and interviews with subject-matter experts to provide an assessment of alternative silvicultural systems and harvesting techniques with a focus on caribou ecology. Impacts are assessed from three main perspectives, considered relative to the dominant clearcutting with retention silvicultural system:

a. *Is forage availability for other ungulates minimized?*

   Clearcutting typically increases availability of early seral stage vegetation favoring other ungulate species such as moose, deer, and elk. These populations support higher density wolf populations, as well as other predators, which incidentally prey on caribou, causing unsustainable mortality. Addressing this mechanism for decline, known as apparent competition, must be a key component of any alternative silvicultural system.

b. *Are caribou biophysical habitat and associated forage resources maintained post-harvest?*

   Clearcutting causes loss of the biophysical habitat that caribou require, particularly mature and old coniferous stands that are abundant in lichens. Caribou need large areas of intact forest and avoid harvested areas. Minimizing loss of biophysical habitat, and/or recovering habitat more rapidly, is important for caribou recovery, particularly where range contraction is evident.

c. *What is the extent and duration of road access required for implementation?*

   Linear features facilitate more efficient access to caribou habitat for predators, prey species, and people, ultimately exacerbating predation pressures on caribou. Minimizing access into caribou habitat, particularly for predators such as wolves, is an important aim.

We identified a number of relevant case studies from Alberta and other jurisdictions, some of which had an explicit caribou focus, while others did not. However, even those that did not set out to test alternative systems in the context of caribou management, still provide important insights around post-harvest forest structure and vegetation responses. The case studies also identify existing trials and data sources that could be re-visited or expanded upon to help answer outstanding questions and guide implementation. Subject-matter expert interviews were open-ended, encouraging participants to discuss a wide range of ideas and identify innovative alternatives. As well as guiding and informing case studies and discussions, insights from these experts are provided throughout the report. Finally, based on the findings of this project, we make a number of recommendations for next steps.

Results

We identify a number of silvicultural systems and harvesting techniques that have potential to be applied in Alberta to improve outcomes for caribou. However, we also caution that results from these systems are likely to be highly dependent on forest type, site productivity, and extent of required access. There is the potential for some systems to have negative impacts if applied in the wrong situation. As such, it is vital that any alternative system is carefully evaluated in the context of local conditions.

In coniferous forest, partial harvest systems with varying spatial layout and levels of removal have the potential to maintain old forest characteristics and associated terrestrial and arboreal lichens that caribou rely upon. Such systems have been trialed extensively in other jurisdictions, although accompanying caribou population monitoring is often unavailable, making it difficult to know if the favorable outcomes for forest structure translate to continued caribou use. For apparent competition, the outcomes are mixed. In some cases, for example in lower productivity areas, the maintenance of canopy cover can prevent a significant response from understory vegetation favored by moose and deer. However, in other cases, partial harvest systems can lead to a major “flush” of highly palatable early seral stage growth, creating excellent habitat for other ungulates, and worsening outcomes for caribou. Therefore, adoption of partial harvest systems must be adapted to local conditions, perhaps with lower removal levels in more productive sites, in order to minimize understory response.

Single-tree selection systems also show potential, for example, through the use of commercial thinning treatments. These treatments result in a more open stand structure, which should favour lichen growth, while still providing some near-term timber volume. Under the right conditions, understory response can also be minimized. However, we lack data demonstrating that caribou will continue to use thinned stands. Again, the outcomes of such treatments will be highly dependent on the details of implementation and the forest in question. To be favorable to caribou in the long-term, a clearcut could be replaced with a commercial thinning treatment and perhaps a series of thinnings over time if the access limitations can be addressed.

Deciduous and mixedwood forests are typically not caribou habitat, but if they are near to or adjacent to caribou habitat, they still have a major impact due to apparent competition. If harvest systems in these forest types are favoring other ungulates, this can lead to increased predator numbers and increased incidental predation on caribou. Understory protection is used relatively frequently in mixedwood stands in Alberta, to remove deciduous canopy while protecting the coniferous understory. Under the right conditions, such as when the coniferous understory is well developed, it may be effective at suppressing aspen suckering and the growth of other browse species. Therefore, this system can potentially extend the time period during which a stand does not favour other ungulates, while still providing timber volume. While understory protection can only be applied in certain situations, there may be opportunities to consider how the system might be best adjusted to minimize other ungulate browse availability in stands within or near to caribou range. Partial harvest systems may also be an option in some cases for reducing understory response by maintaining canopy cover.

We also discuss some site-level treatments such as herbicide use and stocking density. While there is a trend away from the use of aerially sprayed herbicides across Canada, they still remain an effective method of controlling competing vegetation, allowing harvested areas to return to forested cover more quickly and successfully. Increased stocking density is another method of achieving a similar outcome. Therefore, in cases where an alternative silvicultural system would be inappropriate, a clearcut system with additional treatments to minimize other ungulate browse availability could be considered. Repeated herbicide treatments and/or very high stocking densities could be used in this context.

Discussion

While we have much experience to draw upon for understanding the role of alternative silvicultural systems in improving outcomes for caribou, there are also many unknowns. The impacts of alternative systems must be considered in the context of caribou habitat components, apparent competition, and access requirements. The interplay between these components, local site conditions, and the details of how a system is implemented, is crucial to success.

Unsurprisingly, we identified no “silver bullet” solutions. It is clear that silviculture can alter vegetation to favour components of caribou habitat with a reasonable degree of confidence, but there is insufficient information to assess the costs and benefits of different silvicultural prescriptions and if the result is a net positive for caribou. Understanding where a system could be adopted effectively, and how it should be adapted to local conditions, is a challenge. A framework using light conditions and site productivity to identify expected understory responses could be beneficial in this context.

We also still have relatively little data on caribou responses to alternative systems, especially at the landscape scale, which is a major knowledge gap. Large-scale monitoring of caribou, other ungulates, and predators must be a part of future initiatives if we are to make progress in this regard.

One major trade-off and potential Achilles heel of most alternative systems is the requirement for additional access. This can have a serious negative impact on caribou, efficiently bringing more predators, other ungulates, and people into caribou habitat. In some cases, the negative effects of additional access requirements might even outweigh the benefits of adopting alternative systems, although there is much uncertainty in quantifying these effects. Aggregated harvest areas utilizing partial harvest systems with a single entry may be one option to address this but will have significant timber volume and financial costs.

Alternative systems, particularly low removal partial harvest and single-tree selection systems, typically involve additional costs and/or lower timber volume removals per unit area, as well as different equipment needs and operator expertise. If we assume that mill requirements remain constant, adoption of partial harvest systems risks further spreading disturbances and road access across caribou habitat, with unknown but potentially detrimental outcomes for caribou.

Widespread adoption of alternative silviculture systems over conventional clearcut forestry therefore remains constrained by knowledge gaps, financial considerations, and policy restrictions. Nevertheless, given the urgency of caribou declines in Alberta we recommend that large-scale attempts be made to trial, operationalize, and monitor alternative silvicultural systems. To that end, our primary recommendation is to use the information provided in this review as the basis for building a real-world planning study for a large part of a caribou range, which considers the systems and treatments that are possible given the existing forest structure and stand-level objectives. This would involve assembling a multidisciplinary team of biologists and silviculturists with the expertise to design a detailed spatial planning exercise at a scale large enough to elicit caribou response. Completing this planning exercise should provide the localized information for comparison of outcomes, costs, and access requirements between single-entry alternative systems, multi-entry alternative systems, and existing clearcut systems where additional or adjusted treatments would be a major component.

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1 Introduction

Woodland caribou (*Rangifer tarandus caribou*) were assessed as "Threatened" in 2002 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2011), which led to their listing under the Species at Risk Act (SARA) in 2003. An extensive period of critical habitat identification (Environment Canada 2011), risk assessment, and recovery planning then led to a recovery strategy for the Boreal population (Environment Canada 2012) and later the Southern Mountain population (Environment Canada 2014). Forestry activity has been identified as a major contributor to disturbance in caribou ranges, meaning there is a conflict between preserving caribou populations and allowing for a working landscape where industrial forestry can prosper.

In Alberta, caribou recovery planning is ongoing (Government of Alberta 2017a) and a Section 11 agreement has been signed under SARA between the governments of Alberta and Canada (Environment and Climate Change Canada 2020), which commits to achieving naturally self-sustaining populations in Alberta using measures such as landscape planning, habitat management, and population management. This includes forestry-specific measures such as consolidation of harvesting operations into aggregated harvest areas that more closely mimic natural disturbance regimes and reduce fragmentation.

Caribou ranges in Alberta cover approximately 23% of the province, 38% of the green (forested) zone, and include 16 extant local populations, 15 of which are under provincial jurisdiction (the Southern Mountain population in Jasper National Park is under federal jurisdiction, while the Banff population was extirpated in 2009 (Hebblewhite, White, and Musiani 2010)). Twelve of the provincially managed populations are Boreal while three are Southern Mountain, part of the Central Group subpopulation (Environment Canada 2014; Government of Alberta 2017a). Most caribou populations in Alberta have consistently declined in recent years, although predator management through wolf removal has stabilized some populations (Hervieux et al. 2014). Habitat alteration results from many sources, such as oil and gas exploration and development, mining, commercial forestry, and recreational use, but in this report, we focus only on the potential value of alternative silviculture for caribou and commercial forestry operations.

Over half (58%, 7.7 million ha) of boreal caribou range and nearly one third (30%, 0.54 million ha) of Southern Mountain caribou range in Alberta is either under Forest Management Agreement (FMA) or another major form of forestry tenure and therefore is subject to disturbances from commercial forest harvesting (Figure 2). For Southern Mountain populations there is a distinct split between higher elevation summer ranges, almost none of which are under tenure, and lower elevation winter ranges, the majority (90%) of which are under tenure. In Alberta, there are overlapping tenure rights in most commercially harvested areas, with different operators often focusing on different tree species. This makes any implementation of alternative harvesting systems challenging, as operators working in the same area may have very different business models. The successful use of alternative systems at scale is therefore likely to require cohesive planning between all operators in an area.

The vast majority of forest harvesting in Alberta uses the clearcutting silvicultural system in which most merchantable trees are removed from a harvest area in a single operation, allowing for rapid reforestation of even-aged forest. However, clearcutting directly removes caribou habitat and associated lichens that are a primary winter food source (Thomas, Edmonds, and Brown 1996). Mature and old forest with abundant lichens can take 60-80 years to regenerate after harvest. In addition, clearcutting provides the conditions for early seral stage habitats, which are preferred by other ungulate species such as moose and deer. These ungulate populations support higher density wolf populations, as well as other predators, that incidentally prey on caribou, causing unsustainable mortality. This effect, known as apparent competition, is widely implicated in caribou population declines (Serrouya et al. 2021). In addition, roads associated with forest harvesting and regeneration activities contribute to the fragmentation of habitat and facilitate predators efficiently accessing caribou habitat (Dickie et al. 2017).

Alternative silvicultural systems have different impacts on vegetation dynamics as compared to clearcutting systems. Potentially, alternative systems could benefit caribou if they (a) reduce forage availability for other ungulates and thereby reduce the impact of apparent competition, (b) maintain caribou biophysical habitat and associated forage resources, and (c) minimize access into caribou habitat. In addition, silvicultural techniques such as commercial thinning and vegetation control may be useful within this context. In deciduous and mixedwood forests the focus should be on minimizing desirability to other ungulates, while in coniferous forests the focus is on both minimizing use by other ungulates and maintaining caribou biophysical habitat

The relative importance of reducing apparent competition, maintaining biophysical habitat, and minimizing access is likely to vary depending on location. For example, in much of the boreal less than 50% of the land under forestry tenure is managed for timber production, leaving large areas of caribou biophysical habitat unharvested. Addressing apparent competition is likely to be more important in these systems than maintaining lichen availability in harvested areas. In contrast, in the foothills a much larger proportion of tenured area is actively managed for timber production (e.g. 70%), meaning that both apparent competition and maintaining forest structure is important.

A number of different silvicultural systems and techniques have been trialed or used in Alberta and across Canada. In some cases, these systems have been implemented specifically with caribou population persistence in mind. In others, the focus has been on other values, but by re-visiting these through the lens of caribou biology further insight may be gained. Given the urgent need to address caribou declines in Alberta, we believe it is prudent to learn as much as we can from experiences in other jurisdictions and from local trials that may not have originally had caribou as a focus.

In this report we draw on this experience, through literature review and interviews with subject-matter experts, to review alternative silvicultural systems and harvesting techniques that are applicable to Alberta's forests for their potential to alter post-harvest vegetation dynamics in ways that may be beneficial to caribou, relative to existing clearcutting systems. The project took the form of a fact-finding mission, in which we used the subject-matter expert interviews and existing literature to guide the discussion of alternative systems through case studies (Section 7). The subject-matter experts steered the overall content of the report, and we include relevant quotes from the interviews throughout that highlight points of particular importance, consensus, and disagreement. This then leads us to make a number of recommendations for improving our understanding of the potential role of alternative systems in Alberta caribou ranges and in implementing at meaningful scales.

We also identify existing data sources and completed and ongoing trials that could be used to better understand the implications of alternative silvicultural systems for caribou in Alberta. In addition, we provide a broad-scale discussion of the potential economic implications of adopting alternative systems. We also discuss the possible impacts of climate change on vegetation dynamics (e.g. drying of sites) and species distributions (e.g. white-tailed deer range expansion) and how these may affect outcomes of alternative silvicultural systems in relation to caribou habitat.

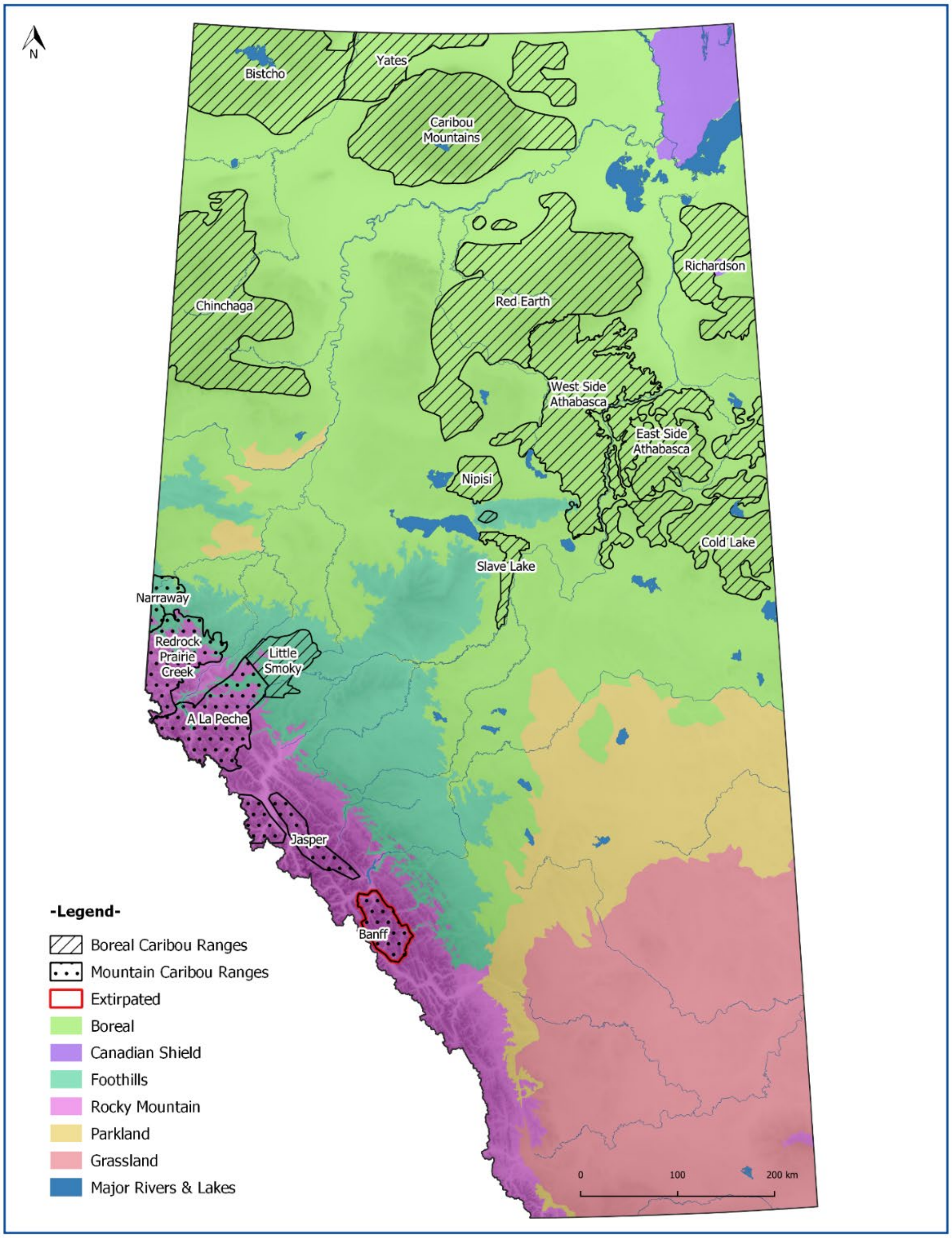

Figure 1. Alberta caribou ranges and natural regions.

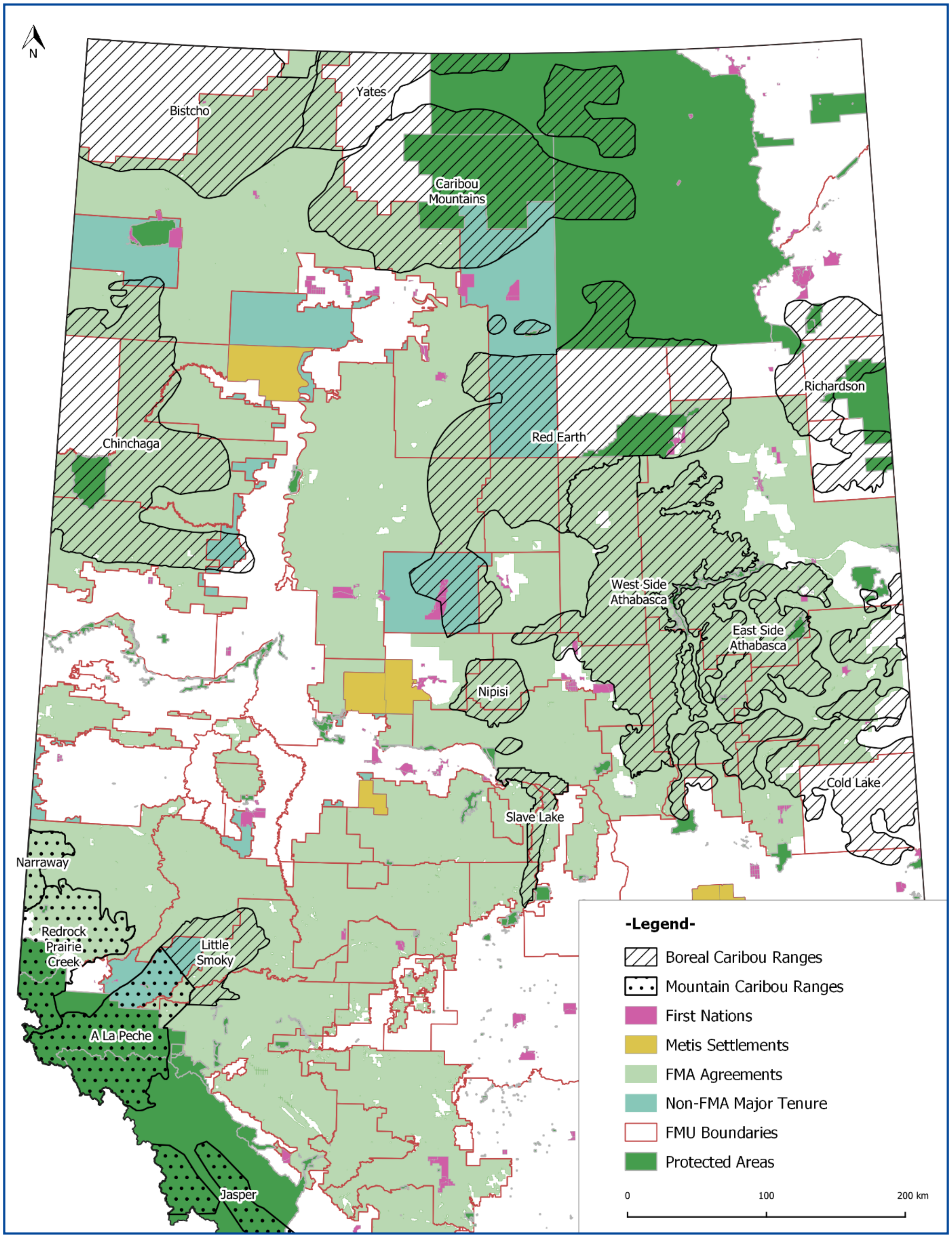

Figure 2. Alberta caribou ranges, First Nations, Metis Settlements, FMA agreements, and non-FMA major tenure.

Natural Subregions of Alberta[1]

Northern Mixedwood

Gently undulating plains, elevation 150–650m
Mean annual temperature = -2.5 °C
Mean annual precipitation = 387mm

The Northern Mixedwood natural subregion is characterized by black spruce peatlands and frozen organic soils. Wetlands are extensive (approximately 70% of area) and generally consist of a stunted black spruce overstorey and poorly developed understories with terrestrial lichen commonly a prominent feature. In upland areas pure or mixed aspen, white spruce and black spruce stands occur, but these areas are relatively uncommon. In more eastern areas jack pine stands are also present. Forest harvesting is limited to the western part of the subregion, typically along watercourses where productivity is greater.

Boreal Subarctic

Undulating and rolling plateaus and highlands, elevation range 575-1000m
Mean annual temperature = -3.6 °C
Mean annual precipitation = 512mm

The Boreal Subarctic natural subregion is found in elevated plateaus in far northern Alberta, including the Caribou Mountains. The area is cold and unproductive, typified by stunted black spruce stands with a well-developed lichen understory. Bogs and fens occupy 65-85% of the area. Upland forests dominated by pure or mixed aspen, white spruce, black spruce, Alaska birch and lodgepole pine also occur. Forest harvesting is extremely limited in this subregion.

[1] See Downing and Pettapiece (2006) for further details.

Lower Boreal Highlands

South - north decline in elevation, range 400-1075m
Mean annual temperature = -1.0 °C
Mean annual precipitation = 495mm

The Lower Boreal Highlands natural subregion is characterized by diverse mixedwood forests and extensive wetlands. Hybridization between jack pine and lodgepole pine frequently occurs. Aspen and white spruce forests are common on uplands, as well as balsam poplar and white birch in some areas. Coniferous and deciduous harvest for pulp and softwood production occurs throughout the area.

Upper Boreal Highlands

Elevation range 650-1150m
Mean annual temperature = -1.5 °C
Mean annual precipitation = 535mm

The Upper Boreal Highlands is enclosed by the Lower Boreal Highlands subregion. Coniferous forest cover is dominant at all stages of succession while deciduous forests are typically stunted and species-poor. At higher elevations lodgepole pine and lodgepole-jack pine hybrids are more common, while more diverse mixedwood stands are found at lower elevations. Extensive wetlands are found in low-lying portions of the plateaus. There is some limited harvest of softwood, but volumes are low and access is poor.

Central Mixedwood

Elevation range 200-1050m
Mean annual temperature = 0.2 °C
Mean annual precipitation = 478mm

The Central Mixedwood is the largest of all the subregions in Alberta, covering 25% of the province. In uplands there is typically a mosaic of aspen, mixedwood and white spruce forests. Jack pine stands are commonly found on dry upland sites in the east. Extensive areas of wetland, primarily treed black spruce fens and bogs, cover almost 50% of the area. There is significant coniferous and aspen harvest throughout the subregion.

Dry Mixedwood

Undulating plains, elevation range 225-1225m
Mean annual temperature = 1.1 °C
Mean annual precipitation = 461mm

The Dry Mixedwood natural subregion is the second largest subregion. It is the warmest subregion in the boreal natural region and has the longest growing season. Though much of the area has been cultivated for agriculture, aspen forests are prominent as well as mixedwood stands including balsam poplar and white spruce occurring in moister sites and jack pine in drier sites. White spruce stands are less common than in the Central Mixedwood subregion due to more frequent fires. Wetlands are common in low-lying areas and cover 15% of the subregion. While some conifer harvesting occurs, the focus is primarily on deciduous species for pulp and paper production.

Lower Foothills

Elevation range 650-1625m
Mean annual temperature = 1.8 °C
Mean annual precipitation = 588mm

The Lower Foothills is a climatic transitional area that shares the cold winters of the Boreal Forest and the high winter snowfalls typical of mountainous climates while generally having drier and warmer conditions than the Upper Foothills. Forests are diverse with lodgepole pine commonly occurring on mesic stands and deciduous stands occurring in both pure and mixedwood forms. Lower, wetter sites have poor to rich fens and shrubby grasslands occur on the driest sites. The forests of this subregion are highly productive and forest harvest is extensive.

Upper Foothills

Rolling to steeply rolling, elevation 950-1750m
Mean annual temperature = 1.3 °C
Mean annual precipitation = 632mm

The Upper Foothills occupies a narrow belt between the Lower Foothills and Subalpine natural subregions. The higher elevations produce cooler and wetter conditions than are typically found in the Lower Foothills subregion. Lodgepole pine is dominant on mesic sties while white spruce occurs at higher elevations along the boundary of the subalpine. Mixedwood and deciduous stands are less common. Lower, wetter sites have poor to rich fens and shrubby grasslands occur on the driest sites. While generally less productive than the Lower Foothills, this region includes large areas of productive timber and sees extensive forest harvesting.

Subalpine

Rolling to steeply rolling, elevation 1300-2300m
Mean annual temperature = -0.1 °C
Mean annual precipitation = 756mm

The Subalpine subregion occurs at high elevations below the Alpine subregion and is dominated by lodgepole pine forests at lower elevations. Engelmann spruce, subalpine fir and larch occur at higher elevations, often interspersed with meadows. Productivity is low but some forest harvesting does occur.

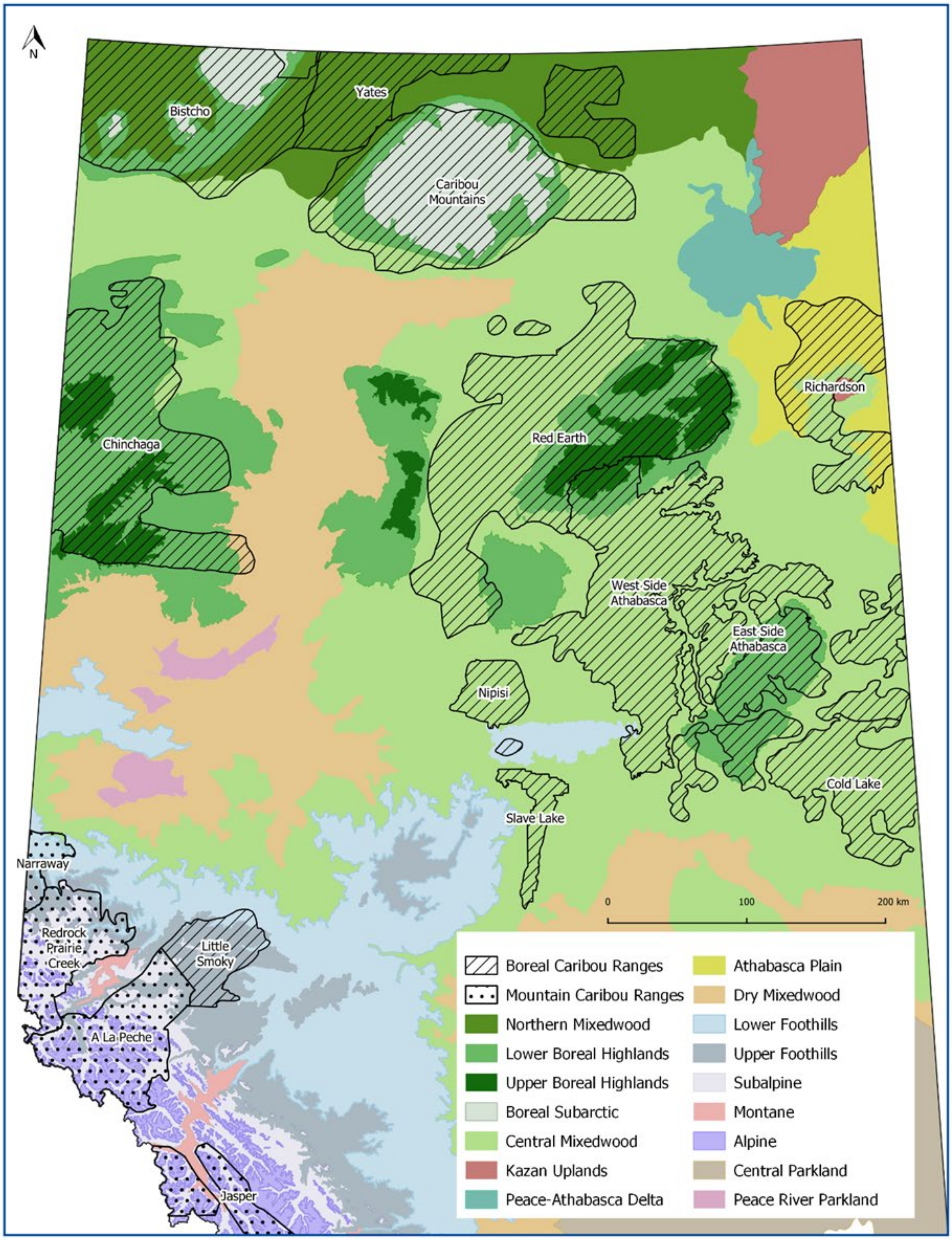

Figure 3. Alberta caribou ranges and natural sub-regions.

1.1 Southern Mountain Caribou

The three Southern Mountain caribou herds that are found in Alberta (Redrock-Prairie Creek, Narraway and A La Peche) are all part of the Central Group, a distinct grouping based on ecological and evolutionary distinctions. This group makes use of alpine areas and subalpine forests at higher elevation in summer, but in winter migrate to use lower elevation forested habitats and wetlands in the foothills. Snowpacks are relatively shallow in these areas, allowing caribou to utilize primarily terrestrial lichens in mature coniferous forests or on windswept alpine slopes. Arboreal lichens are also utilized in lower elevation forests, wetlands and subalpine habitats, but to a much lesser degree than in the Southern Group subpopulation (Environment Canada 2014). Uniquely, the concept of 'matrix' range is also defined for Southern Mountain populations. This includes Type 1 matrix range (areas not delineated as summer or winter range but which may be used for seasonal migration or used at a low rate) and Type 2 matrix range (dispersal areas and areas surrounding annual ranges where predator-prey dynamics can negatively influence caribou populations through increased predation).

The Southern Mountain recovery strategy targets 'minimal' disturbance for summer range and this target is generally met for summer range in Alberta, which is found exclusively within protected areas (Willmore Wilderness, Kakwa Wildland and Jasper National Park). The summer ranges also extend into high elevation areas in British Columbia. However, winter and matrix range overlaps considerably with industrial activities, primarily oil and gas exploration and development, and forestry, as well as some mining.

In the Redrock-Prairie Creek and Narraway ranges increasing disturbance (>100% increase in disturbance between 1998 and 2013) has caused caribou to reduce their home range size and shift their spatial distribution to avoid disturbance. This has resulted in caribou increasing their use of higher elevation and non-forested habitat in winter (MacNearney et al. 2016). In addition, migratory behavior itself has significantly declined due to avoidance of disturbed winter range habitat, with most individuals now remaining resident at high elevation year-round. In a case of maladaptive habitat selection, these summer range residents have a lower survival rate than migrants, contributing to population decline (Williams et al. 2021).

A single FMA overlaps the Redrock-Prairie Creek (85% overlap) and Narraway (100% overlap) winter ranges and makes up approximately one third of the FMA in total. Harvest in the ranges is predominantly in pure conifer stands, with some mixedwood at lower elevations (approximately 54,000 ha in past 40 years or 12.8% of caribou winter range). The A La Peche winter range is relatively small and completely overlapped by timber tenures (two FMAs collectively cover 32% of the range with the remaining area under timber quota). The area has been under heavy harvest pressure (approximately 25,000 ha in past 40 years or 15.2% of caribou winter range).

This reduction in use of winter range is indicative of the loss of habitat that is required for long-term persistence of caribou herds and highlights the importance of minimizing habitat loss from forestry and minimizing the effect of apparent competition wherever possible. Silvicultural systems and techniques that maintain old-growth forest characteristics and avoid increasing early seral stage forage availability may help to reduce impact.

1.2 Boreal Caribou

All other provincially managed caribou herds in Alberta are boreal caribou, which in general are non-migratory and require large continuous tracts of undisturbed habitat with an abundance of terrestrial lichens in mature to old-growth forest and peatland complexes (Bradshaw et al. 1995; Dunford et al. 2006; Stuart-Smith et al. 1997). These large areas are required to allow caribou to maintain the low population densities that reduce risk of predation and to move around the landscape in response to current habitat suitability (Environment Canada 2012). Similar to the Southern Mountain population winter ranges, boreal caribou ranges are affected by direct habitat loss and fragmentation from oil and gas development, mining, and forestry. In addition, early seral stage habitats resulting from disturbance increase the impact of predation via apparent competition, while linear features facilitate predator movement in caribou habitat.

In the north-west, the Bistcho, Yates and Caribou Mountains ranges are predominantly in the taiga plain ecozone. Caribou in this region prefer mature forests with black spruce, jack pine and tamarack and select for older stands than those in other boreal caribou ranges (80+ vs 60+ years, Table 1-1). Wetlands, particularly bogs and fens are also important habitat (Environment Canada 2012). Industrial development in this area is lower than in most ranges (ABMI 2018) and approximately 32% of caribou range in this area is under FMA or other major form of tenure. Historically, harvest pressure on these caribou ranges has been relatively light (approximately 47,000 ha in past 40 years or 1.2% of caribou range), although significant areas in the south of Bistcho and Caribou Mountains have been harvested.

To the south of Bistcho, the Chinchaga range extends into British Columbia and caribou here have been identified as having slightly different habitat selection patterns than other caribou in the boreal plains with disproportionate selection for white spruce stands, in addition to the typical boreal plains habitat preferences (Table 1-1). The range is predominantly in the lower and upper boreal highlands and three different FMAs as well as other tenure overlap 74% of the range. Most harvest has taken place in the south and south-east of the range (approximately 77,000 ha in past 40 years or 4.4% of caribou range) with harvest for hardwoods and softwoods both commercially important.

In the north-east, the Cold Lake, East Side Athabasca River, West Side Athabasca River, Richardson, and Red Earth ranges are all within the boreal plains ecozone. Caribou in this region select heavily for peatland complexes, particularly bogs and fens, and older (60+ years, Table 1-1) conifer forest (Environment Canada 2012; Schneider et al. 2000). Much of this region overlaps with oilsands development, which is a major contributor to habitat loss and fragmentation (Hebblewhite 2017). Approximately 65% of caribou range in the area is under FMA or other major tenure, predominantly within a single large FMA. Forestry in this region involves significant hardwood pulp production, primarily from aspen and balsam poplar, as well as softwood harvest with white spruce and jack pine being commercially important. Harvest within caribou ranges has mostly occurred in the southern portion of this area (approximately 119,000 ha in past 40 years or 1.8% of caribou range).

The Nipisi and Slave Lake ranges, located to the south-west of the other north-eastern ranges, are also in the boreal plains ecozone and are primarily within the central mixedwood natural subregion. Caribou habitat requirements in this area are broadly similar to the other north-eastern ranges, but these ranges are characterized by their small size and extensive industrial footprint. There is a complex mosaic of forestry activity in the area with six different FMAs overlapping 98% of the ranges. Harvest within caribou range is more extensive than in the north-west or other north-eastern ranges (approximately 29,000 ha in past 40 years or 8.0% of caribou range).

The Little Smoky population is also considered a boreal range, although it is adjacent to the Southern Mountain A La Peche range and found predominantly in the upper foothills natural subregion. Industrial footprint from oil and gas development and forestry is particularly widespread in this range (Government of Alberta 2017a). The forests in this area are productive and see extensive harvest (approximately 51,000 ha in past 40 years or 16.5% of caribou range). Three different FMAs and additional major forestry tenure overlap almost all (99.6%) of the range.

While harvest pressure is not as intense in the north-west and much of the north-east, all caribou herds in Alberta's boreal have declined in recent years (Environment Canada 2011). It is therefore important that habitat loss from forestry be minimized and that the effects of apparent competition are addressed wherever possible. Alternative silvicultural systems and techniques could reduce this impact if they can maintain old-growth forest characteristics and avoid increasing early seral stage forage availability.

1.3 Biophysical Habitat

Caribou biophysical habitat can be defined as the *"habitat characteristics required by caribou to carry out life processes necessary for survival and reproduction"* (Environment Canada 2011). These habitat characteristics were defined at a broad scale (ecozone) in the 2011 Scientific Assessment but further refined for Alberta's caribou populations by the Government of Alberta in 2017. Biophysical habitat for all boreal populations was identified as including wet areas, pure and leading black spruce, black spruce mixedwoods, pure and leading pine, leading larch, pure and leading balsam fir, and fir leading mixedwoods (Government of Alberta 2018a). In addition, the Chinchaga population was identified as selecting for white spruce stands. Importantly, the minimum age for forested stands to be considered biophysical habitat was identified as 80 years in the taiga plain and montane cordillera, but 60 years in the boreal plains (Table 1-1).

Table 1-1. Caribou ranges in Alberta by overlap with FMAs, ecozone, natural sub-region and minimum age for forested stands to be considered biophysical habitat.

	Range	% FMA / Other Major Forestry Tenure	Ecozone	Natural sub-region	Biophysical Minimum Forested Age
Boreal	Bistcho	39	Taiga Plain	Primarily northern mixedwood (43%), along with boreal subarctic (29%), lower boreal highlands (19%) and central mixedwood (10%).	80
	Caribou Mountains	28			
	Yates	28			
	Chinchaga	74	Boreal Plains*	Primarily lower boreal highlands (73%) and upper boreal highlands (73%).	
	Cold Lake	28	Boreal Plains	Primarily central mixedwood (68%) with some lower boreal (17%) and upper boreal highlands (9%). Also, some Athabasca plain (7%), most of which is in Richardson (makes up 65% of that range).	60
	East Side Athabasca	87			
	Red Earth	59			
	Richardson	6			
	West Side Athabasca	98			
	Nipisi	100	Boreal Plains	Almost entirely central mixedwood (95%) with a small amount of Lower Foothills in Nipisi.	60
	Slave Lake	96			
	Little Smoky	100	Boreal Plains	Mostly upper foothills (83%) and lower foothills (13%) with a small amount of subalpine (4%).	60
Southern Mountain	A La Peche Winter	100	Montane Cordillera	Primarily subalpine (57%) and upper foothills (39%) as well as some lower foothills.	80
	Redrock Prairie Creek Winter	85			
	Narraway	100			

* Note: Alberta Environment and Parks determined that the Chinchaga population selects for white spruce forests, unlike other boreal plains populations in Alberta.

2 Impact of Harvesting on Caribou

There are three main pathways through which forestry can negatively affect caribou populations. These are (a) directly causing the loss, degradation, or fragmentation of caribou habitat via harvesting of mature and old coniferous forests, (b) causing an increase in predation rates on caribou via apparent competition and (c) access roads providing easier access for predators and other ungulate prey species into caribou habitat, thereby increasing predation risk.

Forest harvesting causes the loss of biophysical habitat, particularly mature and old coniferous stands that are abundant in lichens. Recovery can take many decades. This loss of habitat typically extends much further than the physical limits of a harvested area because caribou actively avoid cutblocks at a broad scale (DeCesare et al. 2012; Smith et al. 2000; Vors et al. 2007). This avoidance effectively reduces caribou range size as caribou shift their habitat use away from disturbance (Donovan, Brown, and Mallory 2017; Faille et al. 2010; MacNearney et al. 2016; Smith et al. 2000). For one Southern Mountain population migratory behavior has declined due to avoidance of disturbed winter range habitat, with most individuals now remaining resident at high elevation year-round, where survival rates are lower (Williams et al. 2021).

HARVEST IMPACTS:

Habitat Loss: Loss of mature and old conifer forest and associated resources, particularly lichen, that caribou rely upon.

Apparent Competition: Increase in early seral stage vegetation favoring other ungulate species, which support larger wolf populations that then also predate upon caribou.

Access Roads: Roads make it easier and faster for predators to travel in caribou habitat, increasing predation rate.

Caribou use a "spacing out" life history strategy to avoid predation (Seip 1991). This involves living at low densities in peatlands and mature conifer forest; lower productivity habitats that are not preferred by moose, deer, and elk due to a lack of foraging opportunities. Wolf populations are primarily sustained by moose and deer, which are more commonly found in upland habitats. Therefore, caribou have historically been able to avoid predation pressure through spatial separation from other ungulates and predators (James et al. 2004).

However, increasing human-mediated habitat alteration has led to increased early seral stage forest in a process that has been referred to as terrestrial eutrophication (Serrouya et al. 2021). Such habitats are preferred by moose (*Alces alces*), deer (*Odocoileus* spp.) and elk (*Cervus canadensis*), allowing them to increase in abundance, which in turn increases wolf and other predator populations. While wolves primarily hunt other ungulates, they will hunt caribou when available and this increased incidental predation leads to caribou declines. This decline via a shared predator is known as apparent competition (DeMars et al. 2019; Holt 1977; Neufeld et al. 2021). It has been observed that the spatial overlap of moose and caribou increase when human landscape alteration is higher, increasing caribou mortality (Peters et al. 2013). Increased predation rate has led to significant declines in caribou population numbers, including extirpations (Seip 1991; Serrouya et al. 2021; Wittmer, Sinclair, and McLellan 2005) and has been well documented in recovery strategies (Environment Canada 2012, 2014).

Climate change and land-use change can also interact to increase ungulate populations and therefore increase apparent competition (Dawe, Bayne, and Boutin 2014; Dawe and Boutin 2016). For example, in northeastern Alberta, dramatically increased numbers of white-tailed deer (*Odocoileus virginianus*) have caused significant increases in wolf density and an increase of caribou in wolf diet (A. David M. Latham et al. 2011). The productivity of a landscape is also important in determining the magnitude of apparent competition. In low productivity ecosystems, such as in northern Saskatchewan, where deciduous and mixedwood stands are uncommon and vegetation growth response to disturbance is low, apparent competition appears less important as a limiting factor for caribou populations (Neufeld et al. 2021).

Linear features, such as roads and seismic lines, particularly those that provide access into otherwise remote caribou habitat, exacerbate predation pressure on caribou. These features can act as travel corridors for wolves and other predators, allowing easier access into caribou habitat (e.g. peatlands) and resulting in increased predation (DeMars and Boutin 2018; A David M Latham et al. 2011; Mumma et al. 2018). Wolves have also been demonstrated to move faster and farther on linear features in north-eastern Alberta (Dickie et al. 2017). While most linear features in Alberta caribou ranges are due to oil and gas development and exploration (Schneider et al. 2010), the importance of forestry access roads should not be discounted, especially in relatively undisturbed areas.

2.1 The Role of Alternative Silvicultural Systems

In this report, alternative silvicultural systems and harvesting techniques are identified and reviewed in the context of how and if they could be used to reduce the negative impacts of harvesting on caribou. This has three main components:

1. In all forest types, apparent competition should be targeted by minimizing the habitat quality for ungulate species such as moose, deer, and elk (see Section 2.2). Any system or technique which reduces the flush of early seral stage vegetation that is commonly seen after harvest is likely to be beneficial in this regard.
2. In coniferous forests, loss of or damage to caribou biophysical habitat and associated forage resources (e.g. lichens) should be minimized. Any system or technique that maintains or changes forest structure in such a way that lichens are retained (or even enhanced via improvements in light conditions) should be beneficial if caribou continue to use the habitat post-harvest.
3. In all forest types, access roads should be minimized in extent and duration wherever possible. Increased access can bring more predators, other ungulates, and people into caribou habitat, to the detriment of caribou populations.

One conceptual way to think about alternative silvicultural systems, caribou habitat, and apparent competition is to consider the role of the forest crown in light exposure at the forest floor and its impacts on species development patterns, as well as the interaction of these dynamics with site productivity. Light models used in forestry (e.g. Beaudet et al. 2011) may provide a framework for determining the details of how a particular silviculture system should be applied.

Lichen growth is favored in older, relatively open stands. When canopy closure is high, this generally favors mosses over lichens (Morneau and Payette 1989), while if canopy cover is suddenly removed, for example through clearcut harvest, lichen is typically unable to survive (Thomas et al. 1996). Thus, the light dynamics post-harvest is of central importance for the maintenance and promotion of caribou habitat and forage. This is a key component of the partial harvest trials in British Columbia described in Section 7.4.

In the context of apparent competition, light dynamics are also fundamental for determining the response of understory vegetation growth and therefore for species composition and abundance post-harvest. An understanding of how alternative silvicultural systems change the light dynamics in a stand is therefore key to being able to predict and control the "flush" of early seral stage vegetation that favors other ungulates. Any system that only removes part of the canopy may be able to reduce understory vegetation growth relative to clearcut and so have less impact on apparent competition. This will be highly dependent on the details of the system, but also on the site characteristics, particularly site productivity. When considering partial harvest to maintain canopy cover, in a low productivity site it might be the case that a large proportion of the canopy could be removed with minimal response from understory vegetation. In contrast, in higher productivity sites even a small reduction in canopy closure may lead to a major understory response (see Section 7.4.3 for an example case study). In Alberta, where site productivity is typically relatively high, in many areas maintenance of a higher percentage of canopy cover may be required to minimize understory vegetation response, as compared to lower productivity forests such as those found in Quebec (Section 7.5.3).

While partial harvest systems to maintain forest structure and lichen abundance are relatively well understood and tested in some jurisdictions (Sections 7.4, 7.5), they have been used sparingly in Alberta. We describe these systems and discuss how they might be applied in Alberta, drawing also on more local trials that have had less of a caribou focus but still provide highly relevant insights (Section 7.2). We also explore how harvesting treatments such as commercial thinning could be used to achieve a similar outcome (Section 7.2). The potential role of herbicides and other treatments are also discussed in Section 4.2. Systems to reduce apparent competition in deciduous and mixedwood stands have been explored less from a caribou-centric perspective, but much experience with systems in these forest types is available to draw upon (Section 7.3). Finally, we also discuss how intensive silviculture and zonation concepts could have potential for allowing a reduction in pressure on caribou habitat by economically enabling the use of more expensive, less efficient harvesting techniques in caribou range (Section 7.6), as well as wider discussions on access requirements, economics and climate change (Sections 8, 9, and 10).

2.2 Other Ungulate Habitat

The population density of other ungulate species such as moose, deer, and elk is the primary determinant of predator carrying capacity. For example, wolf population numbers are directly tied to the availability of ungulate biomass (Fuller 1989). If predator population densities increase in or adjacent to caribou habitat, this often leads to unsustainable incidental predation on caribou. Commercial forestry and natural disturbance events convert old forests to early seral stage forest, which has higher quality browse and edges that are the preferred habitat for moose, deer, and elk (Routh and Nielsen 2021; Smith et al. 2000). Habitat selection for these other ungulate species is largely driven by the stand structure and composition and the resulting understory vegetation, which provides foraging opportunities as well as hiding and thermal cover from predators.

There are two species of deer found in Alberta: white-tailed deer (*Odocoileus virginianus*) and mule deer (*Odocoileus hemionus*). Deer are found in every natural region of the province but are most common in the Grassland, Parkland, and Boreal Forest Natural Regions (ABMI 2020c, 2020b). White-tailed deer populations in North America have been increasing in abundance and distribution since the late 1900s and in Alberta are expanding westward into the Foothills and Rocky Mountains Natural Regions and farther north into the boreal forest (ABMI 2020c). This is due to both changing climate, particularly reduced winter severity and reduced snow depth and cover (Dawe and Boutin 2016), as well as intensifying habitat alteration causing a proliferation of early-seral vegetation (Laurent et al. 2021). Their adaptability to different environments (Hewitt 2011) and exceptional fecundity – an individual may produce up to 30 offspring over their lifetime (McShea 2012) – makes them particularly successful in both natural and disturbed landscapes.

> *"If you think about the distribution of white-tailed deer and how well they do from South Carolina to northern Alberta. They're definitely plastic species that can adapt to living in downtown Victoria or the swamps of Carolina or in -40 boreal forest. They are going to do well in most places."*

White-tailed deer occupy a wide variety of habitats, including mature deciduous and mixedwood forests. Abundance is higher in young harvested stands as compared to equivalent naturally-disturbed stands (ABMI 2020c). They select for forage under 1.5 m in height and are highly generalist, consuming up to 100 different species annually depending on forage availability, although generally focusing on those that are most palatable (McShea 2012; Routh and Nielsen 2021). Routh & Nielsen (2021) noted the importance of prioritizing research on habitat selection, foraging ecology, and population demographics of deer, especially in northwest Alberta where they have newly replaced moose as the primary prey of wolves.

In 2014, population estimates indicated that there were approximately 115,000 moose (*Alces alces*) in Alberta, with population decline occurring across northern Alberta, driven by factors such as habitat alteration, predation pressure, parasites and disease, hunting, collisions, and climate change (Timmermann and Rodgers 2017) – see fRI Research report from Lamy and Finnegan (2019) for a detailed review of Alberta moose populations, monitoring and habitat. Moose primarily inhabit the Boreal and Foothills Natural Regions, with the highest densities found in the west and central areas of the province. However, they have also expanded the southerly extent of their range into the Parkland and Grasslands Natural Regions during the last 40 years (Bjorge et al. 2018). They are much less fecund than deer, typically producing one calf per year, although 2-3 can occur (Lamy and Finnegan 2019).

Moose occupy a wide variety of habitats, including young mixedwood and mature deciduous stands. Abundance is higher in young harvested stands as compared to equivalent naturally-disturbed stands (ABMI 2020a). They prefer browse under 2.5 m in height and like white-tailed deer are highly generalist, sometimes consuming more than 200 different species annually, though they favor only a few of these, with willow, birch, and poplar species preferred (Routh and Nielson 2021). Open habitats are often used for foraging in summer, but moose generally prefer proximity to forest edge in order to minimize heat stress.

Both moose and deer are habitat generalists, easily moving between a mosaic of different habitats as required by resource availability and other limiting factors such as snow depth. Edge habitats are frequented as they offer both forage and hiding opportunities. Both are generalist browsers, typically consuming moderate amounts of a wide variety of plant species while preferentially selecting the most palatable browse when available (Routh and Nielsen 2021). Behavior often changes to avoid predation, with moose trading foraging opportunities for cover, with female cows with calves typically exhibiting the most risk-averse behaviours (Lamy and Finnegan 2019). Although moose and deer abundance is highest in areas with graminoid vegetation, each species display a secondary preference for different habitat types, with moose occupying more wetlands, mule deer inhabiting more mature/old forests, and white-tailed deer having high abundance in mature deciduous and mixedwood stands; there is significant overlap in preferences (ABMI 2020c, 2020a, 2020b).

While both moose and deer generally occupy early seral habitats, the response of each to disturbances is complex and can vary according to productivity, climate, and stand type. Both moose and white-tailed deer have higher relative abundance in young, harvested stands compared to naturally disturbed stands of similar age (ABMI 2020c, 2020a). Moose have been shown to avoid burns in some systems (DeMars et al. 2019) which may be due to the resulting lower quality browse as compared to harvested areas (Routh and Nielsen 2021). In harvested areas the timing of regeneration of the most favourable browse for moose is highly variable, ranging anywhere from 5-40 years, and use may also be dependent on the availability of forest cover (see fRI Research report from Lamy and Finnegan (2019) for a detailed review).

“Low productivity sites can skip that early seral stage, the moose bonanza. In burned areas it can skip the early seral stage and go straight to the terrestrial lichens. It’s so variable amongst the different ecosites.”

“Vascular plants dominate the understory 7-25 years post-harvest […]. Harvest and fire-origin stands become similar in 20-100 years after disturbance. That’s a large range.”

“Large, harvested areas have small amount of remnant forest needed by moose for thermal or security cover.”

The desirability of a post-harvest area to moose and deer is therefore highly variable and dependent on site conditions, block layout, size, and structure, harvesting treatments, and silvicultural system. For example, a partial harvest system might maintain enough canopy cover to minimize new understory browse species growth and so not increase habitat selection by moose and deer, but in another situation could also remove enough canopy to cause a flush of new vegetation growth, while also maintaining forest structure and heterogeneity, providing ideal conditions for moose and deer. It is therefore important to evaluate any silvicultural system or harvesting technique for its likelihood of increasing or decreasing the availability of high-quality browse and the forest structure that is maintained or developed post-harvest.

While deer are abundant in Alberta and potentially reducing their numbers through adoption of alternative silvicultural systems or harvesting techniques in caribou habitat is uncontroversial, moose population numbers are much more of a concern. Moose are a highly significant species to many Indigenous communities, as well as to recreational hunters, and there is concern about population declines in northern Alberta (Lamy and Finnegan 2019). There is therefore a need to consider how the priorities of forest management prescriptions should be determined in different areas. Specific systems and treatments can be used to manipulate post-harvest vegetation trajectories and produce a desired management outcome specific to a certain area.

"In areas closer to Manning, where Indigenous folks are hunting, and non-indigenous people are hunting, we want a lot of moose […] we should let the forest come back in a way that maximizes the advantages for moose and therefore for the people."

"One thing to be cognizant of for moose, deer, and elk is the fact that they're important for hunters and Indigenous communities and an important source of food and recreation. I would prefer if we could separate them spatially. That would be ideal. There are reports of moose decline in some areas. Options to reduce them aren't going to go down well there. So, we want to split them up."

3 Silvicultural Systems

The word silviculture is derived from Latin *silva* ("forest") and *cultura* ("care or cultivation") and at its root means the cultivation of forest, analogous to the term agriculture (cultivation of field). Cultivation in this sense refers to the process of transforming 'natural' forests into managed forests through changes in structure and composition that better suit human needs (Wiersum 1997). Silvicultural systems as defined by Matthews (1991) are *"the process by which crops constituting a forest are tended, removed, and replaced by new crops, resulting in the production of stands of distinctive form."*

These definitions capture the early focus of silviculture on managing forest products, specifically the maximization or efficient production of timber. Prior to the 1990s, silviculture in most of Canada's boreal forest focused primarily on product flow and stand manipulations that were developed to meet provincial stocking criteria by increasing productivity, reducing competition, and shortening establishment time (Lieffers et al. 2003), although there were exceptions to this paradigm in some other ecological regions (Rice 2013). Contemporary management has become more complex and must balance economic, environmental, and social objectives that are often in conflict. While silvicultural systems were originally focused on supporting and increasing timber production, this has shifted to focus on a much broader set of values (Kohm and Franklin 1997).

Forest management in North America has generally shifted toward ecosystem-based management, where protection of ecosystem integrity and biodiversity is of central importance (Patry et al. 2013). The application of ecosystem-based management is often tied to the idea of emulating natural disturbance regimes to produce forests that are structurally and functionally similar to those that would result from natural disturbances, particularly fire. This model acknowledges that ecosystems are naturally adapted to their historical disturbance regime and that these reference conditions should inform management practices at both the stand-level and the landscape-level (Long 2009). In Alberta, fire is the primary stand-replacing disturbance agent that informs forest management. An ecosystem-based management approach has resulted in a move from multi-pass to single-pass harvesting, larger cutblocks, and the retention of more residual structure within cutblocks to better approximate post-fire conditions (Van Wilgenburg and Hobson 2008).

Considering this broader approach to forestry, silviculture is defined by Lieffers *et al.* (2003) as *"the theory and practice of controlling the establishment, composition, growth, and quality of forest stands to achieve the objectives of management"*. A silviculture system is therefore a framework, outlining the set of specific treatments that will be applied in order to achieve a particular set of management objectives (Graham and Jain 1998). We can think about the term silviculture as referring to the overarching harvest and regeneration systems and/or to the specific treatments applied within a system.

A silviculture system can have a range of treatments applied resulting in variations on the outcomes for both timber production and the resulting ecological condition. Understanding of both the system and the treatments is important to control outcomes. Silvicultural systems utilize the natural stand dynamics and are thus applicable to specific ecological conditions and cannot be effectively applied outside those conditions. Silviculture systems may be used to manage and maintain even-aged or uneven-aged stands (three or more age classes) and commonly include seed tree, shelterwood, selection, and clearcut systems (Table 3-1). Typically, they are defined by the final harvest treatment employed, regardless of intermediate tending treatments that may include partial stem removal (e.g. thinning).

Partial harvest is an umbrella term that is broadly defined by the Canadian Forest Service as any cutting in which only part of a stand is harvested (Canadian Forest Service 1995). By this definition, clearcutting with minimal structural retention may technically fall under the umbrella of partial harvest systems. However, for the purposes of this report we use the term partial harvest to refer to any system that involves decision-making about which trees are removed and which are kept at the scale of approximately a single-tree length. This then excludes systems that use clearcutting with lower levels of retention, and instead encompasses a range of alternative systems with lower levels of removal that are typically designed around what is left behind just as much as what is extracted.

Table 3-1. Summary of key silvicultural systems.

System	Variants	Management	Harvesting	Regeneration	Notes
Clearcut		Even-Aged	All trees are removed from the stand in a single cut at planned intervals (rotation).	Planting or natural regeneration. Well-suited for regeneration of shade intolerant species.	Dominant system in Alberta (95%+). Spatial patterns (e.g. strips, patches) and opening sizes vary significantly. Retention referred to by many different terms e.g. green-tree retention, reserves.
	Variable retention	Even-Aged	Includes retention of trees to maintain structural and functional elements of the pre-harvest forest for other values e.g. biodiversity. Retention can be in patches (aggregated) or individual trees / small clumps (dispersed). Retention areas are retained for a rotation.		
Seed-Tree		Even-Aged / uneven-aged	Retains selected trees (10-50 trees/ha) that are maintained in order to supply seed for the next crop. Seed trees may be removed after seedling establishment.	Natural, but can be supplemented with scarification if required. Less successful on rich sites where competitive vegetation invades rapidly.	Rarely used in Alberta. Well suited for species that continually produce seed.
Shelterwood	Uniform	Even-Aged	Removal of mature trees in a series of cuts over a short period (relative to rotation age e.g. 20-30 years), in order to regenerate an even-aged stand under the shelter (from e.g. full sunlight, radiation frost, competition) of existing canopy. Particularly effective for shade-tolerant species.	Natural but planting may also be used.	
	Group / Strip	Even-Aged	Gradual removal of overstory trees via multiple patch or strip cuts. Edges of patches or strips provide shelter.	Natural but planting may also be used.	
	Irregular	Transitional even-aged / uneven-aged	Longer periods between harvesting entries and protection of range of tree sizes results in irregular (multi-cohort) structure. Irregular variants of uniform and group shelterwoods possible.	Natural but planting may also be used.	
Understory Protection	Understory Avoidance	Even-aged	In Alberta, used in aspen stands with a white spruce (or sometimes balsam fir) understory. Understory protection is applied in specific circumstances (landbase defined as coniferous, relatively dense, and uniform understory) and	Stands can be supplemented by underplanting of spruce.	Understory avoidance more commonly practiced in Alberta. Application of understory protection is highly

System	Variants	Management	Harvesting	Regeneration	Notes
			involves removal of deciduous canopy in aspen mixedwood stands in order to encourage recruitment of white spruce found in the understory. In other cases (landbase defined as deciduous, low density or clumped understory) understory avoidance, a lower intensity intervention that simply aims to protect the understory from direct harvest impact (i.e. during harvest, skidding, regeneration), is practiced.		dependent on the density, height distribution and spatial pattern of the coniferous understory, which can be highly variable.
Selection		Uneven-aged	Mature timber is removed in small groups or single trees at relatively short intervals (e.g. 10-25 years), maintaining an uneven-aged stand.		
	Single-tree selection	Uneven-aged	Individual trees (or small clumps of trees) are harvested throughout the stand, maintaining a balanced uneven-aged stand structure.	Natural	More complex planning and harvesting. Pre-commercial and commercial thinning are common treatments to accomplish single tree selection.
	Group selection	Uneven-aged	A mosaic of patches at different ages is created via removal of small patches (e.g. up to two tree heights diameter). Harvesting of an area is slower and removes less volume than in shelterwood system.	Natural but planting may also be used.	
Diameter-limit Cutting		Even-aged / uneven-aged	Trees within specific diameter ranges are removed, the rest are retained.	Natural.	Used to improve stands by removing undesirable stems or tree sizes. Historically was sometimes used as a form of high-grading, causing stand quality loss / regen failures.

3.1 Clearcutting

Clearcutting is the predominant silvicultural system in Canada and accounts for over 85% of the area harvested across the country (Statistics Canada 2018). In Alberta, clearcutting is even more ubiquitous. For example, in the 2015-16 timber year, approximately 98% of the forest harvested on Alberta's public lands was harvested using the clearcutting method. It is the dominant treatment because the majority of Alberta forests are fire origin and clearcutting mimics the open forest conditions that occur post-wildfire, allowing for rapid and efficient reforestation of fire-adapted species that regenerate well in full light conditions. Partial cuts, shelterwood, and seed tree systems accounted for only 2% of total harvest area (Government of Alberta 2017b).

Clearcutting involves the removal of all or most of the available timber volume in an area at one time at planned intervals (rotation length), followed by reforestation, and resulting in even-aged stands (Lieffers et al. 2003). The area treated is often referred to as a cutblock, cutover or harvest block and can vary in size dramatically. Clearcutting is an efficient and inexpensive system that also generally allows for more intensive management (Keenan and Kimmins 1993), such as site preparation and control of competing shrub and herbaceous growth.

With the shift toward ecosystem-based management, which seeks to emulate natural disturbance patterns, significantly more retention is often included in clearcuts. In Alberta, this typically involves the retention of single trees or patches of trees, retention of large snags, riparian buffer zones, debris management, and wildlife corridors (Government of Alberta 2016).

3.2 Seed-Tree

Seed trees are mature, seed-producing trees that are preserved during harvest in order to restock stands through natural regeneration. Seed trees may be harvested in a removal cut once establishment has occurred. The number of seed trees retained is species-dependent, with poor seed producers requiring a higher density than productive seed producers (Graham and Jain 1998). Trees with large crowns located in the upper canopy typically provide the best seed supply with supply increasing considerably during mast years (Gärtner, Lieffers, and Macdonald 2011). Seed tree systems produce even-aged stands and can have variable regeneration results. Tree density and distribution, dispersal limitations, and site preparation (e.g. mounding) are all important considerations in this system (Bose et al. 2014). Seed trees may be grouped in small patches or uniformly distributed throughout the cutblock. Natural regeneration may be supplemented with planting as required.

Species with serotinous or semi-serotinous cones such as jack pine, lodgepole pine, and black spruce have large aerial seedbanks that support natural regeneration following disturbance (Gärtner et al. 2011). Seed release of serotinous species such as jack pine and lodgepole pine is typically initiated by fire, although cones can open in situ due to temperature increases in the canopy or on the forest floor following other types of disturbance (Teste, Lieffers, and Landhäusser 2011), including harvest; however, semi-serotinous species such as black spruce are more favorable for seed tree regeneration. By 30 years of age, black spruce generally have a continuous supply of seeds that disperse over time from standing trees; seeds can also remain viable in fallen cones for over 10 years and tend to seed promptly and regenerate quickly post-disturbance (Rajora and Pluhar 2003). In comparison, white spruce does not bank seeds and tends to have a lower rate of successful establishment that is limited by seedbed and environmental conditions (Gärtner et al. 2011). Accordingly, seed tree systems are more commonly used in the eastern boreal forests of Canada where black spruce is the dominant species.

Seed tree systems are rarely used in Alberta because jack pine and lodgepole pine retain their seeds until sufficient heat is applied. Therefore, standing trees release little seed, making this system ineffective for regeneration of these species. Given that this system has little applicability in Alberta and few potential benefits from a caribou habitat perspective, we do not discuss it further.

3.3 Shelterwood

The primary objective of shelterwood systems is to develop and protect a regeneration layer, typically composed of shade-tolerant species, by maintaining overstory trees that can provide seed and protection (from e.g. full sunlight, radiation frost, competition). This often takes the form of a series of removals over a relatively short period of time (e.g. 20-30 years), compared to the rotation length (Lieffers et al. 2003). The shelter component of these systems may be short-lived, or it may be maintained throughout the life of the regenerated stand (Graham and Jain 1998). A typical series of cuts might take the following form:

- Preparatory Cut: An optional first cut, when trees are mature but dense. Opens up the forest canopy by removing smaller trees and competing species. This removal aims to improve the growth and vigour of the stand and may also allow some harvestable volume to be obtained at an early stage.
- Seed (establishment) Cut: This cut further removes a proportion of trees and opens the canopy to allow for establishment of the sheltered species. Remaining trees should be those that are good seed-bearers and are windfirm.
- Removal Cut: Once the new generation of trees is well established, the sheltering trees are carefully removed. This process might take place in more than one removal, to maintain ideal sheltered conditions until the new generation of trees are larger, particularly if the regenerating species is shade-tolerant.

There are challenges associated with the implementation of shelterwood systems. Advanced regeneration can be damaged by cutting, planning and yield forecasting can be complex and costly, and residual density must be carefully managed to prevent windthrow and shading of regeneration (Raymond et al. 2009).

Shelterwood systems in the classical sense defined above have rarely been used in Alberta because Alberta’s tree species generally do not require this type of system to successfully regenerate. However, understory protection can in some ways be considered a shelterwood system and is often referred to in that context, but in this report, we consider it as a separate system (Section 3.4). The term shelterwood is often also used in a more general context for some forms of partial harvest, as in the British Columbia case studies described in Sections 7.4.1 and 7.5) and may have application in Alberta.

3.3.1 Group and Strip Variants

In a uniform shelterwood system the removals are applied across the stand. In a strip shelterwood system (more likely to be applied in Alberta due to practical limitations such as equipment) the removals are made in linear strips across the stand and harvesting treatments are staggered. This method provides additional protection from windthrow. In a group shelterwood system removal aims to create small gaps (typically 1-2 tree lengths). The adjacent edge trees provide shelter. Gaps can be increased in size through additional removals to gradually establish and release the regenerating species.

3.3.2 Irregular Variants

Irregular shelterwood systems have longer (or indefinite) periods of time between removals, which leads to a range of tree sizes, heights and ages and an uneven-aged stand (Raymond et al. 2009). Regular, group and strip variants can be implemented in an irregular way and typically this system is used for specific ecological or aesthetic management objectives.

3.4 Understory Protection & Avoidance

In western Canada, removal of deciduous canopy in aspen stands with a coniferous understory, in order to encourage recruitment and release of the coniferous understory, is sometimes practiced. These stands can also be supplemented by underplanting of spruce (Lieffers et al. 2003). In Alberta, this system is commonly known as understory protection and is applied in stands with a white spruce (or sometimes balsam fir) understory (Government of Alberta 2016), although it could be applied in other forest types (e.g. conifer forests can sometimes also have a well-developed understory). A significant proportion of the overstory is removed in order to release the coniferous understory, while also maintaining enough stand structure to provide wind firmness. This involves pre-planned harvest design and skid trails and utilizes wind buffering tactics to prevent blowdown and is used when there is a relatively dense and uniform understory.

In other cases, such as when the understory is low density or highly clumped, a less intensive understory avoidance system is used, in which the aim is to minimize harvest impact (i.e. during harvest, skidding, regeneration) on the understory, at relatively low implementation cost. The decision on when to use each system is dependent on density, height distribution and the spatial pattern of the coniferous understory.

In certain situations, such as when there is a well-established spruce understory, understory protection may have benefits for caribou by allowing some harvest while suppressing aspen suckering and the growth of other browse species. From an apparent competition perspective this may be preferable to a clearcut of the entire stand, because even though the resulting white spruce understory will eventually be harvested, leading to significant browse availability, this process is delayed significantly. This system is discussed in the case study in Section 7.3.

3.5 Selection Systems

Selection systems involve the removal of small groups or single trees at relatively short intervals, maintaining an uneven-aged stand structure (Matthews 1991). While these systems do not provide the same level of timber volume as other more intensive systems, they can be used to retain functional attributes of old-growth forest while allowing for some level of harvest volume (Burton, Kneeshaw, and Coates 1999). Typically, selection systems involve many repeated entries into stands, which involves more extensive access requirements and re-disturbance by logging (Lieffers et al. 2003).

Various forms of selection systems have been implemented in other jurisdictions. A group selection system has been implemented in multiple trials in British Columbia, with a specific focus on maintaining caribou habitat. These case studies are reviewed in Section 7.4. Several different selection systems have been trialed and implemented in Quebec and case studies for these are reviewed in Section 7.5. In Alberta, while selection systems have not been implemented at a commercial scale, important trials of selection systems (from the perspective of different levels of retention) have occurred, most notably the EMEND trial, discussed in Section 7.2.

3.5.1 Single-Tree Selection

Single-tree selection is used to maintain uneven-aged stands containing multiple age classes, typically including a mature age class, an intermediate-young age class, and a regeneration class. Frequent entries are required to remove individual trees from each age class in order to preserve a variable age and species composition (Graham and Jain 1998). This system requires both careful planning and skillful execution (Lieffers et al. 2003).

In even-aged stands, single-tree selection is also used to reduce stand density while removing some valuable timber at an earlier age using commercial thinning treatments (Section 4.1). The remaining trees then respond to less light, nutrient, and water competition, allowing them to increase growth rate. Several companies in Alberta are employing commercial thinning in this context. In addition, trials have also been conducted with commercial thinning treatments with the aim of maintaining or improving caribou habitat, further discussed in Section 7.2.

3.5.2 Group Selection

Group selection involves the removal of small patches of timber (e.g. up to two tree heights diameter), large enough that some shade-intolerant species may regenerate. This process creates a mosaic of patches at different ages. The system is easier and more economical to implement than single-tree selection although it still requires more extensive planning than most systems.

3.6 Intensive Silviculture

While not strictly a silvicultural system, this topic was discussed by multiple subject-matter experts as a potential option for facilitating the use of more alternative silvicultural systems in caribou habitat by making up for timber volume losses using intensive management in more productive, less ecologically sensitive areas.

Intensive silviculture refers to the application of a higher intensity and/or number of silviculture treatments to a stand. Most often this is applied for the maximization of timber output and is thus detrimental to other forest values. This often involves rigorous silvicultural treatments to reduce competition and increase timber productivity. Intensive silviculture in even-aged stands usually takes place from bare ground conditions and involves site preparation, planting, tending, aggressive control of competitive vegetation and several harvest interventions. Intensive plantations are typically composed of one or more, even-aged regularly spaced tree species and often involve exotic (non-native) species or genetically selected or modified native species. It should be noted that the term intensive silviculture could apply to a wide range of diverse systems, with extremely highly managed 'tree farm' forests that might be found in Europe at the extreme end of this scale. Any intensive silviculture in Alberta is unlikely to be comparable to such a system.

In Alberta, hybrid poplar plantations on private land have been used in the past, as have large-scale conifer spacing systems for density management. However, in general, intensive management is not widely applied in Alberta, but other jurisdictions have adopted some elements as part of a zoning approach to forestry (Section 7.6).

4 Silvicultural Treatments

Silvicultural treatments are specific actions taken within silviculture systems to change or maintain a stand and ensure that the desired structure and composition is achieved. Treatments are applied at a variety of different points over the lifetime of a stand. After harvest, site preparation is often used to prepare sites for seeding or planting to maximize the success of regeneration. This often involves mechanical or chemical treatments, but prescribed fire can also be used. The regeneration phase, during which trees are re-established, may involve natural regeneration from seed or coppice growth, or treatments such as artificial seeding or planting. After the regeneration phase there is often a need to control competition from other vegetation, such as grasses, shrubs, and herbs, as well as tree species that are not desired (typically deciduous species competing with conifer regeneration). This can involve treatments such as herbicide, applied aerially or from the ground, and mechanical treatments such as manual cutting of vegetation.

While the above treatments are applied early on in the lifetime of re-growing stand, other treatments may be applied at more intermediate stages. The most common of these is thinning, which can be used to change the rate of stand development. Spacing and pre-commercial thinning involves the removal of some trees in the early stage of development, prior to the trees reaching a merchantable size, and therefore without removal of a timber product. This reduces stand density and allows the remaining trees to increase their growth rate. Pruning, where branches are removed to improve stem form, may also be applied before the trees reach a commercial size. A commercial thinning treatment can be applied at a later stage of stand development when trees are of a merchantable size. In this treatment, the trees removed can be used as a commercial product. Finally, fertilization treatments can be used at any stage in stand development, with the aim of increasing growth rates.

Specific site conditions and operational constraints must also be considered when creating a treatment plan due to site conditions, tree species, climate etc. The use of silvicultural treatments is also influenced by technological, economic, and social concerns. For example, public perception of some treatments is particularly important in shaping policy, most notably in the use of herbicides for suppressing competing vegetation (Thiffault and Roy 2011).

Table 4-1. Summary of key silvicultural treatments.

Treatment	Variants	Treatment	Notes
Site Preparation	Mixing	Mechanical treatment to mix or invert surface organic layer and mineral soil, improving nutrient availability.	All treatments aim to create the best possible environment (microsites) for seedling establishment and growth.
	Disc trenching	Exposes mineral soil in continuous strips to provide a range of planting sites.	
	Mounding / ploughing	Creates elevated planting spots in mounds or berms with exposed mineral soil.	
	Scalping	Also known as scarification. Creates patches of exposed mineral soil by removing the surface organic later.	
	Prescribed burning	Can be used to prepare sites for planting by removing organic layer, stimulating nutrient release, and controlling unwanted vegetation.	
	Herbicide	Used to control competing vegetation by reducing its abundance.	
Seeding & Planting	Planting	More costly but promotes uniform stocking and increases regeneration success rates. May sometimes be planned with assumption that some natural regeneration will also occur.	
	Artificial seeding	Seeding aerially or with ground dispersal equipment.	Variable success rates.
Pruning		Branches are removed to improve stem form. May be applied before the trees reach a commercial size.	Very rare in the boreal forest.
Competition Control	Herbicide	Used to control competing vegetation that can suppress seedling growth and survival. Most commonly glyphosate, but other herbicides occasionally used (e.g. hexazinone). Typically applied using aerial spraying but targeted (spot) application can also be used.	Most effective and economical method of controlling deciduous vegetation. Used in Alberta to improve seedling survival (e.g. by controlling competing graminoid growth).But, significant societal push-back against use, particularly aerial spraying. Banned on crown lands in some provinces
	Mechanical treatments	Manual cutting of competing vegetation using clearing saws / chainsaws (brushing). Often requires multiple treatments over several years.	
Density Control (Thinning)	Pre-commercial thinning	Removal of smaller diameter trees at an early stage of stand development (prior to trees reaching merchantable size) in order to increase growth rate of remaining trees. No commercial product obtained.	Can potentially be used to accelerate development of old growth stand characteristics (e.g. larger trees, open structure).
	Commercial thinning	Removal of merchantable trees at an intermediate stage of stand development in order to increase growth rate of remaining trees.	
Fertilization		Addition of fertilizers to address nutrient limitations and increase growth rates. Can be applied aerially or manually.	Difficult to avoid fertilization of competing vegetation and rarely used in Alberta.

4.1 Commercial Thinning

Commercial thinning is a harvest treatment used in immature stands that have reached merchantable size. It allows for some timber volume to be extracted earlier than in a traditional clearcut system where the stand would be left untouched until maturity, while also improving the growth and quality of the remaining trees. This treatment can also capture some of the volume that would be lost naturally to mortality as the stand ages, potentially increasing the overall cumulative volume of timber obtained from the stand (Gupta, Pinno, and McCready 2020). Importantly, thinning can provide additional flexibility in timber flow for forest companies, by redistributing harvest over time to make up for short-term timber supply deficits. Typically, this treatment would be applied as part of a clearcut silvicultural system but could also be applied in partial harvest selection systems where no final clearcut is planned.

From a caribou habitat perspective, this treatment has the potential to accelerate development of old-growth stand characteristics by creating a more open stand structure, which under the right conditions should favor lichen growth, while still providing some near-term timber volume. However, achieving this outcome will be dependent on many factors, including site conditions and the level of removal, and caution will be required to avoid flushes of understory vegetation favoring other ungulate species. An existing trial from Alberta that examined lichen responses to commercial thinning treatments is discussed in Section 7.2, along with opportunities to leverage future trials.

4.2 Herbicides

Successful and prompt re-forestation of harvested areas is a key part of modern forestry and herbicide treatments are a widely used and effective method for managing competing vegetation to ensure successful seedling establishment (Wagner et al. 2006). In Alberta the process of reforestation is guided by and assessed using the *Reforestation Standard of Alberta* (Alberta Agriculture and Forestry 2021). Establishment of conifer seedlings is a key stage in this process which can often be made difficult by competing species, particularly grasses. Herbicide treatments can be used to reduce this competition and allow conifer seedlings to establish and re-grow. In Alberta, around 30% of harvested areas are treated with herbicide (National Forestry Database 2021), primarily glyphosate.

Herbicides are the single most effective treatment for reducing competition in regenerating clearcuts. In the process, herbicide treatments effectively reduce elk, moose and deer winter forage availability (L Strong and Gates 2006; Mihajlovich and Blake 2004), although browse species often re-establish a few years post-treatment (Thompson and Pitt 2011). Evidence from re-analysis of trials in Alberta suggest that while herbicide treatments have long-term effects on forest canopy species composition, understory plant biodiversity was minimally affected at the time of re-measurement (20-25 years after initiation, FGrOW, *in review*).

"The short story is we changed the composition of the tree layer but we didn't have a lot of effect on the herbaceous species."

Reducing browse availability for other ungulate species is a key aim for any silvicultural system or treatment that aims to minimize negative impacts on caribou. To that end, herbicide treatments may have an important role to play in achieving this and multiple subject matter experts identified this potential tool, particularly with multiple treatments to suppress browse species for a longer period of time, albeit with caveats.

"A single herbicide treatment is, biologically, a nudge to the ecosystem towards conifer and away from deciduous and herbaceous. That nudge only holds for 1-3 growing seasons, depending on the species targeted and climatic conditions prior to and subsequent to herbicide use. A single treatment isn't likely to shift that habitat dramatically. It will only moderately change that species composition. If we want to keep browse out, and glyphosate is now our best option for a variety of reasons, we're going to have to think about more than one treatment."

"You can apply aerially, or at different times of the year, different chemicals, different rates, and you will get a different outcome. With caribou, you're looking at coniferous forest, so that's about managing deciduous, and we know a lot about that in Alberta. That's a tool."

"We need to think multidimensionally and I would be very cautious about going into caribou habitat and blanket applying herbicide to every cutblock."

"I'm not averse to herbicide use, but I know a lot of folks are. I'm averse to its use across northern Alberta, I think its use should be limited to certain situations."

While most harvested areas in Alberta that are treated with herbicides receive only one application, the suggestion is that multiple applications would be needed to continually suppress browse vegetation in order to minimize forage availability for moose, elk, and deer. This would involve additional costs, but perhaps more importantly could be undesirable due to increasing societal pressure against the widespread use of herbicides in forestry, particularly via aerial spraying (e.g. bans in some jurisdictions Thiffault and Roy 2011), opposition to herbicide use in forestry amongst many First Nations (e.g. Kayahara and Armstrong 2015). Some certification systems also encourage the reduction or elimination of herbicide use (e.g. Forest Stewardship Council). As such, herbicides should be considered as one tool in a diverse toolbox that could be used in to reduce browse availability.

4.3 Site Preparation

Site preparation commonly refers to the mechanical modification of the soils in preparation for planting of seedlings. It is most often used in a clearcut system but can also be used in other partial harvest systems. While the act of site preparation is designed to create better planting sites, more disruptive site preparation techniques such as ripping could also be considered a treatment to deter movement through the area. This could slow the movement of predators and cause them to avoid the sites.

"Another example is mechanical site preparation, which could have a tremendous place for managing caribou. We can take out the browse with herbicides and then impede predator access and line of site using things like rippers, which make moving across an opening difficult, especially

if you don't rip all in one direction. That makes the habitat more favorable for caribou and less favorable for predators."

4.4 Stocking Density

Manipulating stocking density is another treatment that could be a useful additional measure in areas where an alternative silvicultural system is not appropriate, to mitigate the impact of a clearcutting system. In order to reduce the desirability of an area post-harvest and the period of time that increased browse is available, stocking densities could be increased to regenerate a dense stand that shades out understory species more quickly.

"The other general statement to make would be to get a dense canopy of trees above the browse line as quickly as possible. Whether that's spruce or balsam fir, or even aspen. Dense canopies wipe out a lot of the understory. High density establishment and keeping something from eating it at the early stages gets you to this dense phase fast."

4.5 Artificial Seeding

Artificial regeneration can be achieved through direct seeding, which may be carried out aerially or from the ground (OMNRF 2015). Typically this would involve light site preparation followed by aerial seeding and it is most effective in the absence of competing vegetation. It is a low-cost treatment that can produce high-density stands, which could be beneficial for minimizing browse species growth, but growth rates are often lower than in planted stands and successful regeneration is less consistent. This treatment has been used for many species in Ontario but is less commonly applied in Alberta.

5 Silviculture – what we heard

All silvicultural experts interviewed believed there were opportunities to diversify silvicultural systems and harvesting techniques in Alberta, for a variety of different purposes. Many ideas were discussed that might be preferable to the current status quo from the perspective of improving outcomes for caribou. These ideas are discussed with relevant case studies in Section 7 and throughout the report. Topics include alternative silvicultural systems such as shelterwood and understory protection in mixedwood stands and various forms of partial harvest / retention forestry in coniferous stands as well as treatments such as density management (thinning), herbicides, other vegetation control techniques, and site preparation. The potential for intensive silviculture and a zonation system to increase timber yields in more productive, less ecologically sensitive areas, while reducing pressure in caribou ranges, was also discussed. However, barriers to implementation for alternative systems were also identified.

5.1 Management Objectives

One barrier identified was a lack of clearly defined management objectives and higher-level direction when it comes to managing forestry and caribou habitat. Many felt that there were appropriate tools in the silviculture toolbox that could be applied if we had clearly identified objectives. In addition, there was a sense that if it were understood exactly what stand structures and types would be a preferred outcome for caribou, there were likely to be silvicultural means to achieve that outcome.

> *"If we know what the management objectives are… then we can use silviculture tools to get there in a variety of ways."*

> *"Tell me the habitat you want to create, and we'll get you there."*

> *"A skilled silviculturist should be able use his/her skills to produce stands with a range of stand structures. The issue is that we need to know what type of stand we need in what location on the landscape to benefit caribou."*

> *"We need to be having this conversation among professionals on what that objective is and making that objective bigger, and more robust and multidimensional."*

Other non-silviculture experts also agreed that there was a need to clearly define target stand conditions, trees, and understory.

> *"What's the target? What do we want the forest and the understory to look like down the line, in a decade?"*

5.2 Target Stand Conditions

This discussion around identifying objectives also directly related to a knowledge gap around the identification of target stand conditions for maintaining caribou habitat and minimizing apparent competition and the expectation that the ideal conditions would vary greatly depending on climate, site productivity and location. On alternative systems, while there was acknowledgement of important data and trials in other provinces, particularly British Columbia and Quebec, it was highlighted that there would need to be caution in applying those techniques in different Alberta ecosystems, to make sure that the desired management objectives were achieved.

> *"If you're doing partial harvest, you're going to have to be very knowledgeable about the forest condition in the site that will get you to caribou habitat with partial harvest."*

> *"Equivalent forests out east tend to have poorer soils, so they don't get the same flush of vegetation we get. There's lots of examples from Quebec of partial harvesting systems in the boreal that would be applicable, but they're different environmental conditions. We should be trying some of that here to see what the threshold is or what the stand types are to do some of this."*

> *"We want to start implementing more complex systems, but we have not done the work to get there. That being said, there's been lots of studies and trials and it's happening operationally in other places, so there's no reason we can't learn from it. But there are differences in Alberta too and our soils are the big one."*

> *"I think it would be very useful to establish some good, solid, replicated studies on terrestrial lichen and look at their response to harvesting and silviculture."*

> *"If we had the right picture in our mind, I wonder if the means to achieve that would be first through the lens of ecosite and ecosite phase, and then the prescriptions for harvesting. But, starting first with what is achievable for this ecosite."*

However, it was also highlighted that we do know enough to act now, and that a lack of perfect knowledge should not prevent action.

> *"I think the knowledge is there. There are some things we need to learn but we can work on those in parallel as we try to work together to implement strategies for a caribou forest… There are some gaps to fill, but you can't ever wait for perfect knowledge."*

> *"My thinking is we're better off trying something and learning from it than not trying anything and not learning anything."*

It was also pointed out that any new systems or techniques that are implemented should have associated controls and quantitative monitoring, to ensure that outcomes are as expected, or if not, that systems can be adjusted to address unexpected results. However, others pointed to prohibitive levels of monitoring being a disincentive to trying new systems.

> *"It also points out that whatever you conclude you want to do, leave out some control [areas] and put in some good quantitative monitoring. At the end of the day, you want to be able to look back and see what effect you had."*

> *"The capability is there. Then after trying it, monitor the outcome to see what happens."*

> *"One of the rules in Alberta is if you do anything besides clearcut there's a huge monitoring component... How do you incorporate these things without it being prohibitive in the amount of extra work it requires?"*

5.3 Cross-Discipline Collaboration

It was clear to us from the interviews with subject-matter experts that there was often relatively little cross-over between the two disciplines of wildlife biology and silviculture. Several interviewees identified an opportunity for closer collaboration between the disciplines to work toward improving outcomes for caribou. One specific example given was a potential opportunity to use caribou occurrence data to visit and document sites that are heavily used by caribou and work with silvicultural experts to understand what prescriptions might maintain or promote such habitat. Opportunities to incorporate understory vegetation and/or wildlife monitoring into planned forestry trials were also highlighted (See Section 10).

> *"From my perspective, it's an interesting discussion because in other parts of North America, wildlife and forestry are more intimately linked. Here we tend to deal with things separately and maybe they should be more integrated."*

> *"I think that conversation is at the interface of objective setting and implementation. I think the biggest part of this is we need ecosystem management professionals to sit together and talk these things through. To date, the way we've done it in forestry is we make a plan, and the biologists constrain us, and the next time we make a plan we anticipate these constraints and try to address them but we're not really having that conversation on objective setting."*

> *"If we had the right photos (and description) of the stand conditions we would like to achieve maybe forestry experts could work with that…"*

5.4 Legislation and Culture

Several subject-matter experts identified existing reforestation obligations and standards for forestry companies as being barriers to the implementation of alternative silvicultural systems. A lack of flexibility in the system was also identified as a barrier to trying new techniques. Related to this, some also felt that there was a culture of risk aversion when it comes to doing things differently in Alberta forestry, particularly given a risk of regeneration failure being seen as unacceptable. In some cases, these comments related to forestry in Alberta in a general sense, while others were to do with constraints on specific systems (e.g. understory protection, intensive silviculture).

> *"We tend to have fixed ideas about how we should do silviculture in Alberta, but there's so much more we could be doing, so this may be an opportunity to think about some of the possibilities and not just the current realities."*

> *"We need to define success as encompassing things beyond the trees. I see that as a hard transition for everyone."*

> *"The current reforestation guidelines and obligations for companies and the standards they are held to are not considering caribou at all."*

> *"We need to have flexibility to apply the appropriate tools to come to those 3-dimensional outcomes we're talking about."*

“A big one is the policy constraint around estimating the response and the growth & yield implications of the treatments. That’s one of the problems that’s prevented it from going too widescale.”

“Overall, I think the planning standards have a lot of barriers. As well as the belief that intensive management does not improve the yields.”

“The standards are still not fully developed or accepted for understory protection. It’s a bit of challenge without that.

6 Caribou – what we heard

Subject-matter experts consistently identified apparent competition as an important driver of caribou declines and key focus for any attempt to use alternative silvicultural systems to improve outcomes for caribou. This also included discussion about other ungulate habitat preferences and limitations, as well as the importance of the location of upland disturbances relative to lowland caribou habitat in the boreal forest.

> *"From a management perspective, focus on reducing predation and apparent competition."*

> *"Overall, based on available evidence, I'm convinced that the apparent competition paradigm is still the main event."*

> *"But in the uplands, almost any form of disturbance generally has abundant and high-quality winter browse. A limitation of winter browse can be a big deal for ungulates, with nutritional deficits and deep snows […] The uplands eventually have to be adjacent to the peatlands where the caribou are. Even if we think of the peatlands being the caribou habitat, the larger landscape is a contributing factor."*

While the impacts of predation via apparent competition are for many the most important focus in addressing caribou declines, it was also recognized that it is crucial to avoid the loss of high-quality caribou habitat itself, particularly in areas with a heavier disturbance footprint.

> *"[…] In some situations in the province, and increasingly so, I would suggest that the conversion of caribou habitats to industrial landscapes, particularly forest harvesting activities when it's both intensive and extensive, we're not leaving a place for the animals to be."*

> *"The flip side is if you have a higher amount of quality forage you could presumably have healthier caribou. Body condition, reproductive rates could be slightly higher. It may not offset all the wolf problems but habitat quality is also the engine of recovery, if you remove the wolves in the first place."*

The options for using partial harvest systems were explored in detail and there were mixed opinions on if they could be used successfully. Some identified the lack of information on caribou responses to partial harvest as an unknown and a risk. Others highlighted the increased road network required for access in such systems as a major problem (discussed in more detail in Section 8.2).

> *"Partial harvest could be used to retain usage that's currently occurring, or for setting up stands in the future. There are some risks with partial harvest but they're unclear to us now."*

> *"Thinking about the Mount Tom situation, if we didn't have modified harvesting which the caribou seem to be using, and it was all clearcut, there wouldn't be caribou there at all. Full stop."*

"In my view, I would not strongly recommend partial harvesting for caribou. Or too much partial harvesting. The main reason is that with partial harvesting comes a very extensive road network, and that's the major problem. I don't think having a fairly open conifer stand is a big problem but having a bunch of roads coming in is."

Another element of the discussions involved the potential to identify target stand conditions that could then be worked toward with silvicultural experts. In some cases, this might involve a focus on reducing apparent competition, while in others the focus might be more on maintaining or regenerating high quality caribou habitat. Alternative systems or treatments might vary considerable depending in the relative importance of these targets in any particular stand type. One example given was the possibility of regenerating stands that might support high terrestrial lichen abundance in a way that enables suitable ground conditions for regeneration, which would not currently be acceptable under regeneration standards.

"In terms of poor for other species, basically moose and deer, and elk out west. And beavers. What would those stands be? I think they would be conifer stands, densely stocked, with relatively little understory in terms of grasses, herbaceous vegetation, and palatable deciduous or evergreen shrubs."

"But if our point is to maximize volume everywhere, I expect those terrestrial lichen stands won't happen. I'll show you guys a picture. That's in Chinchaga, and for Alberta that's an awesome Cladina patch. That's in an upland black spruce stand, those trees are probably pretty old. That wouldn't be a commercial stand. But if harvest was on that ecosite, we should be trying to enable what's there now to come back. So doing so would not be planting at current stocking rates, because those lichens won't come back if tree survival is high."

"The current standards wouldn't enable the ground conditions for lichen to be regenerated."

7 Case Studies

In this section we present a number of relevant case studies from Alberta and across Canada (Table 7-1), involving different silvicultural systems and harvesting techniques[2]. Some are directly focused on how to use alternative silvicultural systems to promote caribou habitat or minimize apparent competition, while others are primarily focused on other aspects of forestry but still have relevance to these questions.

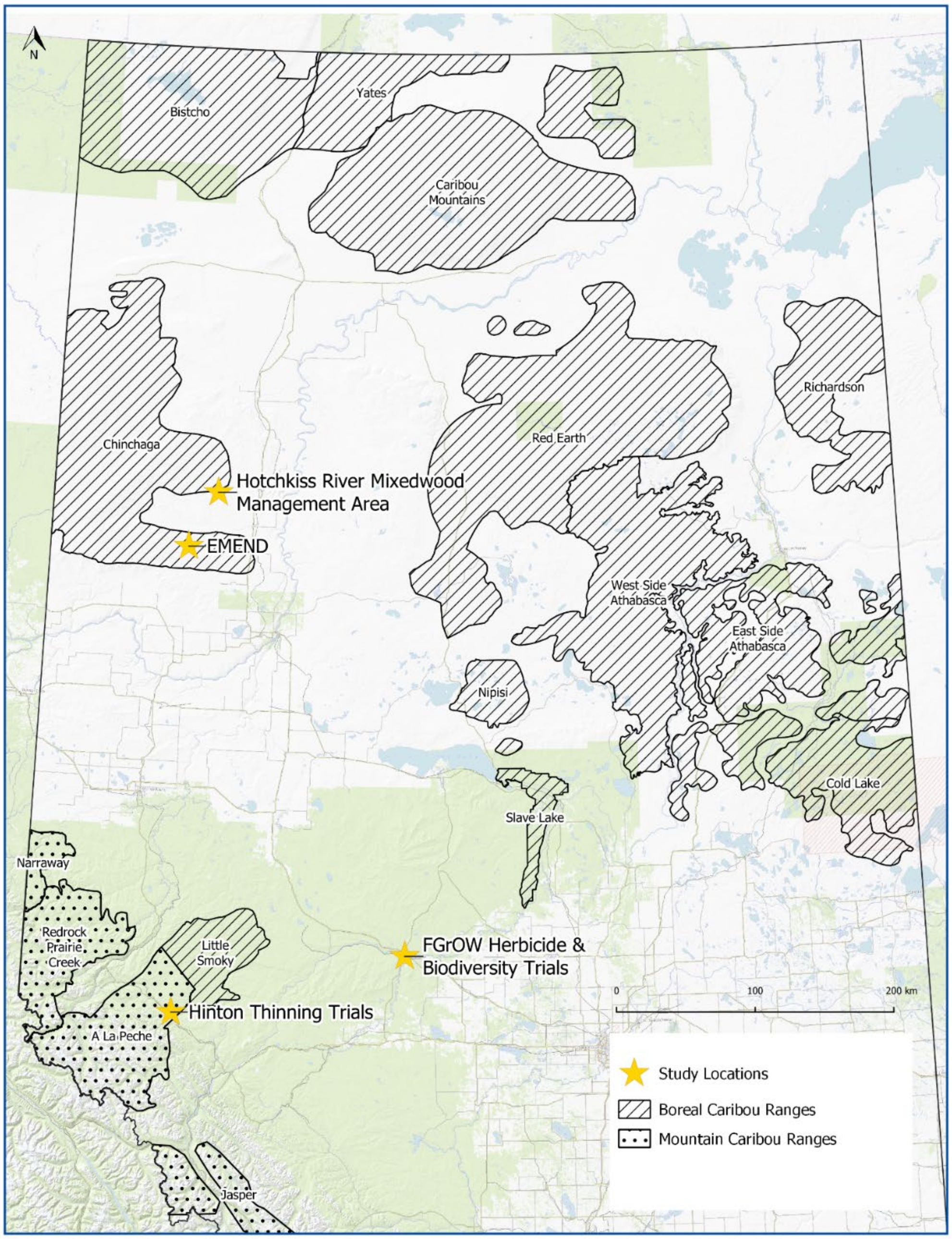

Figure 4. Locations of selected silviculture trials in Alberta.

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[2] Note: fRI Research have a major study on using cutblock design and harvesting treatments to benefit woodland caribou, that was not available for review at the time of this report.

Table 7-1. Summary of case studies described in this report and their key characteristics.

Case Study	Alternative System(s)	Location	Forest Type(s)	Scale	Study Focus	Measurement(s)	Takeaway(s)
EMEND (Section 7.1)	Variable retention (aggregated & clump)	Northwest Alberta	Coniferous, Mixedwood, and Deciduous.	Extensive replicated long-term trial	Overstory and understory vegetation. Also, caribou and other ungulate use.	Understory response (vascular plants, lichen, bryophytes, graminoids), wildlife response (including caribou, moose, and deer via camera traps / pellet transects), soil, productivity.	Caribou didn't use stands with <20% retention, use increased with level of retention. Moose / deer showed no response. Higher retention resulted in less understory cover with evidence for a threshold between 10-20% retention. Understory response differences absent 17 years post-harvest though composition altered. Opportunity to use data to examine understory response in context of moose / deer habitat quality.
Commercial Thinning in West-Central Alberta (Section 7.2)	Single-tree selection via commercial thinning	West-central Alberta	Coniferous (lodgepole pine dominant)	Local trial	Terrestrial lichen abundance and understory vegetation.	Lichen and bryophyte abundance, vascular plants.	Commercial thinning treatments maintained (but did not increase) terrestrial lichen abundance. Understory vascular plant abundance similar to controls in this system.
Hotchkiss River Mixedwood Management Demonstration Area (Section 7.3.2)	Understory Protection	Northwest Alberta	Mixedwood	Long-term replicated trial	Understory protection techniques, including minimizing wind damage and encouraging regeneration.	Understory spruce response, windthrow risk, regeneration.	Data may be useful to investigate how understory protection could be used to minimize understory response in mixedwood stands in or near to caribou ranges.
Itcha-Ilgachuz (Section 7.4.1)	Group selection, variable retention, irregular group shelterwood	West-central British Columbia	Coniferous (lodgepole pine dominant)	Replicated long-term trial	Forage lichens.	Lichen response, windthrow risk, regeneration.	Arboreal lichen maintained with 30% group selection system and terrestrial lichens maintained with 50% shelterwood system. Rate of lichen recovery varied by treatment. Minimal understory vegetation response in this system.
Quesnel Highland (Section 7.4.2)	Group selection	East-central British Columbia	Coniferous (Engelmann spruce & subalpine fir dominant)	Replicated long-term trial	Arboreal lichen.	Arboreal lichen response to harvest.	Arboreal lichen maintained sufficiently at 30% retention.

Case Study	Alternative System(s)	Location	Forest Type(s)	Scale	Study Focus	Measurement(s)	Takeaway(s)
Mount Tom (Section 7.4.3)	Group and single tree selection	East-central British Columbia	Coniferous (Engelmann spruce & subalpine fir dominant)	Replicated ongoing trial	Habitat attributes, caribou use, alternative prey & predator use.	Lichen response, wildlife response (caribou, mule deer, moose), understory vegetation.	Arboreal lichen maintained in residual forest. Caribou avoiding group selection blocks while use by moose has increased.
Northeastern Quebec (Section 7.5.1)	Diameter-limit cutting (CPPTM), single tree selection	Northeastern Quebec	Coniferous (black spruce dominant)	Small-scale trial	Habitat attributes, wildlife use (did not include caribou).	Old growth forest attributes, tree mortality, wildlife response (did not include caribou).	CPPTM negatively impacted closed-habitat wildlife species. Selection cutting with 65% retention recommended to preserve old-growth forest attributes.
North Shore (Section 7.5.2)	Aggregated diameter-limit cutting	Northeastern Quebec	Mixedwood (balsam fir, white spruce, black spruce, birch)	50,800 ha trial area	Aggregation and caribou use.	Caribou occurrence, vegetation surveys.	Couldn't determine a preference between harvest techniques. Caribou avoided cutblocks and adjacent protected areas. Patches 55-182 km^2 too small to maintain populations long-term. Larger protected areas & better connectivity recommended.
Western Quebec (Section 7.5.3)	Partial harvest systems	Western Quebec	Coniferous (black spruce dominant)	Small-scale trial	Terrestrial lichen response to partial harvest.	Terrestrial lichen abundance, lichen transplants	Partial harvest maintained higher abundance of terrestrial lichens than clearcutting. Understory response in more determined by soil disturbance than the level of overstory removal.
Gaspé Peninsula (Section 7.5.4)	Gaspé Peninsula, Quebec	Diameter-limit cutting, seed tree, commercial thinning, single tree and group selection, shelterwood.	Mixedwood (balsam fir, white spruce, black spruce, white birch, yellow birch)	Large-scale retrospective analysis.	Arboreal lichen response to alternative silvicultural systems. Caribou habitat attributes and understory response.	Arboreal lichen abundance, Overstory and understory response (number of sapling and fruit-bearing shrubs, vegetation cover, lichen).	Commercial thinning (67-70% retention) and shelterwood (50-70% retention) maintained some suitable caribou habitat characteristics and minimized understory response; selection and partial harvest treatments with 60-75% retention intermediate. CPRS (clearcut), diameter-limit cutting, and seed tree removed most arboreal lichens and favored predators.

7.1 Retention Harvesting (EMEND) - Alberta

The EMEND (Ecosystem-based Management Emulating Natural Disturbance) forest management project is a large-scale and long-term experiment testing how different forest harvesting management strategies can be used to emulate natural disturbances to maintain ecological function and biodiversity. The study site is located within the Chinchaga range and covers a 7,000 ha area with over 1,000 ha of harvested and burned patches (Figure 4). See CFS (2020) for a broad overview of the project.

Location: Northwest Alberta.

Forest Type: Coniferous, Mixedwood, and Deciduous.

Alternative system(s): Variable retention (aggregated & clump).

Scale: Extensive replicated long-term trial.

Study focus: Overstory and understory vegetation. Also, caribou / other ungulate use.

Measurement(s): Understory response (vascular plants, lichen, bryophytes, graminoids), wildlife response (including caribou, moose, and deer via camera traps / pellet transects), soil, productivity.

Takeaway(s): Caribou did not use stands with <20% retention and use increased with level of retention. Moose and deer showed no response to harvest levels. Higher retention resulted in less understory cover with evidence for a response threshold between 10-20% retention. Differences in understory response absent by 17 years post-harvest though composition remained altered. Opportunity to use data for examining understory response in context moose and deer habitat quality.

Retention forestry, sometimes known as variable retention or green-tree retention, is widely implemented worldwide, including in Canadian forestry operations, to emulate natural disturbance patterns and maintain structural and functional elements of the pre-harvest forest (Gustafsson et al. 2012; Work et al. 2003). Most harvest operations in Alberta leave less than 10% retention, but the EMEND project includes a wide range of higher retention levels. Levels being investigated include 10%, 20%, 50%, and 75% retention, in patches (aggregated retention) or individual trees / small clumps (dispersed retention). Clearcuts (2% retention) and uncut controls are also used for comparison, as well as a prescribed ground fire treatment.

The EMEND project is primarily focused on understanding the relationship between retention levels and the maintenance of ecosystem function and biodiversity, for a wide range of taxa e.g. (Harrison, Schmiegelow, and Naidoo 2005; Lazaruk et al. 2005; Work et al. 2010), as well as on forest productivity, silviculture and soils e.g. (Kishchuk et al. 2014; Solarik et al. 2012). However, the project has particular relevance for understanding the impacts of different partial harvest levels on apparent competition and on caribou habitat use. The large scale of the trial makes it possible to assess changes in habitat use by caribou and other ungulates to some extent and importantly the trial also has long-term high-quality replicated data on understory response.

Harvest treatments were applied to 10 ha compartments and replicated three times over four different stand types; canopy >70% deciduous (deciduous dominated), canopy >70% deciduous with white spruce understory (developing conifer understory), mixed stands with 40-60% spruce and aspen canopy (mixedwood), and canopy >70% spruce (conifer dominated). Six Permanent Sampling Plots (PSPs) were established per compartment. See https://emend.ualberta.ca/ for further details. Harvesting treatments were conducted during the winter of 1998/99 using 5-m wide machine corridors with 15-m wide retention strips between, orientated north-south. The 10%, 20%, and 50% retention levels were achieved by tree removal from the retention strips by reaching with a feller buncher from the machine corridor. The 75% retention treatment included the machine corridors only (Figure 5).

Ungulate use of the different treatments has been directly investigated in conifer dominated sites using remote cameras and scat/pellet transects. There were 102 woodland caribou detections over approximately three years of monitoring (15-18 years post-harvest) and none of those detections were in stands with less than 20% retention. The number of detections also increased at higher retention levels (Franklin, Macdonald, and Nielsen 2019). However, moose and deer showed no response to harvest level, perhaps due to the conflicting benefits of higher browse availability in disturbed areas vs. thermal protection and easy of movement in retention areas.

While remote cameras can only provide a limited snapshot of caribou and other ungulate populations and their larger-scale responses to partial harvest, the EMEND project has highly detailed understory vegetation data, which provides an additional avenue to understanding how the treatments may impact moose and deer populations (and therefore influence apparent competition).

In mixedwood stands 8 years post-harvest the retention level effected understory cover and community composition. Higher retention levels resulted in less understory cover, especially of graminoids, and there was evidence for a threshold between 10% and 20% retention for understory cover. In terms of community composition, the lowest 10% retention level was similar to clearcut treatments, while higher levels of retention allowed community composition to remain in a similar state to the unharvested controls (Craig and Macdonald 2009).

More recently, Bartels and Macdonald (2021) have investigated understory vascular responses in all four stand types at 3, 6, 11, and 17 years post- harvest. Vascular plant cover, richness and diversity tended to increase in the first 3 years, peak between 6 and 11 years and plateau or decline by 17 years. The lower retention treatments (10% and 20%) and clearcut had greater total cover than higher retention treatments in all forest types except for in the mixed stands, where there was no difference between treatments (although unharvested control was ~50% lower cover than treatments). Increased retention therefore generally reduced the amount of understory vascular plant growth, but this effect disappeared by 17 years post-harvest. However, species composition changes were still clear at 17 years post-harvest. Interestingly, unharvested controls in both deciduous and conifer dominated stands had increased understory abundance over time, likely due to mortality of canopy trees. However, understory abundance in control deciduous dominated stands with a spruce understory did not change over time, likely due to the shading effect of understory white spruce. Deciduous dominated treatments showed increased understory abundance, which then declined toward the end of the study, ending with a lower understory abundance than the controls. The authors identify the rapid vegetative regeneration of aspen reducing light to the understory as the likely reason. Conifer dominated treatments also showed increased understory abundance followed by decline, but treatments and controls were similar by 17 years.

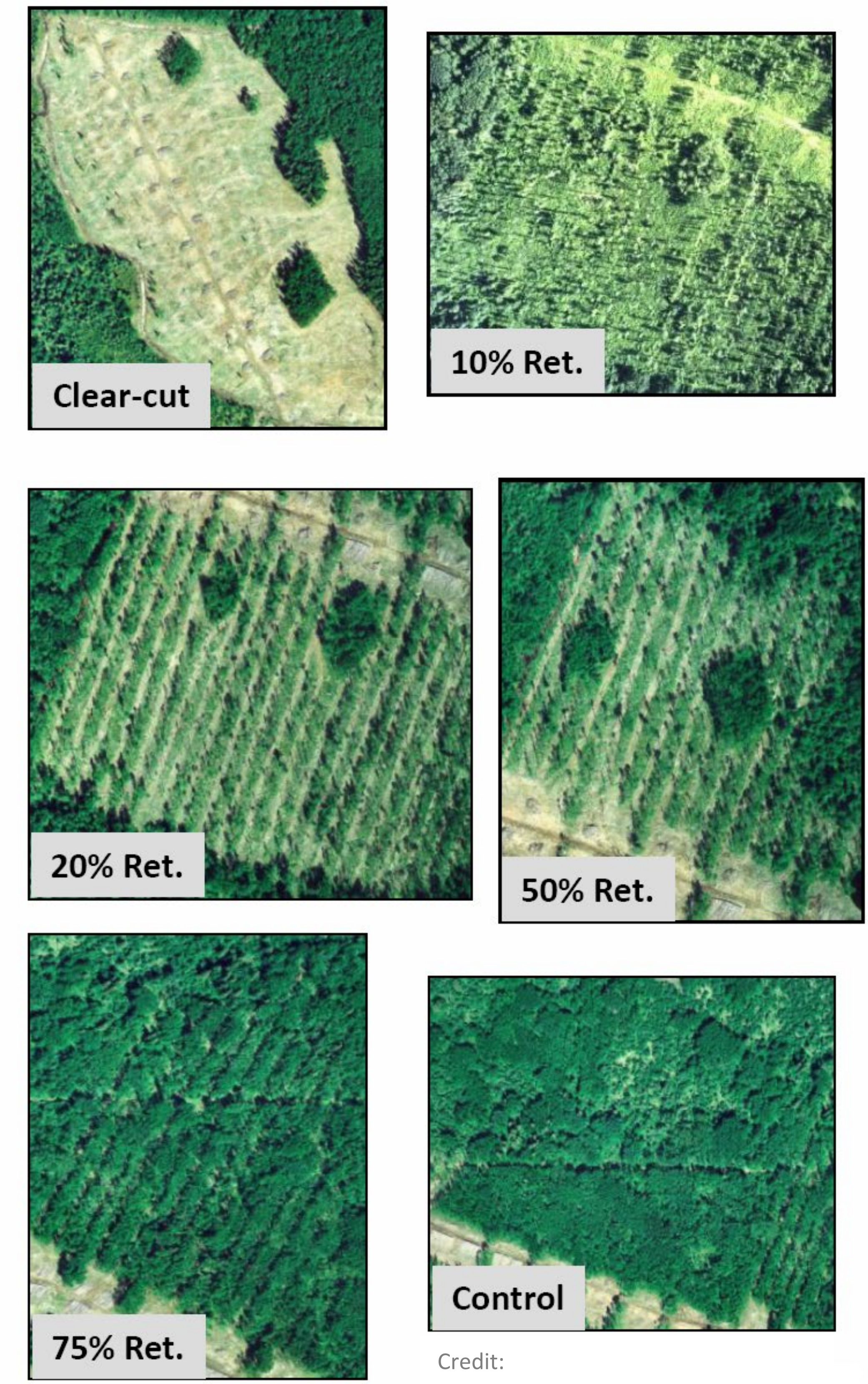

Figure 5. Clearcut, variable retention and control compartments at the EMEND project.

7.1.1 Lessons & Opportunities

The EMEND project has already provided some insights into the relationship between caribou and variable retention levels, with caribou using treatment areas post-harvest only if 20% retention or more. Understory vegetation data also suggests that higher levels of retention reduce the abundance of vascular plants in the understory relative to clearcut or lower levels of retention, which should reduce desirability of those areas for moose and deer. However, population-level responses of caribou and other ungulates are unknown and vegetation trajectories are variable and dependent on stand type.

The scale, long time period and intensive data collection of the EMEND project provides opportunities to better understand the impact of partial harvest systems in mixedwood forests. The large amount of vegetation data particularly could be used to better understand how different treatments could be used to minimize post-harvest desirability of harvest areas to moose and deer. For example, it may be possible to narrow down the range of retention levels that would maintain the understory in a state similar to the unharvested controls and thereby avoid a 'flush' of early seral stage vegetation that is beneficial to moose and deer.

"There's a lot of vegetation data on how those forests changed, and it could be interpreted in terms of how that would be suitable for moose and deer and how it would impact moose and deer populations in the apparent competition context."

Post-harvest terrestrial lichen cover was also measured for up to 10 years post-harvest, but this data has not yet been analyzed. This additional dataset could be used in combination with vascular plant data in a caribou-focused analysis.

"We have amazing datasets and we haven't fully exploited that."

Table 7-2. Ecosystem of the EMEND research site.

Natural Subregion	Subzone	Elevation (m)	Location & Topography	Climate	Tree Species	Ground Vegetation
Boreal mixedwood plains		677 – 880	Clear Hills Upland	(mean annual precipitation = ~386mm, mean annual temperature ranges from -7.8 °C in winter to 12.8 °C in summer).	Dominated by trembling aspen, white spruce, and balsam poplar. Prior to study composed of mature / old (90-120 years old) stands.	Low bush cranberry, green alder, prickly rose, Canadian bunchberry, white violet, twin flower and bluejoint grass common.

7.2 Commercial Thinning – Alberta

Vitt et al. (2019) examined terrestrial lichen abundance in nine stands at three different sites in West-Central Alberta, 19 years after commercial thinning treatments were carried out. Sites were of natural origin, approximately 100 years old, dominated by lodgepole pine, and had at least 30% cover of bryophytes and lichens. Three different thinning treatments (20%, 40%, 60% removal) and a control area (0% removal) were delineated for each stand (approximately 10 ha for each treatment). Operators using single grip processors and forwarders aimed to remove a range of stem sizes and achieve a relatively even tree spacing. However, the removals were highly variable in practice and canopy cover when measured in 2016 was no different between treatments. Therefore, comparisons were limited to between controls and 'treated'.

Feather mosses dominated in control plots and decreased in treatment plots, while terrestrial lichens were more abundant in treatment plots and generally increased with reduced canopy cover. However, overall lichen abundance increased only marginally (8.2% on average) in treatments relative to controls. Lichens therefore had minimal response to more open canopies resulting from the thinning treatments but were also not negatively affected as would be the case with a clearcut system. Understory vascular plant abundance was similar between treatment and control plots. This suggests that commercial thinning may provide an opportunity to harvest timber in caribou habitat without negatively affecting lichen abundance or increasing understory browse species abundance. However, it is important to note that although lichen response was measured, wildlife response was not, and it is unclear if caribou will continue to use thinned sites.

Location: West-central Alberta.

Forest Type: Coniferous (lodgepole pine dominant).

Alternative system(s): Single-tree selection via commercial thinning.

Scale: Local trial.

Study focus: Terrestrial lichen abundance and understory vegetation.

Measurement(s): Lichen and bryophyte abundance, vascular plants.

Takeaway(s): Commercial thinning treatments maintained (but did not increase) terrestrial lichen abundance. Understory vascular plant abundance was similar to controls in this system.

"I think we need to know the wildlife response before we start saying this is a good response or not."

It is also the case that the outcomes of commercial thinning treatments are highly dependent on site conditions, stand maturity and on the level of removal, and so a fulsome understanding of the dynamics of the system is important in achieving successful outcomes.

"Depending on where you are, the response of other vegetation to partial harvest is going to vary considerably [..]. Another challenge is the age of the stand you're doing the partial harvest on. If the stand is moving towards maturity, and I'm using an index of maturity that's not the chronological age of the stand but the depth of the live crown, if the live crown is less than 50% of the total height of the stand, that stand isn't going to suppress other vegetation bursting forth after the partial harvest. You take those trees out and it results in a burst of shrubs […] On the flip

side, Hinton did some commercial thinning and it has maintained beautiful caribou habitat. There were a couple reasons for that. The sites were drier, and the pine was physiologically younger."

7.2.1 Variants

A single-tree selection system can be used to carry out commercial thinning and is usually applied in more complex forests, while in even-aged forests a row thinning system can be more practical.

7.2.2 Lessons & Opportunities

There is considerable interest in commercial thinning in Alberta, primarily because of the benefits in adding flexibility to wood supply and producing larger diameter timber in a reduced time frame. The Forest Growth Organization of Western Canada (FGrOW) is currently looking into establishing a major commercial thinning trial with a network of research plots in both pine and spruce stands. There could be an opportunity to also add a larger-scale investigation of commercial thinning's impact on caribou habitat to this project (see Section 10).

"… you could certainly put a study over top of it and add a treatment. From a science standpoint, it's perfect for a partnership, but right now it's only looking at growth and yield and inventory operationally."

"Right now, FGrOW is working to develop some pine and spruce thinning prescriptions, looking at intermediate age harvest. This is an opportunity for foresters and biologists to start having that conversation about joint objectives. About managing that piece of forest for more values than just the trees."

Figure 6. Aerial view of commercial thinning treatments near Whitecourt, AB.

7.3 Understory Protection – Alberta

Mixedwood stands are common in Alberta's boreal forest and often consist of aspen stands with a white spruce understory. For example, approximately half of pure deciduous stands identified in Alberta-Pacific's FMA have a white spruce understory (Grover, Bokalo, and Greenway 2014), although most are unsuitable for understory protection. In the natural forest cycle, deciduous species re-grow post-fire via suckering to dominate the stand, while coniferous species grow in the understory from seed. Eventually the deciduous overstory will start to decline and die, allowing the shade-tolerant conifers to accelerate their growth in response to increased light exposure, transitioning the stand to conifer-dominated (Chen and Popadiouk 2002).

If aspen stands with a white spruce understory are harvested using traditional clearcut methods to extract the aspen, the white spruce understory is lost. When the aspen is ready for harvest the white spruce is not yet merchantable. Understory protection (see Section 3.4) is a silvicultural system that aims to harvest the majority of the aspen overstory while protecting the white spruce understory. Some aspen is typically left as wind buffers. This system allows the harvest of the aspen at the optimal time, while maintaining the established white spruce. The white spruce is then released and accelerates in growth rate and can be harvested at a later time by clearcutting or with a partial harvest. This system maximizes stand yield and accelerates white spruce growth, without any need for site preparation or planting (Grover et al. 2014). In a managed system it might be 60-70 years from stand origin to removal of aspen and another 50-60 years after that before spruce removal.

The interaction between the understory protection system and caribou is not well understood. While stands that might receive this treatment are not caribou habitat, what happens in these stands can have a major impact on caribou populations through apparent competition if they are nearby to caribou habitat. If an aspen stand with a white spruce understory is clearcut harvested, there is likely to be a flush of early seral stage vegetation which benefits moose and deer, and therefore predators such as wolves. However, if instead the understory protection system is used, then the remaining white spruce understory may prevent significant re-growth of aspen (and other vegetation) if it is well developed. While the resulting white spruce stand will eventually be clearcut harvested and the post-harvest aspen suckering will benefit moose and deer, this is delayed under the understory protection system for many decades. It is generally assumed that clearcutting will be used on the resulting white spruce stands, but potentially partial harvest systems could also be used at this stage to reduce apparent competition.

The response of understory vegetation to removal of the aspen overstory will be highly dependent on the status of the understory. The exact method used for harvesting (e.g. the machine trail width and compaction) will also have an impact.

> *"If you have a well-established spruce understory, it provides suppression of aspen suckering and shrubs and grasses. On an average site, in the extraction trails there's still going to be a fair bit of shrub and grass establishment. I've noticed the moose tend to use those sites heavily…"*

> *"If the spruce are sparse and small you get a pretty substantial response. There are roughly 6 m wide machine trails where the skidder and the feller buncher are travelling up and down, a 6 m*

wide clearcut. Then 6 or 7 m on either side of that trail where the aspen are removed. You end up with a 20 m wide strip where the aspen has been removed with 6 m in the center where all the trees have been removed. If the spruce is 5 m tall or so and dense outside the extraction trail, then you get a lot of shade and it can suppress vegetation both in and outside of the extraction trail. If it's small and open, you get less of an effect of suppression. It's variable from place to place."

Although understory protection has been implemented in Alberta for over a decade, there is little research examining its effects on ungulates. Analysis of avian community response to understory protection (<=12 years after harvest) suggests that in stands harvested with this system the avian community is on a faster trajectory toward pre-harvest conditions than in clearcut with retention stands. This suggests that avian species associated with more mature forests can utilize habitat in areas harvested using understory protection relatively quickly (Charchuk and Bayne 2018). Because the system maintains more characteristics of a mature forest it may be less preferred by moose and deer than clearcuts. There may also be adjustments to the understory protection harvesting system that could be used in stands within and close to caribou range to help reduce apparent competition. However, a better understanding of vegetation responses after aspen removal over a range of site conditions is needed.

7.3.1 Understory Planting

Underplanting deciduous dominated mixedwood stands may be a useful technique for longer term browse control in and around caribou habitat. Where a well-developed natural understory is not present, underplanting could be used to create a suitable white spruce understory that would help to prevent browse species growth. Man and Lieffers (2011) found that for underplanting white spruce in aspen dominated stands a combination of site preparation and planting improved white spruce seedling establishment and growth over seedlings planted under control conditions in cutblocks.

7.3.2 Hotchkiss River Mixedwood Management Demonstration Area

Understory protection trials have been established in a number of locations in Alberta, but one important long-term study on the effectiveness of various harvest systems for protecting white spruce understories is located in the Hotchkiss River Mixedwood Management Demonstration Area. The project was initiated in 1992 and is a partnership between the Canadian Forest Service, Daishowa-Marubeni International Ltd. (now Mercer Peace River Pulp Ltd), the Forest Engineering Research Institute of Canada and Alberta Land, and Manning Diversified Forest Products Ltd. The University of Alberta and the Western Boreal Growth and Yield Cooperative (WESBOGY) are also participants. The study site is located 35 km northwest of Manning, Alberta (Figure 4) within the Lower Foothills Natural Subregion and is representative of mixedwood stands in the area with a trembling aspen and balsam poplar overstory and a white spruce understory. The site is glaciolacustrine, ranging from moderately well-drained to poorly drained depending on slope and the dominant ecosite is 'e' (low-bush cranberry) and ecosite phase is 'e2' (aspen-white spruce-lodgepole pine) with variations in the plant community according to varying levels of moisture (MacIssac and Krygier 2004).

The project was established to conduct operational research on alternative harvest systems over a 20-year span. The principal focus of the study was understory protection and the systems used were designed to minimize wind damage during overstory harvest and encourage regeneration and robust growth of residual spruce. Twelve treatment blocks and four uncut control blocks totaling 530 ha were established and treated using 11 silvicultural systems (Table 7-3).

> Location: Northwest Alberta.
>
> Forest Type: Mixedwood.
>
> Alternative system(s): Shelterwood (uniform, alternate strip cut, progressive strip cut; 1-4 entries).
>
> Scale: Long-term replicated trial.
>
> Study focus: Techniques for understory protection, including minimizing wind damage and encouraging regeneration.
>
> Measurement(s): Understory spruce response, windthrow risk, regeneration.
>
> Takeaway(s): Avoidance of spruce using clearcut not recommended for propagating mixedwoods. One pass harvest with 10-15% aspen retention recommended. Data may be useful to investigate how understory protection could be used to minimize understory response in mixedwood stands in or near to caribou ranges.

In 2004, the *Canadian Forest Services Hotchkiss 10 Year Final Report* was released (MacIssac and Krygier 2004). The alternative systems were found to be more effective at protecting the understory than conventional harvest methods. Most blocks retained 50-70% of pre-harvest white spruce while clearcut blocks with spruce avoidance retained only 19% and 23%. All alternative systems resulted in significantly less windthrow of residual spruce than clearcut avoidance with the best treatment being two-pass modified uniform shelterwood (F-3) with a 5 m buffer of uncut aspen alternating with a 35 m strip of harvested aspen. Harvested strips at least 100 m wide had the lowest mean annual height increment and the highest windthrow risk, with the percentage of windthrow doubling as the distance to an uncut edge increased from 75 m to 100 m. Growth rates of understory spruce were not significantly different between treatments though volume response was variable, with some treatments having a greater volume response than control areas; overall, the spruce growing under aspen displayed 20% less growth than their free-growing counterparts. A retention-response index was developed to measure returns on each system as a function of volume increment and percent volume retained and the F-3 (south) treatment was again found to produce the best results. Regeneration along machine corridors in the alternative treatments differed significantly from clearcut areas and between seasons (with winter harvest generating greater density and larger tree size) but not between treatment types.

The report concludes that the avoidance of spruce using the clearcut system is not recommended for the propagation of mixedwoods, especially in moist sites or stands with aspen taller than 7 m. Systems retaining uncut strips every 2-2 ½ tree lengths are considered effective to prevent the windthrow of residual spruce. Although the release effect did not fully make up for volume losses due to harvest or windthrow in the short term, the report notes that the volume growth rate of released spruce is increasing over time in most of the non-shelterwood blocks. It was noted that the higher index values of the shelterwood treatments were diminished by the shading and abrasion effects from the intimate mixing of spruce and aspen.

Overall, the recommended treatment to balance mixedwood objectives was a one-pass harvest with 10-15% aspen retention, as investigated in the F-3-South treatment. This system is considered to be of a moderate level of harvesting difficulty offering very high levels of protection following the first entry and low to medium levels after the second cut.

Specific understory vegetation information was not recorded as part of the research, though grass cover was measured, and plants and mosses were used as general indicators of the moisture class of the site. The Hotchkiss River Mixedwood Management Demonstration Area should be considered as a future partnership opportunity as the inclusion of understory vegetation abundance, richness, and composition in site measurements could help fill current knowledge gaps around the thresholds of canopy removal triggering understory release.

Figure 7. Aerial view of Hotchkiss River Mixedwood Management Demonstration Area (Credit: Natural Resources Canada, Canadian Forest Service).

Some subject-matter experts interviewed for this report recommended understory protection as a potential strategy for managing habitat for other ungulates such as moose and deer in mixedwood systems. The Hotchkiss study has demonstrated that shelterwood and strip cut systems support understory protection but re-visiting the data from this trial from the perspective of understory vegetation response could be useful in determining if certain methods for understory protection might be more effective than others in reducing aspen suckering and growth of other browse species. For stands in or near to caribou range, any changes that minimize habitat desirability for other ungulates would be beneficial.

Silvicultural treatments could also be used for additional management of the understory. However, while underplanting and herbicide could be used to reduce browse and hasten coniferous canopy closure, natural regeneration is often preferred for both ecological and economic reasons. Natural regeneration also concentrates harvest into a single disturbance. If natural regeneration is supplemented with planting or stand tending, it may be advantageous to perform treatments in tandem with harvesting activities to minimize the spatial and temporal human footprint in caribou ranges.

"I think I would opt for the understory protection system to provide that opportunity. Perhaps coupled with trying to understand better which sites will provide the best conditions after harvesting. Finding the blocks with higher density of spruce understory that will provide that suppression of vegetation."

"The mere presence of people seems to have a negative impact on caribou. Our first objective would be to manage the human footprint in such a way that we only touch that habitat as much as we need to nudge it in the direction we want it to go. We would want to do as much of our reforestation activity in concert with our harvest as we can."

While required in certain circumstances by Alberta's Forest Management Standards, understory protection is largely an underutilized system. The suitability of a stand for understory protection is dependent upon the height and density of the white spruce, the rooting depth, and site conditions and topography (MacIssac & Krygier 2004) and is assessed on a by-company basis. The Government of Alberta has provided some guidance, publishing the *Partial Harvest (Non-clearcut) Planning and Monitoring Guidelines* in 2006 to help direct decision-making for partial harvest systems, including understory protection harvest. However, the rigorous criteria for reforestation, monitoring, damage thresholds, and yield expectations associated with understory protection, along with increased initial investments, may discourage application of the harvest system. Volume losses to conifer operators borne by the removal of the deciduous overstorey in cases of shared tenure has also been acknowledged as an issue, with compensation suggested as an incentive.

Figure 8. Stand level view of Hotchkiss River Mixedwood Management Demonstration Area (Credit: Natural Resources Canada, Canadian Forest Service).

Table 7-3. Silvicultural systems used at the Hotchkiss River Mixedwood Management Demonstration Area.

Harvesting Prescription	Silvicultural System	Treatment Description	Strip Width (m)	Block Name	Level of Protection	Level of Harvesting Difficulty
Clearcut	Clearcut with avoidance	Total removal of aspen with spruce avoidance; stems around boundary perimeter felled parallel to boundary.	N/A	F-1-1	Minimal	Easy
		As above, except stems along boundary were felled into adjacent stands.	N/A	F-1-2	Minimal, none on interior.	Easy
Non-clearcut, full overstorey removal	One entry, modified uniform shelterwood	Machine corridors at 25 m spacing.	>200	F-1-1(S)	Medium to high	Moderate
		Machine corridors at 30 m spacing.	>250	F-2	Very high	Moderate
	Two entry, modified uniform shelterwood	Machine corridors at 40 m spacing; retained buffer harvested in second entry.	>250	F-3	Very high after first entry, low to medium after second entry.	Moderate
	Two entry, alternate strip	Machine corridors at 20 m spacing; upwind strip of equal width harvested in second entry.	50	F-6-1	Medium to high, minimal after second entry.	Moderate to difficult
			100	F-6-2	Medium	Moderate
			150	F-6-3	Minimal	Moderate
	Four entry, progressive strip cut	Machine corridors at 20 m spacing; adjacent upwind strip cut in subsequent entries.	50	F-7	High	Moderate
Non-clearcut, partial overstorey removal	Two entry, shelterwood	Machine corridors at 20 m spacing; all deciduous overstorey cut on strip nearest upwind buffer; 50% of deciduous overstorey cut on downwind adjacent strip.	50	F-4	Medium to high after first entry, medium after second entry.	Moderate to difficult
	Three entry, shelterwood	Machine corridors at 20 m spacing. First entry: All deciduous overstorey cut on strip nearest upwind buffer; 50% of deciduous overstorey cut on downwind adjacent strip. Second entry: Deciduous overstorey trees remaining from first cut felled; ~50% of deciduous overstorey cut on upwind uncut strip. Third entry: Deciduous overstorey trees remaining from second cut felled; all deciduous overstorey adjacent to corridors felled on upwind uncut strip.	2 x 50	F-5-1	High after first entry, high to medium after second entry.	Moderate to difficult
			2 x 100	F-5-2	Medium to high after first entry, medium after second entry, low to minimal after third entry.	Moderate to difficult

7.4 Partial Harvest – British Columbia

The vast majority of forest harvest in British Columbia has been and continues to be a clearcut system, with varying levels of retention (Government of British Columbia 2021). The clearcut system directly removes arboreal lichens through tree removal and reduces the abundance of terrestrial lichens through mechanical damage, suddenly increased light levels, and altered humidity levels (Kranod 1996). Partial harvest silvicultural systems potentially allow for some level of harvest while changing forest stand structure in a way that maintains forage lichen abundance, and/or promotes regeneration. Detailed long-term studies in British Columbia were initiated over the last 30 years to explore the feasibility of partial harvest systems for promoting or maintaining caribou habitat. These include the Itcha-Ilgachuz trials in the west Chilcotin Plateau (Section 7.4.1), the Quesnel Highland trial (Section 7.4.2) and the larger, operational trial that extended the Quesnel Highland work, at Mount Tom (Section 7.4.3).

These and other trials have formed the basis of strategies for both Southern Mountain (Northern Group) in the western Chilcotin and Southern Mountain (Mountain, or Southern Group) in the eastern Cariboo Region (Figure 9). Both of these strategies have been implemented under the Cariboo Chilcotin Land Use Plan (CCLUP) and included no-harvest and aggregated modified-harvest areas that were selected in order to maintain caribou habitat on the landscape, whilst also balancing local stakeholders needs.

The Mountain Group strategy, released in 2000, recommended aggregated 'modified harvest' areas with a group selection silvicultural system (33% removal, 80-year rotation), designed to maintain arboreal lichen. This system was recommended for 53,500 ha of caribou range, in conjunction with a larger area with no harvest (Youds et al. 2000). The Northern Group strategy, released in 2002, recommended aggregated 'modified harvest' areas (cutblocks up to 1,000 ha) for over 200,000 ha in the Itcha-Ilgachuz area, in conjunction with 472,800 ha of no harvest area and approximately 1,000,000 ha of conventional harvest (Youds et al. 2002). In sites managed for terrestrial lichen (80% of modified harvest area) an irregular group-shelterwood system (50% removal, 70-year rotation) was recommended. The remaining modified harvest area was identified as important for arboreal lichen and used the same group selection system as in the Mountain Group strategy. In addition, approximately 64,000 ha were identified as being important caribou winter range but highly susceptible to mountain pine beetle and dwarf mistletoe, making partial harvest unsuitable. This area was therefore identified as a natural disturbance seral distribution area with management aiming to mimic the natural disturbance level. Additional 'caribou enhanced conventional harvest areas' were also established to minimize fragmentation and access to two areas severely impacted by mountain pine beetle (Youds et al. 2011).

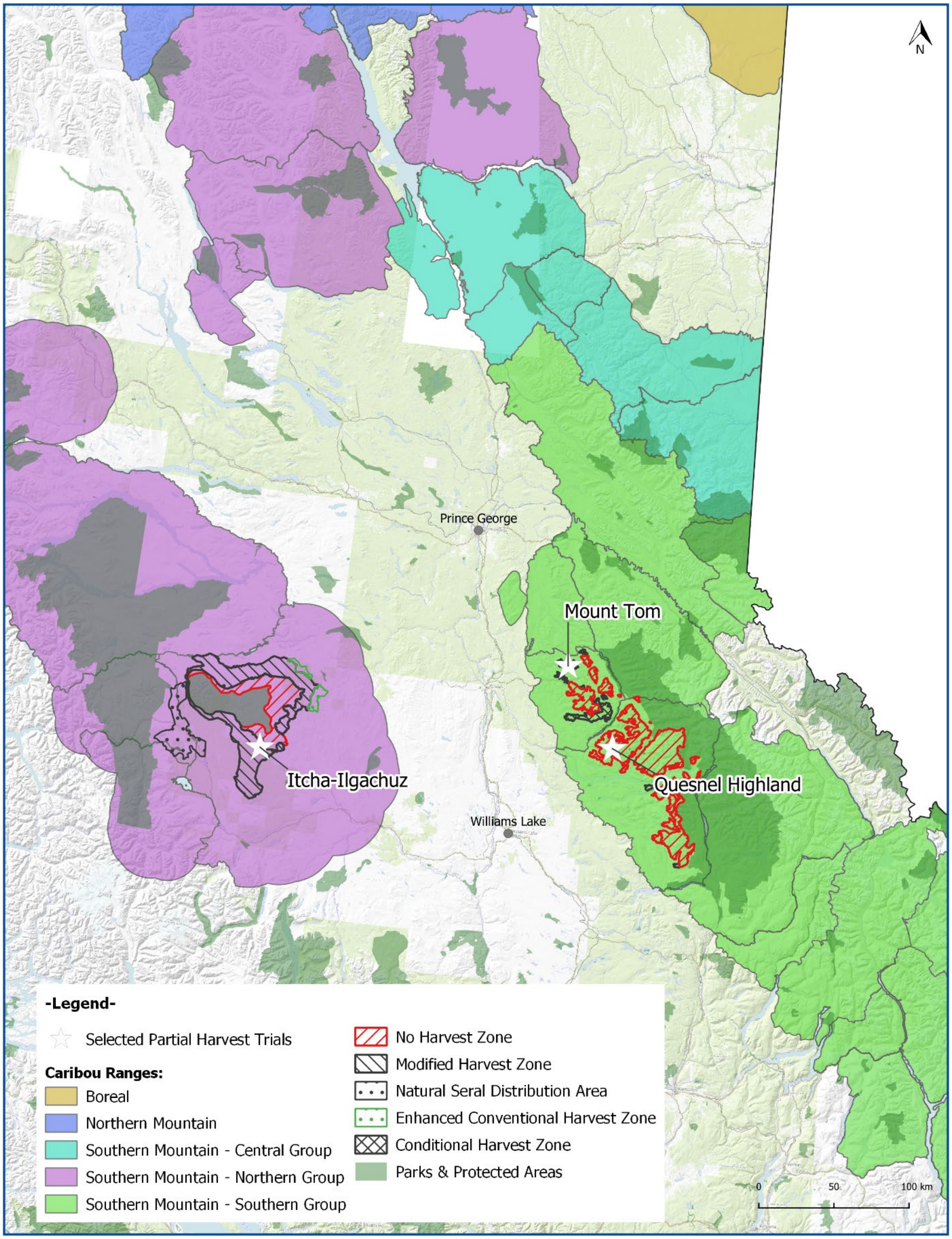

Figure 9. Locations of selected alternative silvicultural system trials with context of harvesting areas identified in the Northern Caribou Strategy and Mountain Caribou Strategy and implemented under the Cariboo-Chilcotin Regional Land Use Plan.

7.4.1 Itcha-Ilgachuz

The Itcha-Ilgachuz, Rainbow, and Charlotte Alplands herds are Southern Mountain (Northern Group) caribou populations in west-central British Columbia. These three herds sometimes share winter range and can be considered to be part of the same larger population. The Itcha-Ilgachuz herd was one of the largest in the province with an estimated 2,150 caribou in 2009 (Youds et al. 2011), but has since declined to approximately 500 caribou in 2020, leading to the implementation of a predator management strategy (Government of British Columbia 2020).

Caribou in the Itcha-Ilgachuz area primarily use high-elevation alpine or subalpine habitat in the Itcha and Ilgachuz mountains during calving and during the rut. In winter, caribou occupy pine forests where they prefer mature (81-140 years) and old (141+ years) stands (Youds et al. 2002). Winter forage includes both terrestrial and arboreal lichens, with a shift toward arboreal lichens in wetter areas as snow depths increase throughout winter. Terrestrial and arboreal lichens are consumed in nearly equal amounts (Cichowski 1989) and are typically dominated by *Cladina*, *Cladonia*, *Peltigera*, and *Stereocaulon* genera. Further details on the biogeoclimatic zones within winter caribou range and their characteristics is available in Table 7-4.

> Location: West-central British Columbia.
>
> Forest Type: Coniferous (lodgepole pine dominant).
>
> Alternative system(s): Group selection, variable retention, irregular group shelterwood (stem and whole tree harvesting).
>
> Scale: Replicated long-term trial.
>
> Study focus: Forage lichens.
>
> Measurement(s): Lichen response, windthrow risk, regeneration.
>
> Takeaway(s): Arboreal lichen maintained with 30% group selection system and terrestrial lichens maintained with 50% shelterwood system. Rate of lichen recovery varied by treatment with group selection being the fastest. Minimal understory vegetation response in this system.

Long-term silvicultural trials have been ongoing in the Itcha-Ilgachuz area since 1994, with a focus on various forms of partial harvest, as potential alternatives to clearcut harvest. A non-replicated pilot study was initially conducted in a single experimental block in the Very Dry, Very Cold Montane Spruce (MSxv) biogeoclimatic subzone on the Chilcotin Plateau (Miège, Armleder, et al. 2001). Lodgepole pine of about 200-years old dominated the area. The study included the following treatments:

- 30% area removal (group selection, 15m diameter circular openings).
- 70% area removal (clearcut), residual groups of 10-13 trees scattered throughout.
- 70% area removal with residual trees left in large islands (0.5 – 1.5 ha islands).
- Unharvested control (5 ha).

A single-grip harvesting system and forwarder was used to minimize equipment impact on terrestrial lichens and harvesting occurred in March to April 1995 on a 50 cm snowpack. The results showed that 70% removal resulted in significantly lower abundance of forage lichens, in comparison to 30% removal where abundance was similar to the control. These losses were attributed to loss of tree cover (i.e. sudden dramatic increase in light levels causing drying of lichens) and to logging slash accumulation (i.e. dramatic decrease in light levels and lack of ventilation causing lichen mortality).

A more comprehensive and replicated trial was established in the same area in 1996 and measured in 1995 (pre-harvest) and 1998 (Miège, Goward, et al. 2001). These sites were then re-measured in 2000 and 2004 (Waterhouse, Armleder, and Nemec 2011). The study included five replicated research blocks (60 – 113 ha), two of which were in the Very Dry, Cold Sub-Boreal Pine Spruce (SBPSxc) biogeoclimatic subzone and three of which were in the Very Dry, Very Cold Montane Spruce (MSxv) biogeoclimatic subzone. SBPSxc sites had more abundant terrestrial lichens while MSxv sites had a larger proportion of arboreal lichens. All blocks were dominated by 100-275 years old lodgepole pine.

The study included the following treatments, each between 15-30 ha:

- Irregular group shelterwood (50% removal, return at 70 years) – stem only harvesting. Openings were approximately 26m in diameter. Feller-buncher and processor used at site, forwarded to roadside. Slash aggregated in harvest openings.
- Irregular group shelterwood (50% removal, return at 70 years) – whole tree harvesting. Openings were approximately 23m in diameter. Felled trees were grapple-skidded to roadside for processing. Slash was piled at roadside and burnt one year after harvest.
- Group selection (33% removal, return at 80 years) – stem only harvesting. Openings were approximately 15m in diameter. Feller-buncher and processor used at site, forwarded to roadside.
- Unharvested control.
- In addition, adjacent clearcuts were also measured.

The irregular group shelterwood treatments were targeted at areas with high terrestrial lichen abundance, while the group selection treatment was designed to retain both terrestrial and arboreal lichens.

When using whole-tree harvesting, skidding can potentially cause more direct damage to terrestrial lichens. However, in this study snowpack (<30cm) minimized direct damage. There was no significant difference in lichen abundance between the stem-only harvesting treatments and the whole-tree harvesting treatments. However, increased slash levels were associated with lichen mortality and the stem-only system resulted in more deposited slash. Careful placement of slash e.g. in the sunniest edges of blocks may help reduce lichen mortality.

Terrestrial lichen cover was reduced in logged areas relative to the control (43-51%). However, many areas of the treatment units had minimal reduction in lichen abundance and the majority of mortality occurred on edges with the least shading. When light levels (direct beam solar radiation) increased beyond a certain threshold (approximately 50% in this study) mortality increased. Lichen recovery occurred at different rates depending on treatment. The group selection treatments recovered to pre-harvest levels by 2004, likely due to the smaller openings and larger amount of residual forest maintaining favorable light, temperature, and humidity conditions. The shelterwood treatments recovered to 68 and 71% of pre-harvest levels. Meanwhile, adjacent clearcuts had significantly less lichen cover than no-harvest treatments in all measurement years.

Importantly, the abundance of herbs and shrubs showed minimal increase in partial cuts, while sedge and grass cover increased by 11% in adjacent clearcuts. This suggests that in this ecosystem and at these harvest levels, partial harvest was not dramatically increasing moose and deer forage availability.

While the study was somewhat limited by small numbers of sampling plots and varying forest cover levels within treatment units (that did not always directly reflect the percentage area harvested in the treatment), the partial harvest systems used did minimize much of the loss of lichen cover that would otherwise occur in a clearcut system and allow for relatively rapid recovery. Smaller openings maintained some level of shading, protecting lichens from the effects of sudden light-level increases.

Table 7-4. Ecosystems for Northern Mountain caribou winter range in Itcha-Ilgachuz area. See Cariboo Chilcotin Land Use Plan, 2002 for further details.

Biogeoclimatic Zone	Subzone	Elevation (m)	Location & Topography	Climate	Tree Species	Ground Vegetation
Sub-Boreal Pine Spruce (SBPS)	Very Dry, Cold Sub-Boreal Pine Spruce (SBPSxc)	< 1,300	South of Itcha and Ilgachuz mountains. Flat / gently rolling.	Strong effect of coast Mountains rain shadow. Driest subzone in SBPS (mean annual precipitation = 389mm, mean annual temperature = 1.7 °C). Vegetation and tree growth severely limited by cold, very dry climate.	Lodgepole pine dominated. Small, scattered stands of trembling aspen. Spruce present on moist lower slopes and on wetland edges. Forest canopies of older stands are usually open and lodgepole pine regeneration common beneath canopy.	Dominated by dwarf shrubs, grasses, and lichens. Lichens are more abundant than mosses.
	Dry, Cold Sub-Boreal Pine Spruce (SBPSdc)	< 1,280	Northeast of Itcha and Ilgachuz mountains on edge of caribou winter range.	Moderate effect of coast Mountains rain shadow (mean annual precipitation = 508mm).	Lodgepole pine dominated. White spruce often scattered throughout mature stands. Lodgepole pine regeneration beneath canopy less common.	Dominated by dwarf shrubs, grasses and lichens, and feathermosses.
	Moist, Cold Sub-Boreal Pine Spruce (SBPSmc)	< 1,250	North and northwest of Itcha and Ilgachuz mountains. Flat / gently rolling.	Moister than other parts of the SBPS zone.	Lodgepole pine dominated but spruce more common than in SBPSxc and SBPSdc. Forest canopies of mature stands are moderately closed. Pine regeneration less dense.	Dominated by dwarf shrubs, lichens, and feathermosses. Extensive moss cover.
Montane Spruce (MS)	Very Dry, Very Cold Montane Spruce (MSxv)	1,280 – 1,600	Middle-elevation slopes surrounding Itcha and Ilgachuz mountains.	Very cold, but slightly moister than in SBPS (mean annual precipitation = 563mm). Deeper, longer lying snowpacks. Short growing seasons.	Lodgepole pine dominated but spruce more common than in SBPS. Canopy more closed with more vigorous and dense trees. Below canopy regeneration is predominantly spruce.	Dominated by dwarf shrubs, lichens, and feathermosses. Limited number of low herbaceous plants. Extensive moss cover.
Engelmann Spruce Subalpine Fir (ESSF)[3]		1,600 – 2,100	Sub-alpine.	Long, cold winters and short cool summers.	Engelmann spruce and sub-alpine fir dominate wetter areas with mountain hemlock in higher snowfall areas. Lodgepole pine acts as pioneer species after disturbance.	

[3] The ESSF within this area is within Itcha-Ilgachuz Provincial Park, which does not permit timber production.

7.4.2 Quesnel Highland

The Quesnel Highland partial harvest trial focused on arboreal lichen because the area is home to Southern Mountain (Southern Group) caribou. This group use high elevation mature and old subalpine forests with deep snowpack and rely on arboreal lichens for winter forage, primarily *Bryoria* spp., but also *Alectoria sarmentosa* (Seip 1992; Terry, McLellan, and Watts 2000). In this area, forests are dominated by Engelmann spruce and subalpine fir. At higher elevations subalpine fir becomes more dominant and clumped (Table 7-5).

> Location: East-central British Columbia.
>
> Forest Type: Coniferous (Engelmann spruce & subalpine fir dominant).
>
> Alternative system(s): Group selection.
>
> Scale: Replicated long-term trial.
>
> Study focus: Arboreal lichen.
>
> Measurement(s): Arboreal lichen response to harvest.
>
> Takeaway(s): Arboreal lichen maintained sufficiently at 30% retention.

The trial blocks were cut in 1993 using a group selection system with 30% removal. Opening sizes of 0.03 ha, 0.13 ha and 1.0 ha were contrasted with uncut control over four sites of approximately 40 ha using a randomized design. Harvesting was completed using feller-bunchers and grapple skidders, on a snowpack of 0.5m-1.5m in all but one site, which was harvested in summer. Arboreal lichen abundance was measured immediately post-harvest and again 10 years post-harvest, in 2003. The loss of lichens due to tree removal was partially offset by increases in lichen abundance on remaining trees and the group selection treatments. This may be due to increased light levels after harvest, while still having the protection from wind by nearby trees. The group selection treatments also appeared more likely to have an increase in the proportion of *Bryoria* species than the unharvested area. The authors concluded that the group selection treatments with 30% harvest maintained arboreal lichens at what is likely to be an acceptable level to retain the area as caribou foraging habitat (Waterhouse, Armleder, and Nemec 2007). However, this study could not assess caribou response to partial harvest directly due to the small size of the treatment area relative to low caribou densities on the landscape. Therefore, a larger operational scale trial was established at Mount Tom to address this gap and to examine operational efficiency and regeneration options (Cariboo Forest Region Research Station 2002).

7.4.3 Mount Tom Adaptive Management

The Mount Tom adaptive management trial was established in 1999 and designed to test partial harvest using a group selection system at a larger, operational level as compared to previous trials in the Quesnel Highlands in the 1990s (Waterhouse (ed.) 2011). The trial area is within the Barkerville caribou subpopulation herd range.

The study area is 4,076 ha and found within the Wet Cool Engelmann Spruce Subalpine Fir (ESSFwk) and Wet Cold Engelmann Spruce Subalpine Fir (ESSFwc) biogeoclimatic zones. The area was split into a development area with harvest (2001-2012) and a remaining area that would not be harvested for 10 years after completion of the first area, allowing for comparison of caribou use between harvest and unharvested areas. Similar to the Quesnel Highland trial, a group selection system is used with openings from 0.1 to 1.0 ha. Some larger (3.0 ha) openings are used for comparison, as well as small areas of single-tree selection. Five of eight planned blocks (1,407 ha) were harvested between 2000 and 2010 and after five years the group selection system had effectively maintained arboreal lichen in residual forest. There was also a shift toward *Bryoria* species, similar to that seen in the Quesnel Highland trial (Waterhouse, Nemec, and McLeod 2015).

At present, researchers at the University of Northern British Columbia are quantifying the distribution of caribou, other ungulate species, and predators across the area (Bradshaw and Johnson 2020). This is of particular importance, because while the impacts of partial harvest on arboreal lichen was made clear through the previous trials, whether caribou actually continue to use the harvested areas was unknown. In addition, the impact of partial harvest systems on other ungulate species that support predator populations had also not been quantified.

A network of remote cameras in unharvested controls, adjacent clearcuts, openings and residual forest in the group selection cuts and on access roads is being used to identify caribou, other ungulate species, and predators. In addition, plant surveys and browse and pellet surveys are being conducted. Preliminary results suggest that caribou are avoiding group selection areas while moose are heavily using them. In all areas, moose are using group selection more than adjacent clearcuts and controls (2-3x). Mule deer have also been identified, despite the higher elevation location of the sites. It appears that with the site conditions at Mount Tom, group selection harvest is resulting in rich emergent vascular plant growth in the openings, which is favored by moose. In addition, the matrix of old forest surrounding the small openings acts as thermal and security cover. In combination with surrounding clearcuts and roads, this has resulted in ideal moose habitat.

Location: East-central British Columbia.

Forest Type: Coniferous (Engelmann spruce & subalpine fir dominant).

Alternative system(s): Group and single tree selection.

Scale: Replicated ongoing trial.

Study focus: Habitat attributes, caribou use, alternative prey & predator use.

Measurement(s): Lichen response, wildlife response (caribou, mule deer, moose), understory vegetation.

Takeaway(s): Arboreal lichen maintained in residual forest. Caribou avoiding group selection blocks while use by moose has increased.

“If there were no clearcuts or roads surrounding Mount Tom, there would probably still be moose, but in the Mount Tom area we created ‘super habitat’ that moose really like.”

Early results from the remote camera surveys suggest that caribou are avoiding the group selection areas. There is also pre-harvest telemetry data showing that caribou used the area prior to trial establishment. Ongoing collection of GPS telemetry data from the Barkerville subpopulation should allow for further analyses examining the impact of partial harvest on caribou use.

Table 7-5. Ecosystems for Southern Mountain caribou winter range in Quesnel Highlands area.

Biogeoclimatic Zone	Subzone	Elevation (m)	Location & Topography	Climate[4]	Tree Species	Ground Vegetation
Engelmann Spruce Subalpine Fir (ESSF)	Wet Cool Engelmann Spruce Subalpine Fir (ESSFwk1)	1,200 – 1,500		Mean annual precipitation = ~1200mm, mean annual temperature = 0.1 °C.	Subalpine fir dominated in lower canopy layers while large Engelmann spruce dominate the upper canopy. Standing dead trees are abundant. Regeneration layer is primarily subalpine fir, with fewer spruce stems.	Thick shrub layer dominated by white-flowered rhododendron, with smaller amounts of black huckleberry. Herb layer is dense. Bryophyte layer nearly continuous and dominated by mosses.
	Wet Cold Engelmann Spruce Subalpine Fir (ESSFwc3)	> 1,500		Cold, snowy winters and cool, moist summers (mean annual precipitation = ~1400mm, mean annual temperature = -1.0 °C). Peak snowpack typically 3m.	Subalpine fir dominated but large Engelmann spruce typically scattered throughout stands. Tree distribution in mature stands tends to be clumped. Regeneration layer is primarily subalpine fir, often established by "layering".	Thick shrub layer dominated by white-flowered rhododendron, with smaller amounts of black huckleberry and oval-leaved blueberry. Herb layer is moderately abundant. Bryophyte layer nearly continuous and dominated by liverworts, mosses.

[4] See Farnden (1994).

7.4.4 Lessons & Applicability to Alberta

The three Southern Mountain caribou herds that are found in Alberta (Redrock-Prairie Creek, Narraway, A La Peche) are all part of the Central Group. This group is similar to the Northern Group caribou found in the Itcha-Ilgachuz in that they both occupy relatively shallow snow areas and forage primarily on terrestrial lichens during winter, as well as utilizing some arboreal lichens. This is in contrast to Southern Group caribou such as those found in the Quesnel Highlands, which occupy areas with deep snowpack and primarily feed on arboreal lichens in winter (Environment Canada 2014). The Itcha-Ilgachuz area has drier, less productive sites, commonly dominated by lodgepole pine. This is more similar to the areas occupied by the Central Group herds in Alberta and so direct comparisons may be possible (Table 1-1).

It is clear that partial harvest using an irregular group shelterwood system or a group selection system can be used to maintain terrestrial and arboreal lichens respectively. Networks of partial harvest and no-harvest areas should be able to maintain caribou habitat over large geographical areas, theoretically allowing caribou to continue to distribute at low density and avoid predation. However, there are several major constraints on this approach and significant risks of increasing apparent competition if applied in more productive ecosystems.

In addition, even in Itcha-Ilgachuz, where site conditions appear favorable for the successful application of partial harvest systems and a long-term plan is in place, caribou populations are still in decline. The reasons for this are unclear, although severe Mountain Pine Beetle outbreaks, overlap with other ungulate populations such as feral horses, and impacts from surrounding clearcut harvest at lower elevations could all be involved.

When the caribou drop in elevation and start overlapping with the horses they are moving into a zone of higher predation. The caribou are actually crossing over on mule deer winter ranges so there's also incidences of cougar kills on caribou as well. None of our low elevation area is in this modified harvest at all, it's all conventional clearcut harvesting.

7.4.4.1 Apparent Competition

While the ecology of Southern Group caribou is quite different to the Central Group caribou found in Alberta, the early results from the population monitoring work at Mount Tom make it clear that under certain conditions, partial harvest systems have the potential to increase habitat suitability and desirability for other ungulate species such as moose. This leads to more predators (particularly wolves) being supported on the landscape and drawn into areas with caribou occupancy. Incidental predation from these predators then causes caribou population decline. This apparent competition is driving caribou decline in many systems and could easily outweigh any benefits for caribou habitat achieved through partial harvest.

Despite the short growing season at Mount Tom, the ecosystem is wet and fairly productive, meaning that early seral stage vegetation can rapidly grow when competition for light is removed through harvest. In contrast, the dry and cold environments found in the Itcha-Ilgachuz trials had minimal flush of early seral stage vegetation and so presumably do not have major effects on desirability for moose and deer, although no ungulate population studies have been carried out in the area to confirm this. It is therefore critically important that local site conditions are carefully considered for any partial harvest system. It is also important to consider the wider landscape disturbance pattern. In the Mount Tom area there are islands of higher elevation habitat (e.g. where the trial is located) surrounded by younger clearcuts. It may be the case that this disturbance pattern is encouraging moose to use the high elevation areas, in addition to the desirability of the group selection habitat.

"In the mountain caribou habitat, the trial [Mount Tom] is surrounded by clearcuts and it's almost forcing the moose up there. Historically they used and they still use the wetlands systems. The nearest intact forest is now up in the same area as the research trials area."

Potentially, the amount of removal in any partial harvest treatment could be tailored to local site conditions. By controlling light availability in the system, it may be possible to limit early seral stage vegetation below a critical threshold and thereby achieve maintenance of forage lichens while still minimizing any increases in habitat desirability for other ungulate species. While the Mount Tom results suggest that group selection is bad for Southern Mountain caribou, small patch openings may yet be effective in less productive ecosystems. Nutrient availability and vegetation establishment are also strongly effected by forest floor disturbance and site preparation treatments (Frey et al. 2003), making these important considerations in any partial harvest system that aims to limit flushes in early seral stage vegetation.

"The ecology of your site will dictate your silvicultural system to a great extent."

7.4.4.2 Access & Economics

The effect of additional access required for partial harvest systems is a major risk factor for caribou (see Section 8 for discussion on this topic).

7.5 Partial Harvest – Québec

Boreal caribou populations in Québec include the Val d'Or, Charlevoix, Pipmuacan, Manouane, Manicouagan, and Québec ranges, which cover over 68 million ha of the province (Environment Canada 2020b). Most populations are found within the spruce-lichen and spruce-moss bioclimatic domain. The Val d'Or and Charlevoix populations are located within the balsam fir-white birch domain and are at greater risk of extirpation due to their isolation and small size (Environment Canada 2012). The Québec population has the most extensive range and is the largest, estimated at 9,000 individuals in 2012. The amended recovery strategy in 2020 showed three boreal populations in decline (Val d'Or, Charlevoix, and Pipmuacan) while two were stable (Manouane and Manicouagan) (Environment Canada 2020b).

Due to longer fire cycles associated with higher precipitation, the boreal forests of eastern Canada are typically shaped by smaller gap dynamics. Disturbances such as pests (especially eastern spruce budworm, *Choristoneura fumiferana*), windthrow, and storms result in uneven aged forest with irregular stand structure. It has been recognized that, compared to clearcutting, partial harvest systems better emulate the natural disturbance regime in this region. While clearcut harvest, referred to as Cutting with Protection of Advanced Regeneration and Soils (CPRS), remains the predominant silviculture system (Courtois et al. 2008), Québec harvests the largest proportion of forest in Canada using alternative systems such as shelterwood, seed tree, selection cutting or commercial thinning. For example, in 2015, Québec accounted for 73% of all shelterwood harvest in Canada (Statistics Canada 2018).

Silviculture systems that remove stems with DBH >14 cm were introduced to protect stand structure and habitat in eastern Québec where uneven stands are most commonly found (Courtois et al. 2008). This system is known as Coupe avec Protection des Petites Tiges Marchandes (CPPTM) ("Cutting with Protection of Small Merchantable Stems"). However, there are concerns that "thinning from above" results in simplified forest structure that may not retain key old-growth attributes and functionality (Ruel, Fortin, and Pothier 2013) and makes stands more appealing to moose (Fortin et al. 2011). Partial harvest systems such as selection cutting and irregular shelterwood are being explored as alternatives.

A major trial exploring zoning, the Mauricie TRIAD project, with a significant role for partial harvest silvicultural systems, has been in an implementation phase since 2008 for a full FMU in central Quebec. This functional zoning approach to forestry (see Section 7.6) was initiated on an 860,000 ha FMU spanning both the boreal mixedwood and northern temperate deciduous forest (Messier et al. 2009). As part of this project 69% of the area was designated as 'ecosystem management zone', where logging is permitted as part of an approach emulating natural forest dynamics. This involves partial harvest systems in approximately 50% of the area - selection systems for softwood stands and some deciduous stands, as well as some irregular long-term shelterwood harvesting (Messier et al. 2009).

Various studies have examined the effects of different silviculture systems and approaches to forest management on old growth attributes, lichen growth and recovery, and caribou habitat suitability and use. Although the boreal forests of eastern Canada differ from Alberta's forests in many respects, research from Québec may help us to understand threshold responses to alternative systems in Alberta.

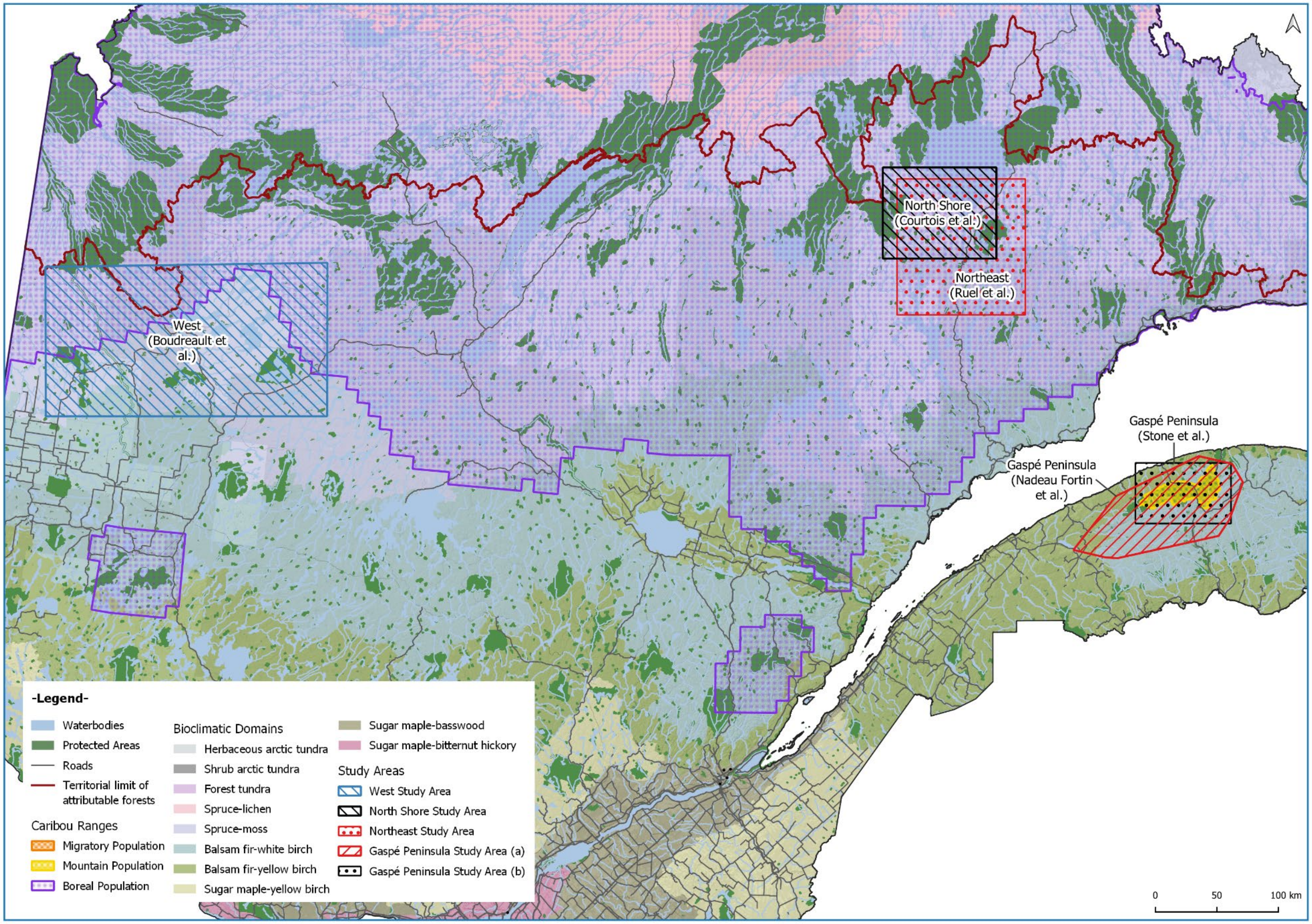

Figure 10. Locations of selected alternative silvicultural system trials in Quebec.

Table 7-6. Ecosystems for bioclimatic domains relevant to the described studies.

Vegetation Subzone	Bioclimatic Domain	Location & Topography	Climate	Tree Species	Ground Vegetation
Continuous boreal forest subzone	Spruce-moss	Occupies the northern portion of the boreal zone, approximately to the 52^{nd} parallel (Gouvernement du Québec, 2003). Topography is generally flat. Organic soils dominate area (36% of area) followed by clay soils (29% of area) (Gauthier et al. 2000).	Mean annual temperature -2.5-0°C (Gauthier et al. 2000). In the western subdomain, average annual precipitation = 700-1,000 mm. 25-50% falling as snow (Messaoud *et al.* 2007). 1100-1170 degree days/year. Length of growing season = 120-150 days (Gauthier et al. 2000). Fires more prominent in the drier west.	Dominated by black spruce, often in pure stands but occasionally accompanied by balsam fir. Balsam fir stands found on slopes. Occasional hardwoods such as white birch , trembling aspen, and balsam poplar (Gouvernement du Québec, 2003).	Hypnaceous mosses and ericaceous shrubs. Herbaceous species are rare (Gouvernement du Québec, 2003).
	Balsam fir-white birch	Northern limit around the 49^{th} parallel (Messaoud *et al.* 2007). Occupies the southern portion of the boreal zone (Gouvernement du Québec, 2003). Relatively flat topography. Clay soils dominate (45% of area) (Gauthier et al. 2000).	Mean annual temperature 0-2.5°C (Gauthier et al. 2000). In the western subdomain, average annual precipitation = 800-1,200 mm. 40-45% falling as snow (Messaoud *et al.* 2007). 1220-1280 degree days/year. Length of growing season = 150-160 days (Gauthier et al. 2000).	Dominated by balsam fir and white spruce stands, often mixed with white birch on mesic sites. On less favorable sites, black spruce, jack pine, and larch grow alongside white birch or trembling aspen. Yellow birch and red maple in southern portion only (Gouvernement du Québec, 2003).	Woody and herbaceous species, ferns, club mosses; e.g. *Coptis groenlandica, Cornus canadensis, Sorbus americana, Pteridium aquilinum, Vaccinium angustifolium, Corylus cornuta, Aralia nudicaulis* (Légaré et al. 2001).
Mixed forest subzone	Balsam fir-yellow birch	Stretches westward as far as central Quebec and encompasses the Gaspe peninsula, the Appalachian hills, the Laurentian foothills north of the St. Lawrence River and the lowlands of Lake Saint-Jean (Gouvernement du Québec, 2003). Rolling topography. Clay soils dominate (45% of area) (Gauthier et al. 2000).	Mean annual precipitation varies according to east-west gradient. Higher precipitation in the eastern subdomain due to influence of the maritime climate while the west is more continental and drier (Gouvernement du Québec, 2003).	Mixed stands of yellow birch and softwoods such as balsam fir, white spruce, and white cedar on mesic sites. Yellow birch and pine stands in the west. Northernmost limit of sugar maple range (Gouvernement du Québec, 2003).	*Rubus ideaeus* often dominates during early successional stage, other common species include Acer spicatum, Corylus cornuta (Pinna, Malenfant, and Côté 2012).

7.5.1 Northeastern Québec

An integrated experiment looking at the effects of harvesting with various levels of retention using alternative silvicultural systems was established in northeastern Québec in 2004 (Ruel et al. 2013). The study area is in the cool and wet spruce-moss bioclimatic domain, which has a mean annual temperature ranging from -2.5°C and 0.0°C and annual precipitation between 1,000-1,300 mm. Four study sites were selected, and these were characterized by stands that had never been harvested (>100 years old), dominated by black spruce and balsam fir. Each location included one control and each of the following harvest treatments on a 10-20 ha unit:

- Coupe avec Protection de la Régénération et des Sols (CPRS) ("Cutting with Protection of Regeneration and Soils"): Removal of all merchantable stems with DBH >9 cm while protecting advanced regeneration. Often referred to as clearcuts.
- Coupe avec Protection des Petites Tiges Marchandes (CPPTM) ("Cutting with Protection of Small Merchantable Stems"): Removal of all stems with DBH >14 cm.
- Selection cutting with temporary skid trails (SCt): Consists of four entries scheduled at 60 to 70-year intervals. At the initial entry, parallel skid trails 5 m wide are established with 25 m strips of forest between them. The 5 m strips adjacent to the skid trails are harvested using 50% basal area removal, leaving 15 m of forest untouched. At the second entry, the 15 m strip is harvested using the same retention rules. During the third and fourth entries, harvesting occurs on the portions of the stands partially cut during the first two entries. New skid trails are established with each entry to protect regeneration. Overall, this treatment removes 35% of basal area at each entry.
- Selection cutting with permanent skid trails (SCp): Entries scheduled at 60 to 70-year intervals. A 30 m strip of forest is flanked by permanent primary skid trails 5 m wide. Secondary 5 m skid trails are established perpendicular to the main trails. Harvest between the secondary skid trails aims to remove 35% of basal area at the stand level. New secondary skid trails are established at each cutting cycle to protect regeneration.

Units were logged using harvesting prescriptions based on local stand structures, meaning stem selection was completed at the discretion of the harvester operator. Each main unit had three 400 m^2 Permanent Sample Plots (PSPs) to measure living stems, snags, regeneration, and downed woody debris. Additionally, a second experimental design (2,500 m^2) with trees marked for cutting was nested within each main unit to ensure that the full potential of selection cutting was captured (*i.e.* operational context and wildlife use on a larger scale and the effects of tightly controlled applications on a smaller scale). PSPs were also established within the smaller units to monitor animal communities and vegetation richness, structure, and composition. The ecological and economical potential of each selection system was evaluated three years post-harvest.

Selection cutting was found to be relatively effective in preserving old-growth forest attributes. The Shannon index of DBH distribution after harvesting using selection cutting was comparable to the control forest, indicating the maintenance of irregular stand structure. Snag volume was higher than in the CPRS and CPPTM treatments but there was no significant difference in downed woody debris. Fir regeneration was highest in the SCt treatment and lowest in the CPRS stands. The effectiveness of partial harvest systems can be inhibited by the subsequent mortality of remaining trees due to wind and other environmental factors. However, the study found that there was no significant increase in mortality in the selection cutting systems as compared to uncut stands. Tree marking was found to have minimal effect on forest structure and composition.

Location: Northeast Quebec.

Forest Type: Coniferous (black spruce dominant).

Alternative system(s): Diameter-limit cutting (CPPTM), single tree selection.

Scale: Small-scale trial.

Study focus: Habitat attributes, wildlife use (did not include caribou).

Measurement(s): Old growth forest attributes, tree mortality, wildlife response (did not include caribou).

Takeaway(s): CPPTM negatively impacted closed-habitat wildlife species. Selection cutting with 65% retention recommended to preserve old-growth forest attributes.

Although ungulates were not included in the experiment design, the effects of the treatments on beetles, birds, small mammals, and snowshoe hare (*Lepus americanus*) indicated that both CPRS and CPPTM had a negative impact on the richness of closed-habitat species while the effect was reduced or negligible when SCt and SCp were used. Previous studies indicate that both moose and caribou tend to avoid CPRS while only caribou avoided CPPTM, suggesting that CPPTM provides better moose habitat than CPRS (Fortin et al. 2011). However, Ruel *et al.* note that additional research is needed to address the viability of selection cutting for managing caribou populations in the boreal.

Economic sustainability was evaluated using a profitability analysis that used the values from the experiment to simulate impacts over a 200-year period. The analysis indicated that both SCp and CPRS should be profitable, though CPRS would be more profitable in most cases. Subsequent entries show an increase in returns for SCp and a decrease for CPRS. Although selection systems can be profitable over a long period of time and provide benefits to future harvests, current clearcutting systems are more profitable, particularly in the short-term. Ruel *et al.* (2013) suggest a certification scheme could provide a market incentive to help overcome the obstacle of a short-term loss in profitability.

7.5.2 North Shore

Courtois *et al.* (2004) proposed a three part zoning approach for managing forests in the province for caribou. Critical habitat areas (*i.e.* wintering, calving, and breeding areas) were recommended to be identified through telemetry and surveys and delimited and buffered, with road development prohibited within these areas. These protected areas are intended to maintain caribou populations in the short to medium term until logged areas recover to a successional stage appropriate for caribou use. They recommended protected areas with forest 40-140 years of age covering large areas (>100-250 km^2) to maintain caribou ranges and minimize the risk of habitat loss to wildfires. For boreal populations, a single protected area of the recommended size would constitute from 0.02-0.04% (largest range; Québec population) to 3-8% (smallest range; Charlevoix population) of a population's range (Environment Canada 2020b). A larger proportion of range would be preserved for mountain caribou due to their limited extent of occurrence (6.6-16.6% for the Gaspésie population) (Environment Canada

2020a). Habitat connectivity should be conserved at the management area scale by avoiding fragmentation and leaving movement corridors within harvest areas (2 km wide in young forests <3 m and 400 m wide in mature forests <80 years). Additional management strategies proposed included concentrating logging areas, reducing access, promoting conifer regeneration to avoid deciduous stages of succession (through scarification, planting, and thinning treatments as site appropriate), training operators, and utilizing predator control for threatened populations.

In 2000, a five-year ecosystem-based management plan was introduced for the North Shore region of Québec with the goal of protecting caribou habitat while maintaining allocation of mature conifer to the forestry industry. Courtois et al. (2008) investigated whether aggregated cuts with the protection of large forest blocks linked with corridors would maintain caribou on the landscape in the short term (5 years post-harvest). Four large forest patches (total of 508 km^2, ranging from 55 to 182 km^2) in areas used extensively by caribou were protected, with travel corridors ranging from 400 to 2,000 m wide facilitating connection between intact areas The study area was enclosed by a 25 km buffer of undisturbed forest and was composed predominantly of black spruce and balsam fir, with occasional jack pine in northern areas. Understory vegetation included mosses, alder, serviceberry, willow, and ericaceous species. Radiolocations of tagged caribou were recorded from 1999-2005 and vegetation surveys were completed on harvested stands. Cutblocks were harvested using the following techniques:

Location: Northeastern Quebec.

Forest Type: Mixedwood (balsam fir, white spruce, black spruce, white birch, yellow birch).

Alternative system(s): Aggregated diameter-limit cutting.

Scale: 50,800 ha

Study focus: Aggregation and caribou use.

Measurement(s): Caribou occurrence, vegetation surveys.

Takeaway(s): Could not determine a preference between harvest techniques. Caribou located in protected patches and buffer zone; avoided protected areas adjacent to cutblocks. Patches 55-182 km^2 too small to maintain populations long-term. Larger protected areas & better connectivity recommended.

- Cutting with Protection of Advanced Regeneration and Soils (CPRS): Careful logging around advanced regeneration (DBH <2 cm). Often referred to as clearcuts.
- Cutting with Protection of High Regeneration and Soils (CPHRS): Careful logging around high regeneration (stems with DBH 2-8 cm).
- Cutting with Protection of Small Merchantable Stems (CPPTM): Careful logging around small merchantable stems (stems with DBH => 9 cm).

The effectiveness of the management strategy was evaluated through observed changes in caribou numbers (5 surveys were completed from 1999-2005), locations, and their habitat selection patterns. Following an initial drop from 104 individuals in 1999 to 42 individuals in 2002, by 2005 the herd had recovered to 88 individuals, indicating this approach was successful in maintaining local caribou population density in the short term. Uncut areas showed more advanced conifer regeneration, less *Salix* and *Vaccinium* species, and more arboreal lichens than cut stands. 97% of radiolocations were recorded within protected patches and the nearby intact forest (buffer zone), though caribou were found to avoid protected areas adjacent to and surrounded by cutblocks. Corridors were used in proportion to availability. Caribou avoided open habitats (both clearcuts and burns), regenerating stands, mixed or deciduous stands, and waterbodies; cut areas were strongly avoided.

Because only 10 radiolocations were recorded within cutblocks, the study could not determine a significant preference between logging techniques; however, it was noted there was little canopy cover or standing stems left in all harvested areas due to extensive blowdown. Courtois *et al.* (2008) suggest that partial harvest techniques that maintain a denser canopy would be more beneficial to caribou in the long-term, as this may provide additional cover and encourage the growth of arboreal lichens. The protection of approximately 70% of coniferous saplings and advanced regeneration and lichen maintenance was considered adequate for caribou in the long term. A literature review by Vanderwel et al. (2009) found that 70% retention led to no change in habitat suitability for both caribou and moose while 50% retention did not mitigate the negative impacts of harvest and improved browse for moose. Additionally, because caribou were frequently located within and beyond the buffer zone, it was determined that the protected patches were too small to maintain populations long-term and that larger areas with better connectivity should be targeted for future management.

7.5.3 Western Québec

Boudreault *et al.* (2013) examined the effects of partial harvest with different levels of removal on terrestrial lichen species (*Cladonia* spp) in the western boreal forests of Québec. The study was located in the western portion of the spruce-moss bioclimatic region, characterized by relatively flat topography, clay soils, and black spruce dominated stands with feather moss ground cover (Table 7-6).

Three sites, all dominated by >120 year-old black spruce stands were treated with different partial harvest treatments (45%, 66%, and 85% of basal area removal). A low-retention clearcutting (removal of all trees with DBH >9 cm) and a control no-harvest block were also included at all sites. All blocks were a minimum of 25 ha in size and lichen abundance was measured 5 years post-harvest. In addition, lichen transplants were used to measure growth rate in each treatment over a period of 15 months.

Lichen abundance was significantly lower in clearcuts as compared to partial harvest treatments and unharvested controls. The partial harvest treatments maintained lichen cover at levels comparable to control plots. The lichen transplants demonstrated that growth rates were higher for *Cladonia* spp. in all harvested areas (including clearcut) as compared to control areas, suggesting that growth is limited by

> Location: Western Quebec.
>
> Forest Type: Coniferous (black spruce dominant).
>
> Alternative system(s): Partial harvest
>
> Scale: Small-scale trial.
>
> Study focus: Terrestrial lichen response to partial harvest.
>
> Measurement(s): Terrestrial lichen abundance, lichen transplants.
>
> Takeaway(s): Partial harvest maintained higher abundance of terrestrial lichens than clearcutting. Understory response in this ecosystem more determined by soil disturbance than the level of overstory removal.

low light levels and that opening the canopy produces favorable conditions for growth. As a result of this, the authors expected the partial harvest sites would have higher cover and abundance of *Cladonia* spp. than the control forest after five years, given the improved growth rates for transplanted lichens and that the partial harvest sites retained existing lichens after harvest. However, this was not the case, with lichen cover similar in partial harvest treatments and controls. This may be due to establishment of taller vascular plants outcompeting lichens for light in the partial harvest openings.

These results align with the findings in the Itcha-Ilgachuz trials in British Columbia (Section 7.4.1) in that partial harvest systems are able to maintain terrestrial lichens, suggesting that partial harvest systems may help to maintain caribou habitat on the landscape while still allowing some level of timber harvest. Vascular plant abundance was not measured in this study but was suggested as a reason for lower than expected lichen abundance in the partial harvest treatments.

However, Bescond et al. (2011) did examine understory community response at two of the three sites included in the lichen study, as well as at other sites. They found that partial harvest had less impact on understory community than clearcuts, but nonetheless there were composition changes in all cases, especially in those sites that had thinner organic layers. They suggest that in these naturally open black spruce forests, soil disturbance is a more important factor than the level of overstory removal in determining the level of understory response.

Figure 11. A black spruce stand typical of those found in western Quebec.

7.5.4 Gaspé Peninsula

The Gaspésie (or Gaspé) is one of two mountain ecotype populations in Québec. The other is the Torngat population in the extreme northeastern part of the province. This isolated population is considered a “relict” subpopulation of caribou herds that formerly occupied the Gaspé Peninsula, the Maritimes and some New England states (Environment Canada 2020a). The range is approximately 150,000 ha and was federally designated as ‘Endangered’ in 2002 (Ministère des Ressources naturelles et de la Faune 2006). This caribou population utilizes both terrestrial lichens (early winter) and arboreal lichens when snow depth is limiting. While wolves haves been absent in the study area since 1850-1900, there is low calf recruitment due to coyote and black bear predation. A long-term predator control program is used to try to maintain calf recruitment, but the population is still in decline, falling from an estimated 131 caribou in 2008 to 70 caribou in 2018 (Morin and Lesmerises 2020).

Location: Gaspé peninsula.

Forest Type: Mixedwood (balsam fir, white spruce, black spruce, white birch, yellow birch).

Alternative system(s): Diameter-limit cutting, single tree selection, and group selection.

Scale: Small-scale trials in three locations in and around Gaspésie National Park.

Study focus: Arboreal lichen response to alternative silvicultural systems.

Measurement(s): Arboreal lichen abundance.

Takeaway(s): Commercial thinning (67-70% retention) and shelterwood (50-70% retention) recommended for maintaining arboreal lichens; selection and partial harvest treatments with 60-75% retention may be acceptable. CPRS (clearcut), diameter-limit cutting, and seed tree systems removed most arboreal lichens.

Mature forests adjacent to Gaspésie National Park are extensively harvested and the early successional stands that result support high abundance of early seral stage vegetation that is directly beneficial to black bears (Mosnier, Ouellet, and Courtois 2008) and indirectly beneficial (via increased prey abundance) to coyotes (Boisjoly, Ouellet, and Courtois 2010). Increased predator populations are therefore supported and then incidentally prey on caribou (Mosnier, Boisjoly, et al. 2008) and this predation is the central limiting factor for the population. This apparent competition is very similar to that seen in Alberta with wolves.

The caribou range and surrounding area falls within the balsam fir-yellow birch and the balsam fir-white birch bioclimatic domains, characterized by a humid-continental climate with cold summers and very high annual precipitation (up to 1660 mm). Three distinct vegetation belts (alpine, subalpine, and mountain belts) result from the altitudinal climate gradient. Terrestrial lichens are limited to the alpine belt while arboreal lichens are abundant in old-growth forest areas. Study sites were located within the mountain belt (<900 m elevation), which is dominated by balsam fir, white spruce, black spruce, white birch (*Betula papyrifera*), and yellow birch (*Betula alleghaniensis*). Understory vegetation is typically composed of hypnaceous mosses and ericaceous shrubs (Saucier et al. 2003). Disturbances include spruce budworm, windthrow, fires, and logging (but no logging in Gaspésie National Park since 1977).

Stone et al. (2008) investigated the impacts on arboreal lichen from a number of alternative silvicultural systems. They evaluated the lichen litterfall pre- and post-harvest in old-growth balsam fir stands harvested in 1997 using the following systems:

- Cutting with Protection of Regeneration and Soils (CPRS): Removal of all stems with DBH >10 cm. Often referred to as clearcuts.
- Diameter limit cutting: Removal of all stems with DBH >19 cm.
- Selection cutting: Removal of 30% of stems, individually or in small groups. Uneven structure is retained.
- Commercial thinning: Removal of 25% or 35% of stems. No effort made to retain uneven stand structure.

The long-term changes in lichen abundance post-harvest were also investigated along a chronosequence of post-clearcut forests (30, 50, 70, and 90 years).

CPRS removed all standing lichen biomass while diameter limit cutting removed 96% of standing biomass. The thinning system that removed 25% of stems retained the highest lichen abundance, removing only 37% of standing biomass. When looking at medium-term effects, the mean biomass of lichen did not change four years after thinning but there were differences between genera; *Bryoria* significantly increased in biomass while *Alectoria* and *Usnea* did not. In the long-term clearcut sites, little lichen biomass was detected before 50 years and the largest increase in biomass occurred between 70- and 90-years post-harvest. Lichen biomass increased as a function of time for all genera, with *Alectoria* showing the greatest accumulation while *Bryoria* decreased in favor of *Alectoria* as the forest aged.

The results indicate that silviculture systems that remove large, mature trees (*i.e.* CPRS and diameter limit cutting) cannot maintain arboreal lichen. Following the initial removal of biomass, stands take 50-70 years to recover to previous conditions. These systems also increase forage for black bears increase apparent competition. Conversely, selection (30% removal) and commercial thinning (25% and 35% removal) retain ~40-60% of biomass and maintain legacy populations of host trees and lichen while producing climatic conditions favorable to growth. While Stone *et al.* speculate that strategic group selection is preferable to thinning because larger patches of trees will prevent windthrow and maintain an appropriate microclimate, studies by in British Columbia indicate that the gaps produced by group selection led to an increase in moose use (Section 7.4.3).

Nadeau Fortin et al. (2016) compared the effects of a wide variety of alternative silvicultural systems from a caribou habitat (i.e. maintenance of mature forest characteristics) and an apparent competition perspective (i.e. avoidance of habitat characteristics beneficial for black bear and moose) in and around the Gaspésie caribou range.

Location: Gaspé peninsula.

Forest Type: Mixedwood (balsam fir, white spruce, black spruce, white birch, yellow birch).

Alternative system(s): Diameter-limit cutting, seed tree retention, commercial thinning, single tree and group selection, shelterwood, "partial cutting".

Scale: 291 sites sampled.

Study focus: Caribou habitat attributes and understory response.

Measurement(s): Overstory response (tree height, DBH, basal area, and canopy cover), lateral obstruction of sight, understory response (number of sapling and fruit-bearing shrubs, vegetation cover, lichen), browsed stems.

Takeaway(s): Commercial thinning (67-70% retention) and shelterwood (50-70% retention) recommended to maintain some suitable caribou habitat characteristics and minimize understory response; selection and partial harvest treatments with 60-75% retention intermediate. CPRS (clearcut), diameter-limit cutting, and seed tree removed most arboreal lichens and favored predators.

The study used a randomized sampling design of areas harvested <15 years ago, with stratification by silviculture system. There were 291 individual sites sampled and mature coniferous forest >90 years-old was used as a control. The 7 treatments represented a gradient of basal area removal. Those producing uneven-aged forest were considered "extensive", while those producing even-aged forest were considered "intensive":

Intensive Systems:

- Harvesting with retention of small merchantable stems (HRSMS): 70-95% (generally 90%) of the merchantable volume is harvested by selecting stems with a DBH > 12 cm.
- Harvesting with seed-tree retention (HSTR): 90% of the merchantable volume harvested, with the retention of a few trees individually or in small groups.
- Cutting with protection of regeneration and soils (CPRS): 97-99% of merchantable volume is harvested by selecting stems with DBH > 10 cm, while protecting soils and regeneration. Often referred to as clearcuts.

Extensive Systems:

- Commercial thinning (CT): 30-33% of merchantable volume is harvested by selecting stems showing a risk of mortality, followed by a complete harvest 15-35 years later.
- Selection cutting (SC): 25-35% of the merchantable volume harvested by selecting stems individually or in small groups, minimum interval of 15 years between entries, no final harvest.
- Shelterwood cutting (SWC):
  - Type 1: Maintains a permanent canopy cover by harvesting 30%–40% of the merchantable volume every 30–40 years.
  - Type 2: Harvests 40%–50% of the merchantable volume and is followed by a final harvest 35–65 years later.

- Partial cutting (PC): Generic term for several treatments that harvest ≤ 40% of the merchantable volume and are not classified under a specific name.

Measurements taken in each plot included tree height, DBH, basal area, canopy cover, lateral obstruction of sight, number of tree saplings and fruit bearing shrubs (excluding *Rubus* spp, and *Ribes* spp.), number of browsed stems, and vegetation cover (%) of mosses, grasses, forbs, ferns, and *Rubus* spp. and *Ribes* spp. The biomass of arboreal lichens was also roughly assessed. Terrestrial lichens were not present in most sites and so were not estimated.

None of the seven treatments were found to retain or provide similar habitat conditions (including abundance of arboreal lichens) to the mature forest, highlighting the need for the maintenance of mature forest within caribou ranges. Harvesting with seed tree retention was considered unsuitable as it resulted in the highest density of deciduous sapling and browsed stems, as well as the highest cover of *Rubus* spp. and *Ribes* spp. Additionally, HRSMS (often referred to as CPPTM) and CPRS were recommended to be avoided near or within caribou ranges as post-harvest conditions favored other ungulate species and predators.

However, commercial thinning and shelterwood cuts (those with the lowest proportion of basal area harvested) provided the closest approximation to mature stand characteristics. Importantly, these treatments also had the least desirable understory composition for bears (fewer berries) and moose (lower deciduous sapling density). The selection and partial harvest treatments were intermediate between the commercial thinning shelterwood group and the intensive treatments in that they resulted in more browse opportunities for bears and moose. However, partial harvest treatments were rare in the sampled sites and selection cutting was predominantly in mixedwood and deciduous forests.

Selection cutting results are consistent with previous research indicating that small cuts <60 ha harvested using a two or three pass system were not favorable for caribou due to the promotion of deciduous species contributing to increased prey and predator populations (Courtois et al. 2004). However, Vanderwel et al. (2009) indicated that partial harvest increased habitat suitability for caribou. Conflicting results may be indicative of the large variation found between partial harvest systems, local site conditions, and the impacts of road access.

7.5.5 Lessons & Applicability to Alberta

The boreal forests of eastern Canada are ecologically distinct from Alberta's forests due to physio-climatic conditions and the resulting disturbance regimes. Because forests in eastern Canada have different species, age composition, and structure, their approach to forest management is different. Nonetheless, there are lessons to be learnt from Québec's forestry policies and use of alternative silviculture systems.

Studies of alternative silvicultural systems and caribou habitat in the Gaspé Peninsula have focused on arboreal lichens, and while the location is climatically very different, the results are broadly similar to those from British Columbia's Southern Mountain caribou populations (Sections 7.4.2, 7.4.3). Unsurprisingly, clearcut (CPRS) systems and systems that remove the largest, most mature trees from a stand do not maintain arboreal lichens and take many decades to recover conditions necessary to support them. Selection systems that retain uneven-aged stands with low levels of timber removal (e.g. 70% retention, Stone *et al.* 2008) are more effective system for maintaining arboreal lichen. However, in both the Gaspé Peninsula and the Southern Mountain ranges in British Columbia, predation pressure exacerbated by apparent competition and access into caribou ranges drives caribou population declines. As such, management of early seral stage vegetation is crucial and must be carefully considered for adoption of any alternative systems.

In the open black spruce forests of western Québec partial harvest systems were able to maintain terrestrial lichens effectively while also minimizing understory response. Increased light levels generally favored lichen re-growth, but in some sites vascular plant regeneration was limiting. Interestingly, in this system it was soil disturbance that was a more important factor than the level of overstory removal in determining understory response. This ecosystem is relatively unproductive and results from similar systems in more productive forests in Alberta would likely very different outcomes. Nevertheless, this work helps in our understanding of how site productivity and partial harvest treatments interact with respect to understory response.

In north-eastern Québec, selection systems with 35% removal were found to best preserve old-growth forest attributes. Work by Courtois et al. (2008) indicated that aggregating cuts could maintain caribou populations in the short-term. These studies from the spruce-moss bioclimatic region indicate that partial harvest can maintain lichen and old-growth forest attributes, but low levels of timber removal are required to achieve this. Increased access was also noted to be a considerable issue and regardless of harvest technique, aggregation, and the setting aside of adequate protected areas and travel corridors was recommended. In Alberta, aggregation of harvesting areas is also an important opportunity for minimizing the dispersal of disturbance across the landscape.

Compared to Alberta, Québec has a long history of using partial harvest systems. For example, CPPTM was introduced as an alternative to clearcutting that was believed to preserve ecological integrity and potentially lead to higher financial returns on the stand due to the improved radial growth of trees left standing. However, studies have indicated that the resulting vegetation structures favor moose over caribou. While harvesting the largest, most mature trees from a stand provides a financial incentive to companies, the resulting stand will likely not allow caribou to persist in the harvested area in the immediate term. Similarly, the group selection system in B.C. at Mount Tom led to less caribou use and more moose use of harvested areas. These examples show there can be negative consequences to introducing partial harvest systems depending on the specifics of the forest ecosystem and the silvicultural system. Additionally, while the use of partial harvest systems is more prevalent in Québec, caribou populations have continued to decline. In response, the government has combined alternative silviculture with major changes to forest management policy, the results of which are still evolving.

Though there are ecological differences between our forests, studies from Québec can help inform removal thresholds that may be appropriate for maintaining caribou habitat and minimizing understory response that favors other ungulates. While many studies from Québec have centered around habitat and lichen maintenance through partial harvest systems, the effects of additional access are a major unquantified risk factor for caribou (see Section 8 for discussion on this topic).

7.6 Intensive Silviculture & Zonation

Intensive silviculture and associated forest zoning concepts are not strictly silvicultural systems, but they are methods that can be used to mitigate timber volume losses that might occur through adoption of alternative silvicultural systems in caribou range. For example, tree improvement programs and intensive management of stands in high productivity, less ecologically sensitive stands can dramatically increase the amount of timber harvested per hectare (Pinno, Thomas, and Lieffers 2021). In Alberta, this could allow for less intensive alternative silvicultural systems to be used in caribou habitat, without unsustainable losses to overall timber supply. In the interviews with subject-matter experts this was discussed multiple times and we therefore felt it would be worthwhile to explore some case studies where these types of initiatives have been implemented and discuss their applicability to Alberta.

Quebec and Nova Scotia (Lahey 2018) have both embraced a forest zoning approach (often known as TRIAD), which represents a major shift in the context of sustainable forest management. TRIAD divides the forested landbase into three sections: protected zones (also called reserve or conservation zones), production zones (also called intensive management zones), and the ecological matrix (also called the extensive management or mixed-use zone). Both the protected and production areas are delineated first according to site suitability and embedded within the larger ecological matrix (Forbes 2019). In the TRIAD approach, each area is managed for a different outcome instead of requiring the entire forest to support a multitude of competing values. The protected areas conserve biodiversity and the old-growth forest characteristics critical for many boreal species, including woodland caribou, while the production zone is managed primarily for timber production. The extensive matrix supports both ecological values and limited timber production through the use of less intensive silvicultural practices chosen based on ecology and natural disturbance processes (Forbes 2019). Theoretically, specialization in each management zone will produce a more efficient system that simultaneously meets social, economic, and environmental objectives.

After the Mauricie TRIAD pilot project the Government of Québec implemented policy in 2014 that permits intensive management in designated areas in concurrence with protected areas and natural disturbance-based management (Larocque (ed.) 2016). Modelling by Côté *et al.* (2010) indicated that TRIAD scenarios with a 12% conservation area and a 60-74% extensive management area maintained volume levels over the long term (150 years) and produced landscapes more similar to those generated through natural disturbance than the status quo. Simulations in the Mauricie region by Tittler *et al.* (2012) also showed that the forest zoning approach resulted in greater harvest volume, more old-growth forest, less fragmentation, and less roads over the 150 year planning horizon. These models suggest that forest zoning may be a sustainable approach to maintaining caribou habitat while minimizing long-term timber losses. However, the long-term outcomes of this approach are not yet clearly understood. Whether such approaches could be effective in Alberta remains an open question.

"When the forest conservation strategy came about, I didn't object to that. I thought, 'you've got to give something to get something' […] to use some proportion of their harvest area for that is probably sensible. They grow crops in all the best areas in the farmland, so why can't that occur in the green zone?

Part of the fear was that the volume would be used to uplift the cut and not to accommodate the relaxation elsewhere […] I don't think that option fails at face value, but the devil is in the details."

"When I look into the future for forestry in Alberta, glyphosate is the big contentious issue, but clearcutting may be the next one after that. Many places have moved past that on public land but it's still the paradigm here."

There are also long-term trials of intensive silviculture practices in other jurisdictions, such as the NEBIE plot network in Ontario, which was conceived to fill knowledge gaps relating to intensification of silviculture in northern temperate and boreal ecosystems (Bell et al. 2017).

7.6.1 Lessons & Applicability to Alberta

For the last 60 years, Alberta has managed its forests under the philosophy of even-flow sustained yield (Pinno, Thomas, et al. 2021). Alberta's forest planning and regeneration standards have been established to ensure the sustainability of our publicly owned forests into the future, predicated on the assumption that ecological function and integrity are best preserved through the maintenance of the composition and distribution of the current forest landbase. Paradoxically, the rigidity of these standards may contribute to poor outcomes for species such as caribou by limiting the development and application of innovative solutions. Some alternative silvicultural systems may be able to reduce the impacts of apparent competition and maintain habitat attributes important for caribou. However, implementing systems that support favorable outcomes for caribou will likely result in reduced timber production and and/or timber volume through reduced harvest levels and extended rotations. This, as well as the expansion of protected areas and landbase withdrawals, suggests that additional harvest areas and/or increased productivity is required elsewhere to maintain timber supply. In this context, intensive silvicultural programs in designated areas are an option worth exploring.

"We have a restricting landbase and our wood supply is pretty tight, especially for conifer. Any more reduction of operations on the landbase is going to reduce the harvest rates."

"If we want to maintain harvest levels across the landscape […] there are probably things you can do outside of caribou zones to offset some of that. Plantations is probably one of them. And things like shorter rotations have huge potential in many areas of the province."

"If you have the best site preparation, the best genetics, the best vegetation management, and couple it with thinning you can do some enormously successful things as far as increasing productivity. We could do better than we're doing now. We're getting a 3 m^3/ha/year average for many of the FMAs. I'm sure on some of the better sites we could double that if we used intensive management."

"There are places in Alberta that could be incredibly productive if we manage them like tree farms. Our current restrictions are quite challenging […] we're not growing trees nearly as fast as we could."

Alberta's forests are a good fit for intensive management with much of the interior plain being exceptionally productive with deep, fertile soils with a high-water holding capacity (Pinno, Thomas, et al. 2021). Additionally, Alberta and B.C. contain nearly 80% of Canada's "marginal lands", *i.e.* lands of borderline profitability when used for agriculture, that could potentially be designated for wood production purposes (Anderson and Luckert 2007). A move towards production forestry is also supported by a well-developed forestry industry, an extensive road network, and the increasing availability of new knowledge, tools, and technologies such as LiDAR to determine the most favorable areas for plantations. The modernization of the provincial Forests Act by the passing of Bill 40, the *Growing Alberta's Forest Sector Amendment Act, 2020* has added flexibility for policy changes to better align with current and future management goals. However, there are significant hurdles to consider – Pinno *et al.* (2021) identified several barriers to the implementation of intensive forestry in Alberta:

- Insecure land tenure.
- Rigid regeneration standards (*i.e.* stocking, density, and species composition requirements).
- Inflexible landbase designations.
- Requirement to use local seeds when planting.
- Prohibition of exotic species on public lands.
- Managing for even-flow sustained yield (maximizing volume).
- Long modelling periods (200-year planning horizon).
- Minimum rotation age (typically 70-100 years).
- Approved yield model (*i.e.* GYPSY) does not include intensive options.
- Perception of intensive management as uneconomical.

Subject-matter experts interviewed for this report also noted the poor public perception of plantations and the sometimes risk-averse nature of forestry in Alberta as obstacles. The need for broad public buy-in and stakeholder agreement as well as the requirement to introduce the idea of zonation as a "package deal" that comes with increased protection of wild spaces was strongly emphasized.

"Overall, I think the planning standards have a lot of barriers. As well as the belief that intensive management does not improve the yields."

"From the public perception part, the plantations are always hard. It's great for public relations to say you'll protect areas. But they're usually not sold as a package […] and that's not a good model – it needs to be […] out in the open. Here's what we're planning on doing and here's why it's important to do it that way."

"The public perception is going to be a tough one there. They're happy to set space aside for caribou but not so happy with intensive treatments, which would be genetic manipulation, fertilizer, herbicide, exotic species – there will be some pushback."

"I think there needs to be broad buy in from different stakeholders and different groups that this is the right thing to do."

While a perception of plantations as uneconomical may exist, financial analyses and policy scenario modelling have indicated that priority use zoning for plantations using exotics such as hybrid poplar could be financially viable, reducing inefficiencies and increasing net present value (Anderson et al. 2012; Anderson and Luckert 2007). Analyses on native white spruce have indicated that intensive management (consisting of an increased planting density, commercial thinning, and a shortened 50-year rotation) in productive sites can result in comparable or greater mean annual increment and tree size than standard silviculture on an 80-year rotation (Pinno, Hossain, et al. 2021). The main barriers to forest zoning and intensive management may be as much sociopolitical in nature, as ecological or economic.

In addition to potentially minimizing timber losses while affording broader environmental protections, forest zoning can introduce elements of adaptive management that are lacking in Alberta's current approach. For example, shortened rotations provide a considerable management benefit by allowing for more rapid decision making based on feedback. A zonation approach may also be better adapted to withstand the effects of a changing climate. From an ecological perspective, protected ecosystems that retain high levels of biodiversity and functional integrity are more resilient to change. From an intensive management perspective, using plantations to grow species or genotypes that are better adapted to a warming climate may lead to a more stable wood supply and greater economic longevity of the forestry industry. Within the larger ecological matrix, the canopy cover provided by partial harvest systems moderates the effects of drought, heat, and killing frosts that contribute to slower growth rates and failed regeneration. Underplanting and understory protection systems was also recommended during interviews as a way to help safeguard conifer from the effects of increased droughts and fires.

> *"If you're going to be harvesting in 50 years you don't have to be right to 200 years because you can change that decision and do something else in 50 years. If you're looking at long rotations, you have a lot longer to live with the decision you've made today […] Right now, there's no opportunity to do anything different if your information gets better or your management objectives change."*

> *"One opportunity might be to look at species like Siberian larch and to grow some of these kinds of stands; they have lower fire risk and can be closed canopy as well. We're going to have to use every trick we can to keep forests on the landscape in the future. Having rules that prevent use of an exotic species, especially in high yield plantations, is not going to be a smart policy."*

Sub-regional planning for caribou ranges and surrounding areas is underway to provide guidance on the placement and duration of disturbance footprint in Alberta. While forest zoning could provide a significant benefit to caribou management and potentially help to bring Alberta in line with federal requirements of the *Species at Risk Act*, this approach faces significant sociopolitical, economic, and cultural obstacles. Many experts interviewed for this report asserted that the current standards and regulations are too restrictive and that forestry practices in Alberta do not align well with caribou recovery goals. It is outside the scope of this report to make policy recommendations. However, it appears that localized solutions such as alternative silviculture may need to be paired with an improved policy framework.

8 Economics & Access

The clearcutting with retention silvicultural system is effective and efficient for forestry in Alberta and forestry companies and their operations are generally optimized around the use of this system. A homogenous (even-aged) forest is ultimately easier to manipulate in order to optimize production and timber output, and thus revenues (Puettmann et al. 2015). In addition, management plan modelling is simpler and growth and yield models for conventional clearcut forestry are well-developed and considered to be theoretically sound (Tahvonen and Rämö 2016). Reforestation standards and other legislation also fit within this paradigm and can be restrictive toward the adoption of alternative silvicultural systems (Section 5.4). It is therefore clear that any major changes to the status quo will require professional and government buy-in and support, and are likely to come with additional costs, at least in the short-term. However, given increasing legal and societal pressure to ensure self-sustaining caribou populations, as well as other biodiversity, cultural, recreational, and aesthetic values, pursuing innovative silvicultural solutions should help to increase social license. Indeed, if a point is reached at which access for forestry using a clearcut system in caribou ranges is limited or restricted, having a diverse range of options for lower impact harvest should provide operators with greater flexibility in adapting to such challenges.

In this section we discuss the economic considerations associated with the adoption of alternative silvicultural systems. Part of this discussion revolves around access, as in general, alternative silvicultural systems tend to involve a larger network of access for the same amount of timber volume and often require re-use of this network over time to facilitate re-entries. Not only is this an economic constraint, it is also a major constraint on the effectiveness of such a system for improving outcomes for caribou.

As such, there is a need for caution and careful consideration of how adoption of alternative systems could affect the system as a whole. They are not a "one size fits all" solution that can be applied uniformly across a region, forest management unit, or even a single planning unit.

8.1 Economic Considerations

Partial harvest systems are inherently more complex to plan, operationalize, and carry out, and therefore come with additional costs. On the other hand, economic benefits of partial harvest systems become more apparent when viewed over an extended timeframe. This is clearly demonstrated by commercial thinning, which can provide growth rate benefits and flexibility in timber supply (Section 7.2). Costs could also be reduced or offset through the aggregation of harvest areas, efficient spatial layout, and increased utilization of harvested wood. Other systems in mixedwood stands such as understory protection may also have some potential to reduce browse species availability for other ungulates while implementing a system that is economically beneficial (Section 7.3).

8.1.1 Volume to Area Reduction

The most self-evident impact of adoption of partial harvest systems is that only a proportion of the stand is available for harvest at any one time, or potentially at all, in the case of a single-entry system. For example, the partial harvest systems trialed and implemented in British Columbia used 50% removal in the case of the irregular group shelterwood system and 33% removal in the case of the group selection (Section 7.4). Because harvesting a smaller portion of a stand during a single operation is less efficient than clearcutting an entire stand in one entry, harvesting costs per unit volume are generally higher in partial harvest systems, especially in mixedwood stands where species must be sorted (Puettmann et al. 2015). There may also be a longer-term timber supply cost if there is delayed or no re-entry possible, or if regeneration cannot be achieved.

There is also risk inherent for caribou because if the lower volume retrieval from partial harvest systems (i.e. less intensity) is made up for by additional harvest elsewhere (i.e. greater extent) then this can increase disturbance across the landscape and neutralize the benefits of partial harvest for caribou (e.g. if a 50% removal system was being used, but twice the area of land was disturbed for harvest in order to maintain the same timber volume). This could even result in worse outcomes for caribou than traditional clearcut harvesting.

> *"If you can only take half the volume per hectare, and the mill isn't changing, then you need to double the hectares. I wouldn't be comfortable with that because we don't know enough yet."*

8.1.2 Planning

Block layout is more complex and time consuming for partial harvest systems. Increased time and capital is often required for pre-harvest planning, tree marking, site supervision, monitoring, and road construction and maintenance; residual stand damage and crew safety are additional concerns (Puettmann et al. 2015; Soman, Kizha, and Roth 2019). For example, one subject-matter expert described the planning process for a particular group selection partial harvest system.

> *"Instead of the blocks being 40 or 60 ha they're only a ½ ha. Establishing the roads where you wanted them, and then the streams, drainages, and wet areas. You need to know where those are. […] Establishing the base road locations and streams and even the ecotyping in the non-snow seasons so you have a good feel for the ground. Then layout the patches from there. Once you start your pattern, you can only leave so much space and they can only be so close together. Using streams as boundaries on one side. Often the stand would have micro types, where it's all big trees and then it switches to a clump of smaller ones, so trying to take advantage of natural boundaries as much as possible."*

The scale of additional planning costs will vary dramatically depending on the specifics of the system.

> *"A word of advice on the practical side for silvicultural systems, anything that's a group removal approach is generally preferred by the forest industry compared to single tree selection or thinning. Thinning is far more expensive than a group approach […] Group selection is generally more practical for layout and calculations of cut."*

8.1.3 Equipment & Operators

Equipment requirements and operator skillsets vary greatly depending on the particular partial harvest system, but changes in equipment needs and associated specialized training are likely to be additional up-front costs in the adoption of alternative systems. The scale of these costs would be highly dependent on the specifics of the situation and the companies involved.

> *"Initially, there were concerns it would cost a lot more, but in the end I think the bunching isn't that much slower. They move a little bit more, so maybe a buck or two there. Skidding minimally. They have to move over patches, but it's minor. Same thing with processing, they're just roadside processing. They have to move a little more. Loading had more delays. If you only have one or two little patches you may only have one load or a load and a half. The loader had to walk to load the trucks so there's more delays that way. Overall, the costs weren't as extreme as they thought. I would guess maybe 20% more off the top of my head."*

8.2 The Costs of Access

Road building, watercourse crossings, maintenance and restoration all contribute to the expense of providing access. The majority of alternative silvicultural systems require more extensive access and/or require access to be open for a longer period of time. This is an additional cost to companies but is also a major risk for caribou. Linear features, including roads, can improve access for predators (Dickie et al. 2017) and for other ungulate species. For example, it has been suggested that moose use access roads as conduits for elevational migration. Given the preeminence of predation as a proximate cause of caribou decline, this is particularly concerning. The impact of new roads can be especially detrimental in relatively inaccessible habitat, as is the case for B.C.'s Southern Mountain caribou.

> *"One of the biggest footprints we can leave is roads, especially if we don't deactivate them and they become legacy features. […] Old roads are a super-highway for everything. Moose, bear, elk, deer, lynx, wolverine, wolves, etc."*

Case studies from Québec predominantly focused on caribou habitat and lichen abundance (Section 7.5), but recent studies have demonstrated the detrimental effect of additional road access. Modeling from Vanlandeghem et al. (2021) suggests higher mortality for caribou with more extensive road networks. Similarly, a study by Labadie et al. (2021) indicated that salvage logging in forests already significantly disturbed by spruce budworm increased caribou mortality in multi-prey systems even though the disturbed area was kept relatively constant except for the addition of haul roads. Subject-matter experts also identified extensive road networks as a major risk to caribou.

> *"In my view, I would not strongly recommend partial harvesting for caribou. Or too much partial harvesting. The main reason is that with partial harvesting comes a very extensive road network, and that's the major problem."*

> *"But when you do salvage logging and create a road network to extract some of the forest in an area that is already considered disturbed, it's worse even though it's disturbed already according to Environment Canada […] I think the road network is key in all these things."*

In Alberta there is a focus on the restoration of linear features for the purpose of reducing encounter rates of predators and caribou and achieving large contiguous areas of undisturbed habitat (Filicetti, Cody, and Nielsen 2019; Government of Alberta 2018b). Adopting alternative silvicultural systems that then increased linear feature density in caribou ranges would not mesh well with this priority, but deactivation of roads or access controls after silvicultural treatments can be used to mitigate these impacts to some extent. However, this comes with additional costs, and once roads have been constructed it can be difficult to remove them from the landscape again if other land-users make use of them for recreational activities (e.g. snowmobile or ATV activity). Aggregation of harvesting areas may also provide an opportunity to minimize the extent of access network disturbances at any one time, while also providing operational efficiencies.

"Controlling access is well within our technical realm – will cost money and affect values such as recreation (public pushback) but that's one place the research is telling us we can have some significant benefits for caribou."

"But the main road systems, no matter the silvicultural system, they seem to stay in place. People start using them for other things."

8.2.1 The Trade-Off

Ultimately, if we assume that mill requirements and timber supply volumes are maintained, there is a clear trade-off between adoption of partial harvest systems that are potentially beneficial to caribou and the need for additional access on the landscape. It is unclear what the relative costs and benefits to caribou would be in this case, but there is a very real risk that the negative effects of additional road access and dispersed disturbance would outweigh any benefits of partial harvest.

It therefore seems likely that partial harvest systems will only have significant benefits to caribou over clearcut systems if they directly replace clearcut, with the associated loss of timber volume, rather than attempting to make up missing volume through an increased area of harvest within caribou range. Clearly, this would have significant economic implications for commercial forestry.

9 Climate Change

"The climate change question is an interesting one as it's so complicated, there's so much going on and so many interactions. There's probably no simple answers for any of this."

A changing climate is expected to trigger significant changes to the composition, extent, and persistence of Alberta's forests. As part of the interview process, we asked subject-matter experts for their thoughts on climate change and the potential mitigation strategies that may help keep caribou, and the forests they rely upon, on our landscape.

Climate change is anticipated to raise the mean annual temperature of the boreal forest by at least 2°C by the 2050s with increases expected to be especially significant at northern latitudes (Barber et al. 2018; Gauthier et al. 2014). While the eastern Canadian portion of the boreal forest has experienced more rainfall, the west has faced intensified drought conditions and the modest precipitation increases predicted for the west are not expected to offset the elevated evapotranspiration caused by rising future temperatures (Gauthier et al. 2014). The prairie-forest ecotone may be pushed farther north because of decreased water availability and increased evaporative demand, with Gauthier et al. (2014) noting that heat and water stress has already caused aspen mortality within this transitional area.

These conditions will lead to an increase in the frequency of wildfires with the incidence of days with fire conducive weather projected to grow 50 to 100% in the western boreal forest (Barber et al. 2018). Warming temperatures also directly and indirectly facilitate the spread of pests, parasites, and pathogens. In addition to biophysical impacts affecting tree growth, reproduction, establishment, mortality, composition, and structure, the boreal forest and the species it supports will have to withstand more stochastic events as extreme weather events become more common (Gauthier et al. 2014). Changes to baseline conditions and disturbance events will impact the forestry sector through reductions in timber quality and quantity, uneven access and increased delivery costs, and an intensification of forest management requirements (Gauthier et al. 2014).

Climate change pressures are expected to negatively impact caribou populations through a number of pathways. Festa-Bianchet et al. (2011) cautions that *"[a] warming climate will affect all aspects of caribou ecology and exacerbate the impact of other threats."* Negative consequences for caribou include the loss or conversion of forest habitat, increased predation pressure, increased prevalence of pests and pathogens, reduced movement potential, and diminished recruitment (Barber et al. 2018; Bauduin et al. 2018; Festa-Bianchet et al. 2011; A. David M. Latham et al. 2011; Mallory and Boyce 2018; Vors and Boyce 2009). Milder winters also lead to additional overlap between caribou and their predators. 78.8% of adult female caribou mortalities in northeastern Alberta occurred during the snow free months, suggesting that shorter winters may increase incidental encounters and predation events (A. David M. Latham et al. 2011).

The persistence of caribou is threatened by land alteration, which is compounded by the effects of climate change (Vors and Boyce 2009). Of the two factors, the extent of disturbance is more easily mediated at a regional level; however, because impacts are interrelated, interactive, and cumulative, localized measures to preserve caribou can be jeopardized by the wider effects of climate change (Gauthier et al. 2014). Furthermore, a lack of action can cause a reduced adaptive capacity, both from an ecological and institutional perspective. Being proactive about the potential future impacts of climate change during management planning leads to greater efficiency and resiliency in the face of unpredictable outcomes. Strategies to minimize the negative impacts of climate change include:

- **Mitigation**: Avoid or minimize negative impacts (e.g. lowering GHG emissions).
- **Adaptation**: Moderate negative impacts and possibly exploit beneficial ones (e.g. plantations).
- **Compensation**: Offset negative impacts (e.g. restoration, assisted migration, afforestation).

These strategies are not mutually exclusive, and solutions will involve a mixture of strategies to address climate change on varying spatial and temporal scales. Because forests act as carbon sinks, changes in the boreal landscape can initiate strong positive feedback mechanisms that intensify the effects of climate change and induce rapid changes. Trajectories can be challenging and slow to alter because of this inertia (Bauduin et al. 2018), making actions taken in the boreal particularly important.

9.1 Forest Conversion and Fragmentation

Forest conversion occurs in response to natural disturbances, anthropogenic disturbances, and climate change. The effects of localized land-use changes can be exacerbated by a changing climate, and climate change can be intensified by human activities, creating a positive feedback loop. Rising temperatures, drought stress, and increasing fires are predicted to cause fragmentation and a shift towards ecosystems typically found at lower latitudes (Gauthier et al. 2014), which in Alberta includes deciduous-dominated parklands and grasslands. Within the Canadian boreal forest, a shift from late-successional conifers to early successional softwoods and broadleaf species is already occurring (Barber et al. 2018). Because mature trees are resilient to change, conversion will primarily occur following extensive mortality events (e.g. fires, insect outbreaks, clearcut harvest). The resulting fragmented and patchier distribution of habitat is expected to be detrimental to caribou populations (Festa-Bianchet et al. 2011).

"The other concern is that if we see drought effects on conifer you will slowly see the conifer converting more to mixedwood and aspen. The "leafing out" – that's what they call it in Quebec, "enfeuillement" – and conversion of that forest, that's a possibility."

"The spruce is most vulnerable to drought conditions, so we have the greatest risk of losing spruce."

Modelling by Barber et al. (2018) investigated the potential impacts of different climate scenarios in northern Alberta and found that early seral deciduous forests would expand through the 2050s with upland forest predicted to be largely replaced by extensive grasslands by 2080. Forest composition changed dramatically, with grasslands increasing from a <1% baseline to up to 50% of the area, upland conifer decreasing from a 20% baseline to 2-12% of the area, and deciduous cover increasing slightly in all scenarios. Predation and disease risk were found to be higher in converted grasslands and lower in the holdout peatlands. Because peatlands moderate water table fluctuations and can take centuries to undergo vegetation change, they may act as critical hydrologic refugia, especially in Alberta where caribou strongly select for bogs and fens.

9.1.1 Natural Disturbances

"Under climate change, the big risks are going to be fire and insects. It's hard to predict what insects might hit us next."

Caribou habitat can also be altered by natural disturbances such as wildfire and forest pest outbreaks that reset succession and create early seral stage habitat. Stand replacing disturbances can diminish or eliminate the resistance of stable ecosystems to compositional change, leading to changes in species distribution and abundance (Gauthier et al. 2014). An escalation in natural disturbance events paired with the continued expansion of human activity may increase risk for caribou populations.

The frequency and severity of wildfire is expected to intensify under changing climatic conditions (Gauthier et al. 2014) and increased fire occurrence will reduce old-growth caribou habitats and lichen availability (Price et al. 2013). Modeling has predicted a 74 to 370% increase in annual area burnt and a 300% increase in the number of future fires (Barber et al. 2018). Frequent and repeated disturbances can trigger a rapid transition of cover type and in extreme cases regeneration failures can transform closed canopy stands into open forests (Gauthier et al. 2014) though the shift towards deciduous cover creates a negative feedback process that eventually moderates fires (Barber et al. 2018). Literature indicates that the effects of wildfire on caribou are not as severe as those resulting from forestry. While caribou generally avoid post-fire habitat for 6 to 60 years, they do not permanently alter their home ranges but instead avoid the burnt patches (Finnegan et al. 2021). In comparison, harvesting has been found to shift or change the size of home ranges (Smith et al. 2000).

"With more severe fires, I'd be concerned with a general shift on the landscape towards more deciduous dominated forest, and that would be really bad for caribou."

Climate change also acts as a catalyst for extensive forest pest outbreaks, the most economically notable being mountain pine beetle (*Dendroctonus ponderosae*) in British Columbia and Alberta and spruce budworm in the eastern provinces. Insect populations are typically limited by cold winters that increase mortality and milder seasonal conditions are leading to an expansion in historical range. Additionally, climatic stressors such as heat and drought can make trees more susceptible to pest outbreaks (Gauthier et al. 2014). Canopy defoliation can also trigger a flush of understory vegetation that could increase apparent competition. Labadie et al. (2021) demonstrated that an outbreak of spruce budworm modified food web interactions and increased predation on caribou.

The recovery of timber resources through salvage logging adds a secondary level of disruption following natural disturbance events. Labadie et al. (2021) found that salvage logging operations in areas already considered disturbed intensified caribou mortality risk and was an additive disturbance as opposed to a compensatory one. The deployment of an extensive road network was proposed to be the primary reason for this result. Similarly, Festa-Bianchet et al. (2011) suggest that road development may explain why harvest has a greater impact on caribou than wildfire, even when losses of mature forest are comparable. The degree of impact on caribou likely varies with the reforestation strategy employed following salvage logging. Planting could provide a benefit to caribou by shortening the early successional stage that occurs post-disturbance, especially following low intensity burns where coniferous recruitment is delayed.

9.2 Species Distributions

"But now the snow conditions, because of climate change, are more consistently suitable for deer."

Climate change and land-use change can also interact to increase deer populations and therefore increase apparent competition (Dawe et al. 2014; Dawe and Boutin 2016). Secondary predators such as black bears (*Ursus americanus*) also benefit from additional early successional habitat (Barber et al. 2018). In northeastern Alberta, dramatically increased numbers of white-tailed deer (*Odocoileus virginianus*) have caused significant increases in wolf density and an increase of caribou in wolf diet. Latham *et al.* (2011) found that industrial expansion in northern Alberta from the mid-1990s to the late 2000s led to a 17.5-fold increase in white-tailed deer and an increase in wolf density from 6 to 11.5 animals per 1,000 km^2, but no observable change in moose occurrence. Climate change, through vegetation change, milder winters, and decreasing snow cover and depth, is a key driver of this expansion because winter deer density is closely tied to snow depth (Laurent et al. 2021). The impact of habitat alteration on deer density was found to be strongest in the north, indicating that there would be a disproportionate benefit of habitat protection or restoration in northern areas of the province to reduce deer expansion.

(2021) found that apparent competition decoupled moving northwards latitudinally in Saskatchewan, likely as a result of poor productivity post-fire, a lack of browse, and a corresponding low density of moose; however, this was in the absence of alternative prey such as white-tailed deer and significant anthropogenic disturbance. These findings underscore the importance of minimizing disturbance in northern areas to avoid apparent competition becoming more severe for caribou.

The continued northerly expansion and overlap of ungulate ranges may increase the risk of introducing new parasites and epizootic pathogens to caribou and increase prevalence and transmission between species (Vors and Boyce 2009). Deer are a vector for the meningeal brain worm (*Parelaphostrongylus tenuis*), a parasite that is harmless to deer but causes a fatal neurological disease in caribou (Vors & Boutin 2009). The extirpation of several caribou populations in eastern Canada have in part been attributed to *P. tenuis* and it is believed that the presence of infected deer led to the failed reintroduction of caribou to Cape Breton and other former ranges where wolves are absent (Festa-Bianchet et al. 2011; Vors and Boyce 2009). Deer can also expose caribou to chronic wasting disease (Barber et al. 2018) and changes in moose distribution and abundance can increase incidences of *Echinococcus Rudolphi*, a parasite that links moose, caribou, and wolves (Festa-Bianchet et al. 2011). Moose, deer, and elk populations in Alberta may also be affected by winter tick (*Dermacentor albipictus*) and giant liver fluke (*Fascioloides magna*) (Lamy and Finnegan 2019).

9.3 Mitigation Strategies

This report focuses on mitigation strategies through the lens of silviculture and alternative harvest systems and recommends measures that are likely to assist with caribou persistence and/or recovery. However, several strategies that are out of the scope of forestry are also considered. The majority of those interviewed remarked on the difficulty of planning for climate change due to the complex interplay of many unpredictable and unknown factors. A few provided examples of potential benefits to caribou and forestry, at least in the short-term. Overall, the consensus was that climate-driven changes to Alberta's forests would negatively impact caribou in the future.

"One approach for adaptation to climate change if there is concern about drought is density management. You have fewer trees needing water and you concentrate on those trees."

"One of our biggest challenges is cold, wet soils so in the short term, climate change will probably have a positive effect on many tree species. Spruce is a great example of this […] But when is that tipping point? 5 years, 10 years, or 50 years from now?"

"Where I have seen the climate change impacts be greater is where we're relying on natural regeneration. Allowing expansion into new areas or seed crop failures, in some cases. When we're planting, we're bypassing that vulnerable stage of succession."

"In the boreal, there's probably a role for other species. Or other genotypes of the same species perhaps. It's never as simple as just moving things northward. I haven't seen that work as well."

"I could envision more eastern species becoming common, such as burr oak. It may move into Alberta in the future so maybe it's worthwhile establishing some of them now. Conifer has less options, but something like Douglas fir may be an option."

"The understory protection probably is broadly beneficial on sites that can support both spruce and aspen. They're more robust and a lot more resilient. More resistant to short term drought."

"One opportunity might be to look at species like Siberian larch and to grow some of these kinds of stands, they have lower fire risk and can be closed canopy as well."

"We can expect to see conifer slow down in its growth rate […] Less moisture means slower growth rates"

A heterogenous forest is a resilient forest. Silviculture systems and treatments that maintain diversity at the stand and landscape scale, combined with adaptive management processes, are typically recommended to mitigate the effects of climate change. In addition to managing for climate and natural disturbance-driven changes to Alberta's forests, the intensity and extent of anthropogenic disturbances must be moderated while measures to protect caribou are employed. Many recommendations for resiliency in the context of caribou conservation also support the overall maintenance of biodiversity and ecological integrity of forest ecosystems. Specific measures identified through the interview process and literature review to mitigate, adapt to, and compensate for climate change are listed in Table 9-1. For a detailed review of climate change mitigation strategies for Canada's boreal forests see Gauthier et al. 2014.

Table 9-1. Mitigation, adaptation, and compensation strategies for climate change.

Impact	Mitigation	Adaptation	Compensation
Forest Conversion & Fragmentation	Increasing protected areas, including biodiversity hotspots, representative forests, climate refugia, and areas critical to species at risk. Implementing integrated land management to manage cumulative effects from multiple forest users. Aggregating harvest and utilizing travel corridors to minimize effects of fragmentation on caribou movement. Using density management (i.e. thinning) to minimize effects of drought and increase resource availability for remaining trees.	Planting novel tree species or genotypes in anticipation of future climate conditions. Modifying seed transfer zones. Using plantations to increase productivity to compensate for AAC losses resulting from increased protected areas and/or partial harvest. Utilizing assisted migration/range expansion of tree species.	Enhancing or maintaining functional connectivity inside protected areas networks to support caribou movement throughout their ranges. Planting to bypass vulnerable stages of succession during post-disturbance regeneration. Fertilizing to increase stand productivity. Allocating the forest landbase using zonation approach, including utilizing high intensity forestry in productive areas.
Natural Disturbances	Reducing non-climatic stressors, e.g., fragmentation, pollution. Reducing fuels, using prescribed burning, and/or implementing fire management programs. Using harvest techniques that create heterogeneity in the forest. Utilizing understory protection systems to protect and shelter conifer.	Planting tree species or genotypes less susceptible to disturbance events. Implementing partial harvest systems to introduce heterogeneity in managed forests. Underplanting spruce (or other tree species) to supplement regeneration. Harvest stands most vulnerable to insect outbreaks, plan landscapes to minimize spread of pests/diseases, and proactively control invasive .	Shortening rotation lengths outside caribou ranges to compensate for AAC losses, hasten the establishment of better adapted species, and reduce the risk of timber being lost to stochastic natural disturbance events. Regenerating forest promptly following disturbances. Letting forests regenerate naturally following disturbances under some circumstances.
Changing Species Distributions	Increasing caribou habitat protection, especially in the north. Choosing protected areas that limit predator-prey interaction, *e.g.*, through habitat types, distance to roads. Minimizing boundaries shared by protected areas and cutblocks.	Implementing partial harvest systems to maintain or promote future caribou habitat. Enhancing relationships and dialogue between wildlife biologists and forest managers to support knowledge exchange, technology transfer, and capacity building.	Restoring caribou habitat. Deactivating and restoring roads to maximize forested areas. Increasing harvesting pressure for alternative prey to reduce apparent competition

10 Recommendations

In this section we make a number of recommendations based on the findings of this report. While these are guided by the literature review and interview process, they do not necessarily reflect the opinions of the interviewed subject-matter experts.

Our literature review and interviews show the complexity, intricacies, and uncertainty in attempting to apply alternative silviculture systems to manage for caribou habitat and maintain a working landscape (Table 1-1). This is exemplified through the variability of habitats caribou use, the generalist nature of other ungulates, and the impacts of access infrastructure on caribou, other ungulates, and predators. While it is clear that silviculture can alter vegetation to favor components of caribou habitat with a reasonable degree of confidence, there is insufficient information to assess the costs and benefits of different silvicultural prescriptions and if the overall effect will be positive for caribou. This is compounded by the large spatial scales required by self-sustaining caribou populations. Treating small areas of a range with alternative silviculture systems will have limited impacts that are not likely to affect caribou population trends.

10.1 Pilot Planning Study

We recommend that the information assembled in our review on the role of alternative silviculture systems be applied in a strategic planning exercise designed to better assess the cumulative trade-offs for a large component of a caribou range. A detailed planning approach is required as alternative (non-clearcut) silviculture systems can only be successfully applied to a limited range of stand conditions whereas clearcutting can be applied to any stand condition with merchantable timber. The limitations on the extent and amount of alternative silviculture systems will have impacts on their ability to influence caribou habitat. Detailed local knowledge will be required to develop plausible plans. As effects are both spatial and temporal, especially when the necessary access requirements are incorporated, strategies should be forecasted for 40 years or more into the future to assess short- and longer-term effects. This planning study would be designed in a such a way as to prepare for implementation if the results suggest that favorable outcomes may be achieved.

Recommendation 1: Assemble a multidisciplinary team of biologists, forestry professionals, and government representatives with the necessary expertise to carry out the planning exercise. A detailed understanding of vegetation limitations and requirements coupled with the practicable ability to create or maintain those structures through silviculture is required.

We propose the following steps:

- Select a large-scale component of an Alberta caribou range where harvesting is permissible. One opportunity could be to make use of Harvest Timing Units (HTUs) that have been or are being developed by Alberta forestry companies for the purpose of aggregated harvest planning. It is assumed that these HTUs will be clearcut harvested, but for this study a selection of HTUs could instead be re-planned with a focus on alternative harvest systems. Other HTUs scheduled for clearcut and HTUs with no near-term harvest plans would make effective controls. However, at this scale it may be difficult to assess impacts to timber harvest volumes (AAC) and to better address this, planning at an FMU scale could be more appropriate. Ultimately the scale and location of the study area would need to be discussed and defined by the participants in the process.

- Consider the application of treatments that are possible with the existing forest structure to achieve the stand level objectives (varies by range). Evaluate the present stratification for the forest and enhance it where necessary to align with the proposed silviculture alternatives.
- Develop a matrix of scenarios to test.
- Develop stand-level vegetation objectives that are positive for caribou and negative for other ungulates, to direct silviculture prescriptions.
- Develop silviculture treatments to either maintain or speed up the development of desirable vegetation, considering practical operational limitations but without restrictions on the use of existing equipment or costs.
- Develop growth and yield models and transitional yield curves that would be representative of alternative silviculture treatments. Include yield curves for lichen abundance if possible. Identify costs for operational planning, access requirements, etc.
- Quantify the costs, timber extracted, and rates of production from each treatment and assign scores for caribou habitat or other prey. This would take the form of generalized qualitative rankings by experts for some attributes.
- Field visits will be required to determine practicable applications and plausible vegetation trajectories. Areas with existing trials or implementation of alternative systems will be of particular value in this process.
- Integrate alternative silviculture, including estimated growth and yield projections, access requirements, and costs into a spatial modeling framework to evaluate and assess management scenarios.
- Compare and contrast scenarios for caribou and other ungulate habitat values considering access impacts along with timber production and costs.
- Detail how monitoring of vegetation response, caribou and other ungulate response, and predation response would be achieved and the associated costs. Without an effective monitoring component, it will not be possible to evaluate success or failure.
- If the pilot planning study indicates that positive outcomes could be achieved, move to an implementation phase.

10.2 Knowledge Exchange

This report attempts to bring together expertise from the fields of silviculture and wildlife biology. In general, these disciplines have relatively little day-to-day crossover for the majority of professionals, and we identify this as an area where improvements can be made. Based on the information and opinions collated in this report, we believe it would be beneficial to have organized events bringing together experts from these fields to discuss silvicultural options for addressing caribou habitat concerns. For example, workshops in which wildlife biology experts identified the key forest characteristics of high-quality caribou habitat in different parts of the province and silvicultural experts identified possible systems or techniques for maintaining or creating these forest characteristics would be valuable. Private-sector professional foresters would also need to be part of this conversation, to help understand operational concerns and facilitate dissemination of ideas amongst industry.

Recommendation 2: Organized workshops to facilitate knowledge exchange between silviculture experts, professional foresters, and wildlife biologists. This could be incorporated into the pilot planning study.

Recommendation 3: A project to provide a practical, visual guide to the forest characteristics of high-quality caribou habitat in different parts of the province, perhaps driven by existing telemetry data and on-the-ground data and image collection.

10.3 Utilizing Existing & Planned Trials

We have reviewed a wide variety of trials, studies, and interventions in this report, some of which have a clear caribou focus, while others do not. Many of these, particularly those that have not generally been considered from a caribou perspective, have potential to be further explored in order to inform how we might use alternative silvicultural systems and harvesting techniques to improve outcomes for caribou, such as in the context of the recommended pilot planning study.

10.3.1 Alberta

Recommendation 4: The EMEND project has a wealth of long-term detailed data on understory response to different levels of retention, the higher rates of which are essentially a partial harvest system. The vegetation data could be used to better understand how different treatments could be used to minimize post-harvest desirability of harvest areas to moose and deer. For example, it may be possible to narrow down the range of retention levels that would maintain the understory in a state close to the unharvested controls and thereby avoid a 'flush' of early seral stage vegetation that is beneficial to moose and deer. In addition, the project has post-harvest terrestrial lichen cover data that could also be analyzed.

Recommendation 5: Existing trials such as the Hotchkiss River Mixedwood Management trial, as well as existing operational experience, could be used to help inform if and when understory protection systems could be used or adapted to reduce habitat quality for other ungulates in mixedwood stands. The application of understory protection can have very different outcomes for understory browse abundance depending on understory tree size, distribution, and other factors. Using existing data to identify best practices for applying this system in areas in or near to caribou habitat could help to minimize the effects of apparent competition.

Recommendation 6: There are opportunities to "piggyback" on future trials with a caribou-focused component. The large-scale planned trials for commercial thinning mentioned in Section 7.2 are a good example of this. Single-tree selection through commercial thinning treatments has potential for maintaining or creating high quality caribou habitat, but could also have negative impacts, depending on factors such as site productivity. By incorporating an understory monitoring component in these trials important insights could be gained at relatively low cost.

10.3.2 Other Jurisdictions

Extensive information on partial harvest systems aiming to improve outcomes for caribou is available from work done in British Columbia and Quebec. While ecological conditions are often different to Alberta forests, there is a huge amount to be learnt from experiences in other jurisdictions.

Recommendation 7: Utilize the knowledge gained from partial harvest trials in British Columbia and Quebec to identify specific partial harvest systems that might be used in caribou ranges to replace clearcut harvesting. We know that in some cases these systems can be negative for caribou, so it is vital that there is careful consideration of site conditions and desired stand outcomes.

10.4 Research

The review presented in this report, as well as the feedback from subject-matter experts, makes it clear that the impacts of any alternative silvicultural system or harvesting technique are highly dependent on the specifics of the system and the local forest and ecosystem. There are no “silver bullet” options and in fact, there is significant risk with many systems because under some conditions, outcomes for caribou might be worse than clearcutting (e.g. Section 7.4.3). In the context of apparent competition, we expect there to be a range of understory response that can be quantified based on light levels (amount of canopy removal) and site conditions (productivity). A research goal should be to define the boundaries of these axes and identify if there are “sweet spots” where minimal understory response and maintenance of caribou habitat can be achieved.

Recommendation 8: Explore ways to identify the specific site conditions, level of harvest and associated light conditions under which a partial harvest system would minimize understory response. In more productive sites, as are common in Alberta, this might be a low level of removal (e.g. 40%). Use

a. Forage availability (e.g. biomass, species, quality).
b. Ecosite types and site index.
c. Canopy cover, structure e.g. using LiDAR
d. Light models

to inform the amount of basal area removal/gap sizes appropriate for partial harvesting in different ecosystems and estimate forest growth trajectory (e.g. when crown closure occurs).

Table 10-1. Summary of harvest systems reviewed and their possible impacts on caribou habitat, other ungulate habitat, costs, and access requirements. Entries are colour coded (reds = negative, greens = positive, grey = not applicable or unknown).

Silviculture System	**Caribou Habitat:** *Old-growth forest characteristics + lichen/forage availability.*	**Other Ungulate Habitat:** *Early-seral forest + herbaceous forage availability.*	**Economics:** *Costs of harvest, regeneration etc.*	**Access:** *Requirements for additional infrastructure & length of time roads must remain open.*	**Notes:** *Additional considerations and research needs.*
Clearcut	Old forest characteristics and associated lichen resources are lost.	Early seral stage habitats are created, favouring other ungulates.	Efficient and cost-effective system for harvesting and regeneration.	Access and disturbance can be minimized by using a single-entry and aggregated harvesting.	Herbicide treatments, site preparation, and increased may be able to mitigate the increase in habitat quality for other ungulates by minimizing early seral stage vegetation and maximizing rate of forest re-growth.
Seed Tree					Seed tree systems unlikely to benefit caribou and not well suited to Alberta's tree species.
Shelterwood	Can be used to maintain forest structure and terrestrial lichens in some circumstances.	Could be used to minimize understory response in some circumstances.	Harvesting in patches or strips more cost-effective & efficient than single tree removal. Additional pre-planning costs.	Access requirements vary by number of entries. In-block roads/skid trails can be temporary or permanent.	Shelterwood may prevent a flush of understory vegetation depending on the size and spatial pattern of removal. High levels of retention likely required to maintain caribou habitat; varies by productivity of the system. Windthrow is a significant concern.
Understory Protection	Accelerates the succession of deciduous stands to coniferous stands which may lead to the development of caribou habitat earlier than would have occurred naturally.	If coniferous understory is well developed, it may effectively shade out aspen suckering and other browse species.	Harvesting in patches or strips more cost-effective & efficient than single tree and group selection removal. Additional pre-planning and monitoring costs but can accelerate conifer development resulting in increased AAC at forest level.	Final entry eventually required when understory matures. If natural regeneration is successful, roads can potentially be deactivated between entries.	A well-developed coniferous understory that is released may hinder deciduous vegetation growth. Can also provide economic and ecological benefits as conifer volume growth is accelerated without the use of site preparation, planting or tending with herbicides.

Silviculture System	**Caribou Habitat:** *Old-growth forest characteristics + lichen/forage availability.*	**Other Ungulate Habitat:** *Early-seral forest + herbaceous forage availability.*	**Economics:** *Costs of harvest, regeneration etc.*	**Access:** *Requirements for additional infrastructure & length of time roads must remain open.*	**Notes:** *Additional considerations and research needs.*
Group Selection	Can effectively maintain old-growth forest characteristics and associated arboreal lichens.	Can promote ideal habitat for other ungulates through early seral stage response and edge habitat availability, but results depend on site conditions.	Harvesting in patches or strips more cost-effective & efficient than single tree removal. Additional pre-planning costs. Re-entry to stands required for subsequent harvests.	Access requirements higher but vary by number of entries. In-block roads/skid trails can be temporary or permanent.	Group selection using small openings has been used to maintain arboreal lichens in British Columbia, but also led to increased habitat use by moose. This might be less of an issue in lower productivity systems. System could be adjusted in terms of patch size and layout.
Single-tree Selection	Can effectively maintain old-growth forest characteristics.	With low removal level and suitable site conditions a large understory response favouring other ungulates can be avoided.	Additional planning, marking, site supervision, and specialized skills and machinery typically required.	Extensive road network typically required. Access may be required indefinitely for repeated entries.	Single-tree selection or thinning treatments may accelerate development of old-growth stands and maintain or even promote lichen. Should also avoid major understory response if removal level is low enough relative to site productivity.
Diameter-limit Cutting	Removing the largest trees causes loss of arboreal lichen but unclear impacts on terrestrial lichens.	May result in increased other ungulate habitat desirability.	Additional planning, marking, site supervision, and specialized skills and machinery typically required. Light removals typically made on short (e.g. 15-20 year) cycles.	Extensive road network typically required. Access may be required indefinitely for continuous cover forestry.	Used primarily in Quebec and Ontario. Some indication that CPPTM cutblocks are avoided by caribou but frequented by moose. The removal of large, mature trees removes arboreal lichens and increases forage for other ungulates.

Silviculture Treatment	**Caribou Habitat:** *Old-growth forest characteristics + lichen/forage availability.*	**Other Ungulate Habitat:** *Early-seral forest + herbaceous forage availability.*	**Economics:** *Costs of harvest, regeneration etc.*	**Access:** *Requirements for additional infrastructure & length of time roads must remain open.*	**Notes:** *Additional considerations and research needs.*
Commercial Thinning	Can be used to maintain forest structure and terrestrial lichens.	Can minimize understory response but dependent on site conditions and level of removal.	Provides flexibility in wood supply and can be used to produce larger diameter timber more quickly.	Expectation that access remains available to allow for multiple entries.	Existing research shows this treatment can effectively maintain terrestrial lichen availability, but it is unclear if caribou continue to use treated areas.
Herbicide	Reduces abundance of terrestrial lichens.	Arguably the most effective silvicultural treatment available to control competing vegetation.	Cost-effective treatment used to improve seedling survival.	No additional access requirements unless ground application is utilized.	Significant societal push-back against use, particularly aerial spraying. Banned on crown lands in some provinces.
Stocking Density		High stocking densities decrease time for overstory to shade out understory browse species.	Additional planting costs incurred to increase stocking density.	No additional access requirements.	Growth rate of stands will decrease following stand closure which would impact the rotation age and potentially the AAC for the forest .
Artificial Seeding		Typically results in high-density stands and so may decrease time for overstory to shade out understory browse species.	Relatively cheap treatment but not effective for all species, variable success rates.	No additional access requirements.	

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12 Appendix I: Additional Management Comments

Table 12-1. Additional management recommendations and comments from the interview process.

Category	Specific Recommendation	Additional Details
Untouched Areas	There should be areas left untouched for caribou.	Any type of disturbance or human footprint negatively impacts caribou.
Harvest Level	The harvest level should be reduced.	Any reduction in harvest is beneficial for caribou.
Aggregation	Harvest should be aggregated.	Aggregated harvest means reduced access requirements. Aggregating harvest in one area is better than many small disturbances across the landscape.
Rotation Length	Rotations should be lengthened or even doubled in some areas.	Longer rotations allow the forest to develop into high quality caribou habitat. Longer rotations keep tree cover on the landscape for longer. Not harvesting mixedwood stands until they've reached successional climax can prevent aspen regeneration.
	Rotations should be shortened in some areas.	Shorter rotations outside of caribou ranges can compensate for timber losses due to extended rotations and/or partial harvest in caribou ranges.
Vegetation Management	Herbicide	Arguably the best silvicultural treatment available to control understorey vegetation.
	Pre-harvest girdling of aspen/herbicide injections	Reduces aspen regeneration.
	Broadcast spraying	Leaves less of a footprint on the ground than backpack applications.
	Manual brushing	May reduce nutritive quality of some browse with repeated applications.
	Sheep grazing	Reduces browse.
	Mulching	Reduces soil fertility.
	Aspen should be allowed to regenerate naturally in mixedwood sites	Allowing aspen to sucker back can suppress/shade out more desirable understorey browse species.
	Burning	Creates lower quality browse. Provides a regeneration benefit as well (exposes mineral soils, intense fires open serotinous cones).
	Brush raking	Piling up organic matter can supress competitive vegetation but won't harm spruce.
Reforestation	High density planting	Leads to a closed canopy faster and suppresses understorey vegetation.
	Underplanting	Underplanting aspen with spruce can provide protection.
	Larger stock sizes	Leads to a closed canopy faster and suppresses understorey vegetation.
	Clump planting	Clump planting mimics gaps found in the natural forest and may be preferable to uniform planting. This is beneficial for caribou in terms of lichen abundance but also may cause vegetation release in rich sites.
	Natural regeneration	Causes less disturbance to the soil and does not require a subsequent entry.
	Reforestation and site preparation should occur at the same time as harvest	One single disturbance instead of repeated entries ("get in and get out").
Site Preparation	Mounding	Mounding can impede movement through cutblocks. However, soil disturbances usually result in a flush of vegetation in rich sites.
Minimizing Soil Disturbance	Winter harvest	Prevents flush of vegetation associated with soil disturbance.

Category	Specific Recommendation	Additional Details
	Roadside processing	Preferable to stumpside processing for minimizing damage to terrestrial lichens.
	Harvester forwarders	Some equipment can have less of an impact (also requires less in-block roads).
Connectivity	Movement corridors	Movement corridors provide cover for caribou to move through their range.
Access/In-block Roads	Rip and plant roads	Faster regeneration.
	Slash/coarse wood application	Impedes travel on linear features.
	Use narrow trails	Maintain overstorey influence.
Training	Continuing education	Continuing education to keep operational foresters familiar with new tools, technologies, knowledge, and other innovations.
Policy Changes	Regeneration standards	Regeneration standards are sometimes not favorable for caribou.
	Stand designations	Inflexible stand designations prevent strategic placement of habitat.
	Tenures	Shared tenures can prevent application of new strategies.
Other (outside the scope of forestry)	Wildlife monitoring	Ongoing monitoring is required to know if caribou use areas harvested under alternative systems and therefore if they can be considered a success.
	Predator management	Wolf populations have historically been reduced by humans. Less trapping means more wolves on the landscape.
	Increased hunting	Wolf hunting can reduce number of predators. Increased hunting opportunities for moose and deer can reduce apparent competition pressure. Short-term fix.
	Restoration of seismic lines	Less access and ability to move into and through caribou ranges. Reduces sightability.

13 Appendix II: List of Interviewed Subject-Matter Experts

Brad Pinno (University of Alberta)

Brian Roth (FGrOW)

Chris Elden (West Fraser)

Chris Johnson (University of Northern British Columbia)

Daniel Fortin (Laval University)

Dave Hervieux (Government of Alberta)

Ellen MacDonald (University of Alberta)

Jake Bradshaw (University of Northern British Columbia)

Laura Finnegan (Foothills Research Institute)

Michaela Waterhouse (Government of British Columbia)

Milo Mihajlovich (Consultant)

Phil Comeau (University of Alberta)

Scott Nielson (University of Alberta)

Tim Vinge (Government of Alberta)

Vic Lieffers (University of Alberta)