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Alberta Regional Caribou Knowledge Partnership

PROJECT REPORT

Towards Undisturbed Habitat: Forest Management in Alberta's Caribou Ranges

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Executive Summary

This report addresses the lack of guidance from the federal recovery strategies for woodland caribou on when suitable habitat, after being disturbed by anthropogenic activities such as forest harvesting, should once again be considered "undisturbed," for the purposes of caribou recovery planning. In the absence of federal direction, Alberta has adopted a 40-year threshold for considering caribou habitat undisturbed, but the adequacy of this metric is not fully known. As management efforts increasingly turn to actions designed to restore the functioning of caribou ranges, there is a need to further define restoration endpoints to clarify objectives and measure progress.

Here, I advance the characterization of undisturbed caribou habitat by:

1. Reviewing work on this issue by other jurisdictions as they align recovery efforts with the federal boreal and mountain caribou recovery strategies;
2. Present a review of relevant literature to inform the development of undisturbed habitat definitions;
3. Propose caribou forest management goals, desired outcomes, forestry objectives, related strategies and beneficial management practices for managing to undisturbed habitat conditions;
4. Identify a proposed workflow for companies operating in caribou habitat, and,
5. Identify knowledge gaps and next steps.

I proposed the following three caribou habitat management goals:

- Minimize early seral habitat and therefore primary prey and predator abundance;
- Minimize predator access; and,
- Maintain/recover caribou forage.

And posit that the goals should be applied differentially to four broad forest types, according to the functional roles the forests serve as caribou habitat:

1. Spruce-mixedwood forests – which are generally avoided by caribou but are important to the broader predator-prey system;
2. Black spruce-larch forests – generally selected by caribou and where predator access is a concern;
3. Pine forest – important winter range for mountain caribou, selected by boreal caribou in some contexts, but also capable of generating a significant primary prey response; and,
4. Subalpine forest – critical for all mountain caribou in summer and some fraction of the population in winter.

Companies can contribute positively to caribou recovery by understanding the functional roles of the forest types in which they operate, understanding what characteristics constitute undisturbed habitat conditions, and implementing strategies and practices to achieve those conditions as rapidly as possible. Effective practices are expected to vary with site conditions and additional research is required to:

1. Develop a more precise definition of early primary prey forage conditions that are inconsistent with caribou recovery.

2. Develop detailed planning guidance for pine-leading forests to optimize conditions for caribou.
3. Assess the effect of forest interspersion on the functioning of habitats serving as refugia from predation for caribou.
4. Determine the extent to which high-elevation refugia for mountain caribou are compromised by linear features.
5. Balance caribou forest management goals with those for other species and biodiversity in general.

This report presents several broad concepts as well as proposed goals and strategies that can form the basis for dialogue with the Governments of Alberta and Canada on strengthening the evidence considered in range planning in the Province. Key themes for discussions could include that:

1. Different forest types serve different functional roles in the caribou system and therefore no single "undisturbed" definition is likely to drive caribou recovery efforts effectively or efficiently.
2. An older forest is not necessarily a better forest for caribou. Disturbance is required to maintain functional components of fire-adapted ecosystems on which caribou have evolved to depend.
3. Current evidence is not consistent with some current federal and provincial direction and alternatives to improve the effectiveness and efficiency of caribou recovery should be explored.

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Introduction

Boreal and mountain woodland caribou (*Rangifer tarandus caribou*) subpopulations are generally declining across Alberta, with negative population growth rates recorded during the majority of years for which data are available (Government of Alberta, 2017; Hervieux et al., 2013). Wolf management has forestalled declines for some subpopulations, and some in the far north of the Province remain self-sustaining (Government of Alberta, 2024). Caribou are listed as *Threatened* under both the Alberta *Wildlife Act* and the federal *Species at Risk Act.*

The federal recovery strategy for Canada's boreal population was published in 2012 and was amended in 2020 (Environment and Climate Change Canada, 2020). A recovery strategy for the mountain population was posted in 2014 (Environment Canada, 2014). In their definitions of critical habitat, both strategies rely in part on the concept of habitat disturbance, which is a proportional measure of an area within caribou ranges affected by anthropogenic land-clearing visible on 30-m Landsat imagery, excluding permanent infrastructure,[1] buffered by 500 m, plus the perimeters of recent (i.e., <40 years) fires. If not disturbed, habitat is considered undisturbed, and the recovery strategies set thresholds for undisturbed habitat to which jurisdictions are expected to manage. In the boreal strategy, a threshold of at least 65% undisturbed applies to the entire area within a subpopulation range. For mountain caribou subpopulations, the same threshold applies to low-elevation winter range, as well as "Type 1" matrix habitat, which is defined as areas within the annual range of a subpopulation that are used relatively infrequently, such as migration corridors. The disturbance threshold for high-elevation summer and winter ranges is defined qualitatively as "minimal" (Environment Canada, 2014; page 45).

Because conditions in most ranges do not meet the undisturbed habitat threshold, the recovery strategies state that restoration of anthropogenic features will be required; however, no guidance is provided on when caribou habitat, after being disturbed by activities such as forest harvesting, will be considered undisturbed. This policy gap resulted from the decision to anchor critical habitat requirements on a statistical correlation between habitat disturbance and caribou recruitment among boreal subpopulations, which left to speculation the functional processes causing the relationship. That is, without knowing the characteristics of disturbed habitat that are responsible for the negative association with caribou recruitment, the characteristics of habitat that render it "undisturbed" are equally unknown.

Without a clear articulation of the functional pathways, what constitutes an undisturbed condition consistent with sustainable caribou populations remains undefined. Nevertheless, the Province of Alberta has provided a 40-year time-since-disturbance metric to define undisturbed habitat, based on the predicted onset of declining suitability of regenerating stands for moose.

[1] "Permanent alterations" are defined in the boreal caribou recovery strategy as, "existing features found within a range, such as industrial and urban developments, permanent infrastructure, and graded or paved roads that do not currently possess or have the potential to possess the biophysical attributes of critical habitat for boreal caribou" (page 50). "Permanent features' are referenced in the southern mountain caribou recovery strategy as, "features such as maintained trails, roads and existing infrastructure (e.g., buildings), agricultural fields" (page 44). These features are subtracted from the area of critical habitat polygons before habitat disturbance is calculated.

The forestry sector shares a stewardship responsibility with governments and other land users for the management of caribou ranges, and forest companies are uniquely positioned to influence stand conditions throughout the forest rotation via the application of specific harvesting and silviculture treatments. More clarity on what constitutes desirable range conditions could lead to revised forest management plans or practices that could improve caribou recovery. In this report, I aim to improve this clarity by 1) reviewing approaches to defining undisturbed caribou habitat being taken by other jurisdictions; 2) reviewing literature relevant to forestry on the issue of caribou habitat recovery; 3) proposing definitions for undisturbed habitat that reflect the functional role that broad forest types play in the caribou system; and 4) identifying beneficial management practices that could be implemented by the forestry sector to contribute positively to recovery efforts.

Jurisdictional Scan of Approaches to Defining Undisturbed Habitat

British Columbia

A draft range plan for British Columbia's (BC) boreal caribou herds (except the BC portion of the Chinchaga range) is currently under review (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2022). The plan adopts a 40-year timeline for considering cutblocks to be classified as undisturbed habitat, citing the federal science review (Environment Canada, 2011). Note however that the 40-year criterion applies only to fires;[2] no explicit guidance was provided for anthropogenic features. As for linear features, a decision on when to consider treated features to once again be undisturbed is deferred: "as part of BCPRP implementation, the characteristics that determine undisturbed habitat will be defined and incorporated into the monitoring program. These characteristics and criteria will be refined over the course of the effectiveness monitoring program and be responsive to site-specific observations" (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2022; page 40).

The range plan includes modelled forecasts of undisturbed habitat after 50 years under various management scenarios. For these forecasts, linear features were assumed to recover within 50 years and no explicit assumptions were made about the expected benefits of restoration.

BC is also home to both southern and northern mountain caribou subpopulations. There is currently no provincial management plan for mountain caribou in BC but actions are being implemented under the auspices of BC's Provincial Caribou Recovery Program[3] in alignment with the federal recovery strategy for southern mountain caribou (Environment Canada, 2014) and the 2020 conservation and

[2] This was a consequence of available data; there was no analysis relating this age threshold to caribou demography (Environment Canada, 2011) that demonstrated that 40 years was an ecologically appropriate forest age for caribou management purposes.

[3] https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/caribou/recovery-program

intergovernmental partnership agreements with Canada.[4][5] As part of the Partnership Agreement, a restoration implementation plan has been prepared, which provides near-term targets for restoration success (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2021).

Northwest Territories

Boreal caribou in Northwest Territories (NWT) occur in only one large subpopulation range (NT1) that extends from the jurisdictional boundary of the 60th parallel to the Arctic coastal plain. Regions within NT1 vary in their levels of human-related habitat disturbance, with levels in southern NWT considerably above those in the north, due to legacy seismic activity and forestry. So, while the territorial government has committed to managing to a disturbance threshold of 35% overall (i.e., 65% undisturbed, as required by the federal recovery strategy), it has set a threshold of 40% in the south and 30% in the north.

The NWT range planning framework sets out a tiered approach to habitat management, where areas identified for *Enhanced* or *Intensive* management are to be subject to more stringent development conditions than in *Basic* areas, including the use of functional and ecological restoration treatments (Government of Northwest Territories, 2019). "Long-term" disturbances are those features that are not expected to recover within 40 years to the point of being functionally restored as caribou habitat.

Ecological restoration is intended to ensure that disturbed areas will provide the biophysical attributes required by caribou, and restored lichen ground cover and conifer-dominated forest cover are provided as examples in the range planning framework of restored conditions. For cutblocks, conifer-dominated forest cover is expected to naturally regenerate, or be treated to regenerate, at an age of 30-40 years. No specific threshold is provided.

While not strictly being considered undisturbed, treated or regenerating areas are to be managed in a manner similar to undisturbed areas (e.g., avoid issuing timber cutting permits) to ensure the areas will eventually provide the biophysical attributes of undisturbed caribou habitat. How long this may take is identified as a knowledge gap.

For linear features, the factors determining rates of vegetation regrowth, the responses of predators and prey to treated or regenerating lines, the criteria that should be used to determine when features are considered restored, as well as the current state of regrowth on legacy seismic lines, are all identified as knowledge gaps. As well, appropriate restoration treatments that could be applied in the northern region of NT1, as well as their costs and effectiveness, are also cited as knowledge gaps.

Saskatchewan

In Saskatchewan (SK), range plans have been developed for the central and west portions of the SK2 subpopulation range (Saskatchewan Ministry of Environment, 2019, 2021a), and a draft plan for the east portion has been released (Saskatchewan Ministry of Environment, 2021b). In those plans there are no definitions for when disturbed areas are considered to have transitioned to undisturbed. For linear

[4] https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/conservation-agreements/southern-mountain-caribou-british-colombia-2020.html
[5] https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/conservation-agreements/intergovernmental-partnership-conservation-central-southern-mountain-caribou-2020.html

features, this is acknowledged explicitly: "Definitions for what constitutes reclaimed and restored (i.e., undisturbed) caribou habitat are not currently well-defined. . . Definitions for linear features are not currently available. . . Currently, the revegetation condition and human use status of many linear features have yet to be verified" (Saskatchewan Ministry of Environment, 2019; page 42).

Like BC, SK developed landscape forecasts of habitat disturbance that used a simplified assumption of a 40-year recovery period for all human-related disturbances. Scenarios assumed reclamation of roads with a licensee liability immediately following harvest but applied a reclamation delay of 10 years to legacy roads.

SK range planning emphasizes "maintaining adequately sized and well-connected patches of undisturbed caribou habitat across, and between, caribou administration units" (Saskatchewan Ministry of Environment, 2019; page 35). They also include in the definition of disturbed habitat wetlands with altered drainage systems resulting from road construction and other activities.

Manitoba

Manitoba (MB) is in the initial phases of range planning and have not developed any guidance or metrics related to habitat restoration.[6]

Ontario

Planning for caribou in Ontario (ON) is guided by its Woodland Caribou Conservation Plan,[7] Range Management Policy,[8] and corresponding range-specific integrated range assessments. The range assessments report on caribou population sizes, trends, habitat distribution and abundance, and levels of disturbance.

Ontario developed detailed forestry guidance that included onset ages for different stand types to be considered caribou habitat (Ontario Ministry of Natural Resources, 2014). Ages ranged from 41 to 101 years, although the document cautioned that emerging knowledge might alter the guidance. Currently, forty years is being used in range planning as the threshold for cutblocks to be considered recovered, regardless of stand type.

The Province has yet to develop specific guidance related to when linear features (primarily roads) are to be considered undisturbed habitat. There have been initial surveys of road recovery characteristics following various treatments (Hall et al., 2016), but no specific policy development. Ontario has committed to various restoration-related activities under its Section 11 agreement with the federal government.[9]

[6] https://gov.mb.ca/nrnd/fish-wildlife/wildlife/boreal_caribou/index.html
[7] https://www.ontario.ca/page/woodland-caribou-conservation-plan
[8] https://www.ontario.ca/page/range-management-policy-support-woodland-caribou-conservation-and-recovery
[9] https://prod-environmental-registry.s3.amazonaws.com/2022-04/En_Caribou%20Conservation%20Agreement%20-%202022April07_230pm_Revised%20-%202022April15_CLEAN_April21.pdf

Québec

Québec (QC) announced a woodland caribou habitat stewardship plan in 2016[10] consisting of immediate actions and a longer planning phase to develop a strategy aimed at achieving the federal critical habitat requirement of 65% undisturbed, as well as generating large intact areas. The need for habitat restoration in areas of high disturbance was recognized. An independent commission reported in 2022 on public consultations regarding management options for Québec's boreal caribou populations as well as the Gaspésie mountain caribou population (Gouvernement du Québec, 2022).

For considering habitat again undisturbed, QC uses a 50-year threshold for cutblocks. As for linear features, all but winter roads are considered permanent and there are no assumptions being made regarding restoration trajectories. There are active road restoration efforts underway (St-Pierre et al., 2022, 2021), but these have yet to inform the planning process.

Newfoundland and Labrador

There are three boreal caribou subpopulations in Labrador (Mealy Mountain, Red Wine Mountain, and Lac Joseph) and they are notable for having some of the lowest levels of habitat disturbance in Canada. With <10% habitat disturbance and little threat of significant landscape development, the government of Newfoundland and Labrador (NF) is focused on addressing other priorities for reducing risks to these subpopulations, including knowledge improvement, Indigenous engagement, caribou guardianship, and habitat protection.[11]

Literature Review

It is helpful to stratify the discussion of caribou habitat recovery with the functional pathways associated with declining caribou populations (DeMars et al., 2023). A proposed state-of-knowledge description is captured in the Boreal Caribou Ecological Model (Habitat Restoration Working Group, 2021; Figure 1), developed for the National Boreal Caribou Knowledge Consortium (NBCKC). Basing this literature review on the model has several advantages:

1. The model has the tacit endorsement of the NBCKC and aligning evidence with the model can support dialogue between the forest sector and the governments of Alberta and Canada.
2. The model clarifies how habitat disturbance is hypothesized to be affecting caribou along different, interacting pathways. This understanding informs how habitat conditions need to change to disrupt the pathways.
3. The model report reflects the best information available on caribou-habitat relationships as of its publication in 2021, which limited the volume of new research that needed to be reviewed.
4. The model describes conceptually many of the outstanding questions central to this project, such as relationships with caribou vital rates, habitat use, predator mobility, primary prey habitat, etc.

Although the model is focused specifically on Canada's boreal caribou subpopulations, the functional pathways described share similarities with key pathways in southern mountain caribou systems.

[10] https://mffp.gouv.qc.ca/documents/faune/napperon-caribou-forestier-2016.pdf
[11] https://www.gov.nl.ca/hunting-trapping-guide/2022-23/labrador-caribou/

Consequently, I include literature from BC and Alberta focused on southern mountain subpopulations in the following sections.

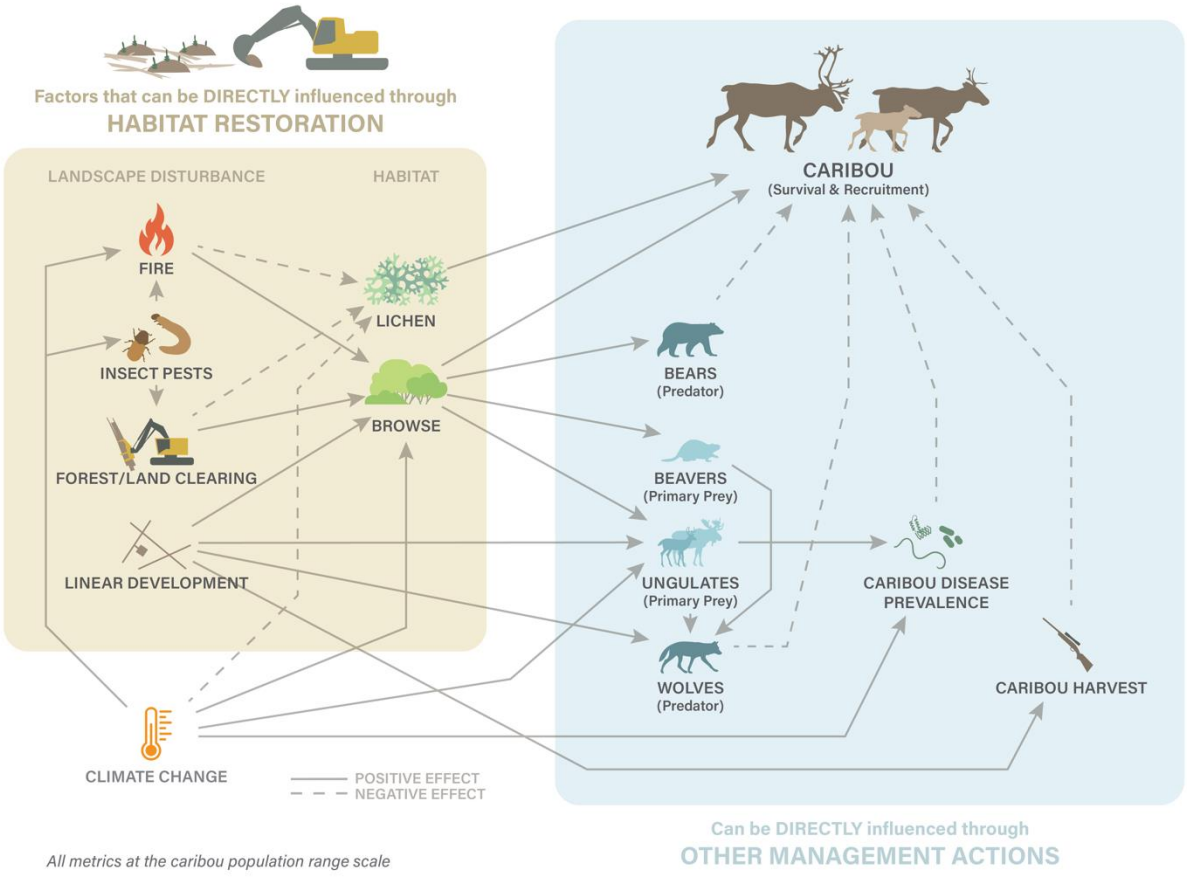

Figure 1. National boreal caribou ecological model (Habitat Restoration Working Group, 2021).

Forest/land clearing > browse > primary prey > wolves > caribou

The pathway described in the boreal caribou ecological model that is most directly relevant to forestry activity is *forest/land clearing > browse > primary prey > wolves > caribou* (Figure 1). The focus in this instance is primarily the shrub-forb community and the response of browse to clearing is assumed to be positive. Surprisingly, the specific characteristics of this response are not particularly well-studied (in Alberta or elsewhere), but the response is necessary for the mechanism of habitat- or disturbance-mediated apparent competition, which is hypothesized to be the most significant driver of declining caribou populations (DeMars et al., 2019; Neufeld et al., 2021).

The increase in browse causes a response in a spectrum of primary prey (McKay and Finnegan, 2022), most importantly moose (*Alces alces*: Fisher and Burton, 2018; Potvin et al., 2005; Rempel et al., 1997; Serrouya et al., 2021) and white-tailed deer (*Odocoileus virginianus*; Charest, 2005; Côté et al., 2004; Darlington et al., 2022; Dawe et al., 2014; Fisher et al., 2020), which then support higher predator populations (Frenette et al., 2020; Messier, 1994; Serrouya et al., 2017), and negatively impact caribou through higher predation rates (DeMars et al., 2019; Neufeld et al., 2021). Because moose and deer are generally more demographically productive than caribou, caribou then decline in this system. Additional browse also benefits bears (Brodeur et al., 2008; McKay and Finnegan, 2022; Schwartz and Franzmann, 1991), which can generate additional predation pressure on caribou (Leblond et al., 2016), and in particular, on neonates (Bastille-Rousseau et al., 2011). There is some evidence that beavers could also be a factor in this pathway and provide a prey subsidy for wolves in a manner similar to early seral ungulate prey (Latham et al., 2013; Potvin et al., 2005).

Table 1. Habitat selection of different forest types by caribou subpopulations in Alberta for which telemetry data are available. Ranges of selection ratios are presented as different colours, with greens representing forest types used more than expected, based on the proportion of telemetry locations recorded in a forest type divided by the proportion of the range covered by that forest type. Percentages in each cell reflect the distribution of different forest types by range. Use by forest type was aggregated from Government of Alberta telemetry data summaries (Government of Alberta, 2018).

Population	Range	Pine	Black spruce-larch	Spruce-balsam	Mixedwood	Deciduous
Boreal	BIST	3.6%	51.1%	10.2%	6.1%	16.8%
	YATES	0.1%	52.8%	8.4%	4.7%	17.1%
	CM	2.8%	42.6%	12.7%	4.9%	16.8%
	ESAR	7.8%	54.2%	2.6%	2.9%	10.9%
	WSAR	4.9%	61.2%	2.4%	3.2%	1.8%
	LSM	51.5%	27.8%	8.2%	2.9%	2.0%
	CHIN	20.0%	27.4%	8.9%	7.8%	24.0%
Mountain	NARR	36.2%	14.0%	14.2%	11.3%	12.3%
	RRPC	57.9%	5.2%	23.5%	5.5%	2.7%
	ALP	56.9%	11.6%	21.5%	0.64%	0.21%

0-0.5	0.5-0.95	0.95-1.05	1.05-1.5	>1.5

In addition to productivity, forest age is an important driver of caribou and primary ungulate prey habitat selection, with caribou generally avoiding young age classes (Figure 3). Black spruce forests are selected relative to their availability at >40 years in boreal subpopulations and pine stands at >80 years for boreal plains subpopulations. Pine forests are rare in Taiga ranges and are avoided by caribou. Patterns are similar for the three southern mountain caribou subpopulations.

In contrast, both moose (Figure 4) and white-tailed deer (Figure 5) are generally more abundant in early seral cutblocks than in older conifer forests. These species appear to benefit more from forest harvesting than from fire, based on models derived from camera trap data in Alberta (https://beta.abmi.ca).

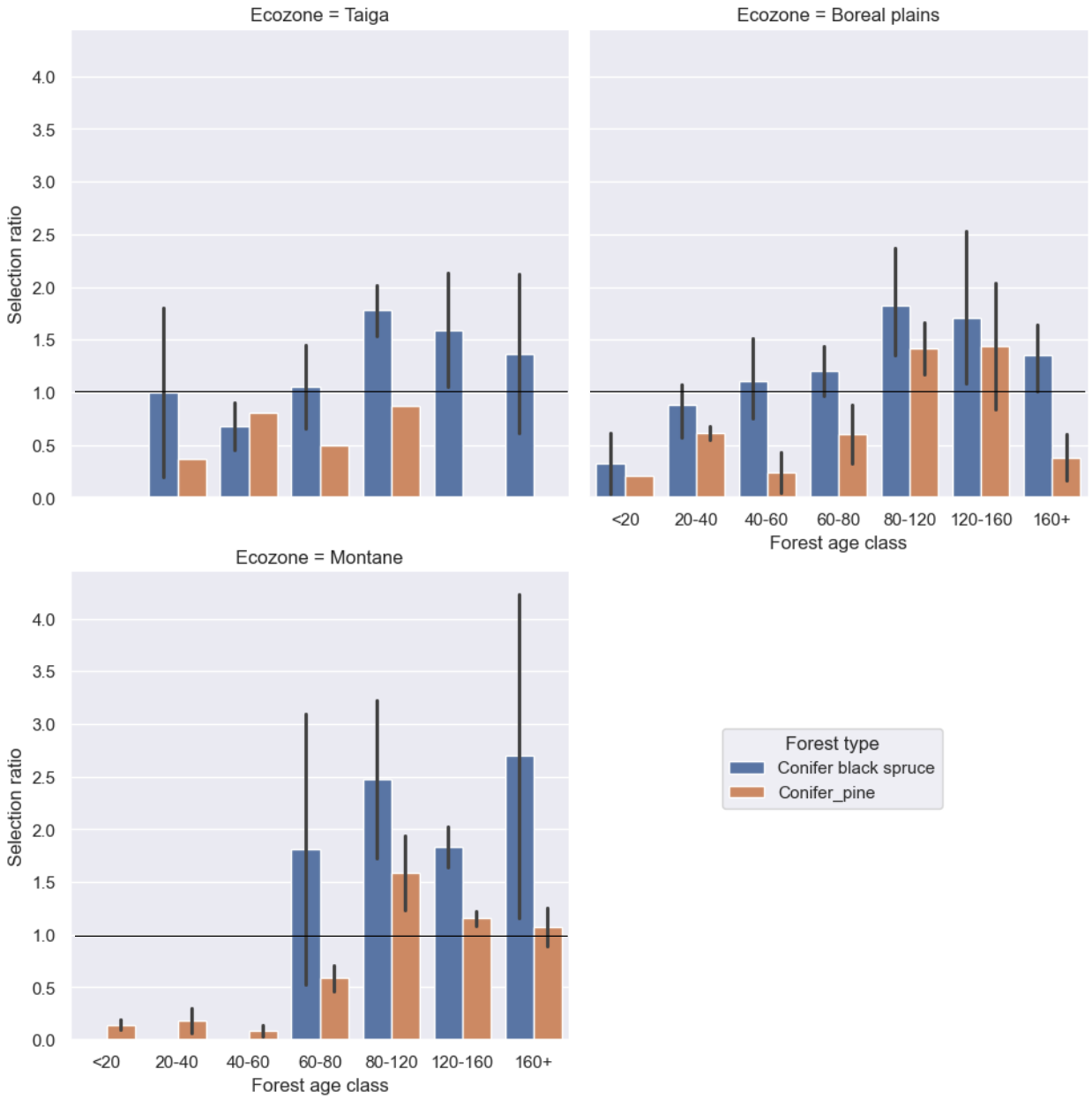

Figure 3. Selection of forest types by caribou subpopulations by ecozones. Values >1 indicate selection. Data are aggregated from Government of Alberta telemetry data summaries (Government of Alberta, 2018).

In southern mountain caribou populations the predator-prey response to disturbance includes a higher proportion of cougars (*Puma concolor*), deer, and elk (*Cervus canadensis)* than in most boreal systems, particularly in the southern extent of mountain caribou range in British Columbia (Serrouya et al., 2015; Wittmer et al., 2007). Low elevation habitat disturbance is considered to be the greatest contributor to the abundance of shrubs and forbs and subsequent primary ungulate prey response because those ecosystems are more productive than those at higher elevations (Anderson et al., 2018). The zone of influence around

which higher browse generates a greater predation risk to caribou is estimated to extend about 30 km, which is roughly the width of the average wolf territory.[12]

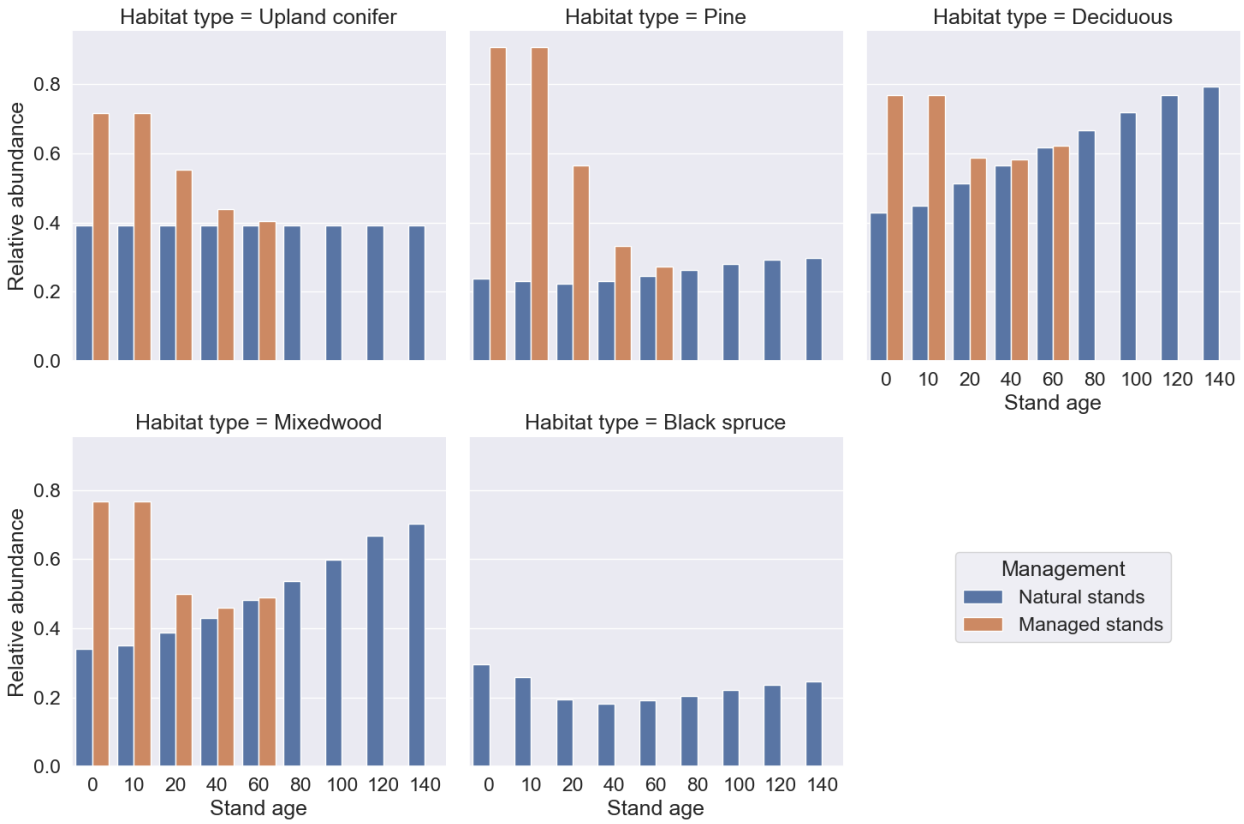

Figure 4. Relative abundance of moose by forest type, stand age, and origin, as derived from regression coefficients of models relating camera grid data to ecosystem types and ages (Alberta Biodiversity Monitoring Institute, 2014), as by reported by the Alberta Biodiversity Monitoring Institute (https://beta.abmi.ca).

Primary ungulate prey and their predators tend to occur at lower elevations where habitats are more productive and, in winter, snow is shallower (Anderson et al., 2018; Finnegan et al., 2021; Peters et al., 2013; Stafford, 2004). Therefore, wintering at high elevation provides a refuge from this predation because wolves remain close to the densest concentrations of their primary prey (Ehlers et al., 2016), but in summer, range overlap between caribou and other ungulates increases the risk of predation for caribou (Apps et al., 2013). Southern mountain caribou mortalities in general tend to be lowest in late winter and highest in summer (Wittmer et al., 2005).

Wintering at high elevations is a strategy among only some southern mountain caribou subpopulations; in particular, those inhabiting the interior wet belt of BC. Elsewhere, seasonal movement to low-elevation pine-lichen winter ranges is the more common strategy (Environment Canada, 2014), although some

[12] The size and shape of wolf territories obviously vary widely, but the BC government has used this distance as a rule-of-thumb to define "matrix" habitat that buffers the caribou "core" habitat of southern mountain caribou subpopulation ranges (D. Seip, *pers. comm.*).

fraction of many subpopulations still winter at high elevations. But while wintering at low elevations they still spatially separate from moose (Peters et al., 2013).

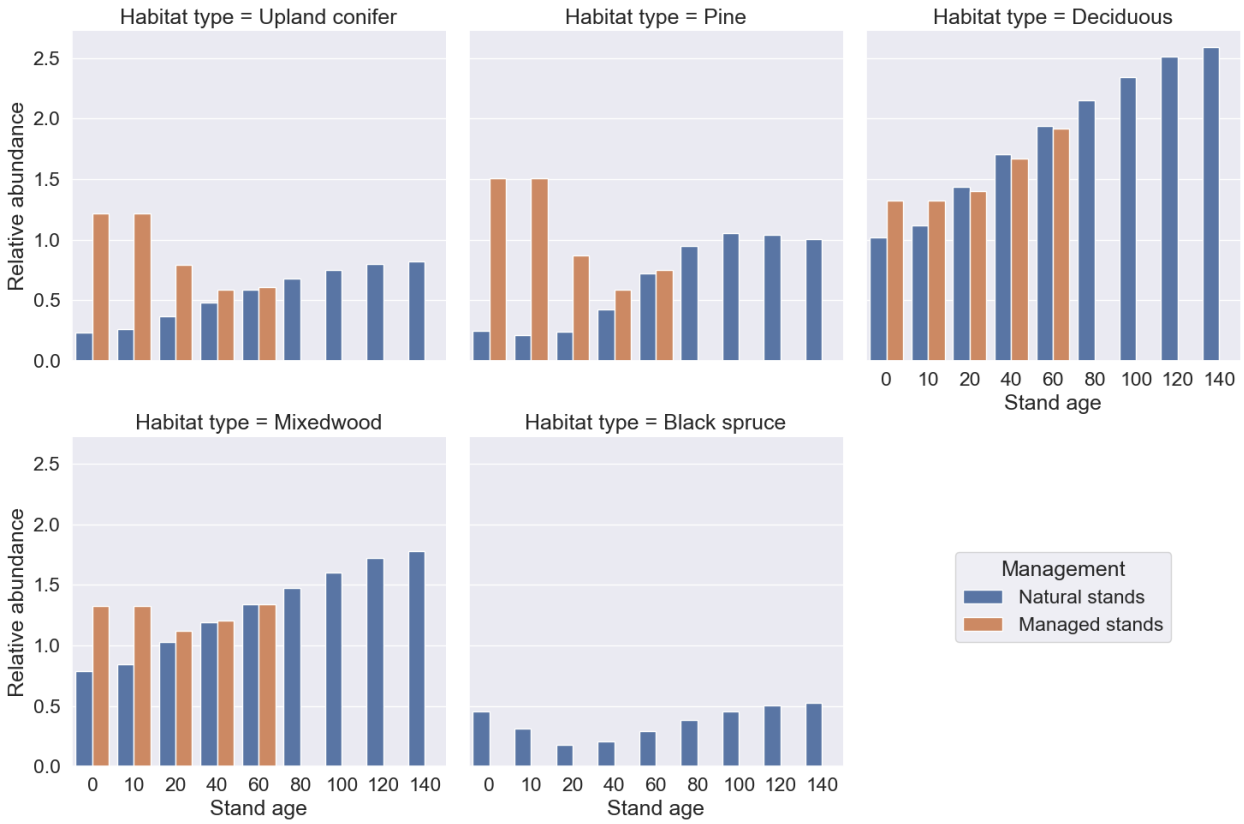

Figure 5. Relative abundance of white-tailed deer by forest type in Alberta, as modelled from camera grid data by the Alberta Biodiversity Monitoring Institute (https://beta.abmi.ca).

There is evidence that the fraction of Alberta's southern mountain caribou wintering at high elevations is increasing (MacNearney et al., 2016; Williams et al., 2021). Peters et al. (2013) found that spatial overlap with moose increased caribou mortality risk (varying by season and spatial scale), and that anthropogenic disturbance increased this overlap and therefore the risk. While this effect was most evident at low elevations, Williams et al. (2021) presented evidence that survival is lower for caribou wintering at high elevations.

The abandonment of low-elevation winter ranges could be due to the direct disturbance of caribou by anthropogenic activities (e.g., motor vehicles and industrial activity), the loss of winter forage resources, and/or elevated predation risk. These stressors often co-occur and are therefore difficult to disentangle as causes of changes in caribou habitat use, especially when considered among different spatial scales. McGreer et al. (2015) found that caribou in northern Ontario selected for high forage biomass, low wolf density, and avoided roads at both coarse and fine scales, supporting all of the potential drivers. Wasser et al. (2011) found that caribou did not avoid linear features with no or unknown human use, suggesting that it was human activity rather than the presence of these features that were altering caribou habitat use behaviour. Studies of infrastructure avoidance by caribou have generated variable results, perhaps because

of these interactions (Dyer et al., 2001; Johnson et al., 2015; Palm, 2021; Polfus et al., 2011; Superbie et al., 2022).

Forest/land clearing > browse > caribou

Increasing browse might also positively influence caribou by providing more abundant forage. While lichen abundance is often the focus of caribou browse management, diets of caribou in summer and fall are broader, but still highly selective (Denryter et al., 2017). Like all ungulates, caribou survival and reproduction are strongly influenced by energy balance, and not just during the winter season (Cook et al., 2021). However, caribou appear to generally (but not always) trade off the higher forage value of more productive ecosystems against the higher predation risk (Briand et al., 2009; Thompson et al., 2015). For example, Denryter et al. (2017) found that food resources selected by caribou were most abundant in some sites, such as spruce-fir stands in mountain caribou habitat and white spruce (*Picea glauca*) communities in boreal ranges, that radio-collared caribou generally avoid (Table 1). Conversely, lower-productivity black spruce (*Picea mariana*) stands were found to provide limited forage resources, but radio-collared caribou demonstrate selection for that stand type across all studied subpopulations in Alberta, both mountain and boreal.[13]

Forest/land clearing > lichen > caribou

Terrestrial lichens are the primary forage eaten during the winter by boreal caribou, and southern mountain caribou wintering at low elevations or high elevations on windswept ridges (Johnson et al., 2002). Communities of ground lichens, most commonly different mixes of *Cladonia*, *Cladina*, *Cetraria*, and *Stereocaulon* spp., can be abundant in black spruce bogs, dry pine stands, and in alpine meadows and other higher-elevation sites. Lichens are relatively slow-growing and recovery after disturbance can take decades. Lichens are generally most abundant in old forest conditions in bogs, dry pine stands, and alpine, but in mature conditions in mesic pine and black spruce stands, closed canopies can lead to the loss of lichen understories to bryophytes such as feathermoss (*Pleurozium schreberi*), *Sphagnum* spp., as well as shrubs. These stands rely on disturbance (historically fire) to maintain lichen productivity (Cichowski et al., 2022; Dunford et al., 2006; Maikawa and Kershaw, 1976; Skatter et al., 2014; Sulyma and Coxson, 2001).

Caribou also feed on arboreal lichens (*Alectoria* and *Bryoria* spp.). These are critical for mountain caribou wintering at high elevations in deep snow conditions, which make other forage resources unavailable (Rominger and Oldemeyer, 1990). These conditions are more common among the southern group of southern mountain caribou, while central group subpopulations either migrate during winter to lower elevations or use windswept ridges or other features where snows remain shallow and ground lichens available, although they will also feed on arboreal lichens, where available (Thomas et al., 1996). Boreal caribou dependent primarily on terrestrial lichens will still use arboreal lichens, where available, especially when snow conditions make cratering for terrestrial lichens difficult (Johnson et al., 2001; Proulx and Gillis, 2017).

[13] Note that habitat selection data provided by the Government of Alberta was pooled among all seasons. There is evidence that boreal caribou increase their use of upland conifer forests in summer, perhaps in response to forage availability (DeMars, 2018).

Because arboreal lichens acquire all their resources for growing from the air, they grow very slowly and are dependent on particular stand and tree characteristics that provide adequate ventilation and moisture. As a result, arboreal lichens are absent from young, densely stocked stands but thrive on the dead branches of older trees in multi-storied stands (Goward and Campbell, 2005; Rominger and Oldemeyer, 1989).

Linear development > browse

Linear development increases browse in a way analogous to forest/land clearing (Dawe et al., 2017; Finnegan et al., 2018). This is particularly true for pipeline corridors, winter roads, and similar features that generate limited soil disturbance and compaction. But road developments can lead to increases in browse because of the shrub and forb response on cleared rights-of-way (Darlington et al., 2022). Again, the characteristics of the response will vary by ecosystem (Finnegan et al., 2019; van Rensen et al., 2015).

While linear features such as seismic lines can occur at high densities, they nonetheless cover relatively small areas because of their narrow widths compared to polygonal disturbances such as fire footprints and cutblocks (DeMars et al., 2023). As a result, they contribute to relatively little direct surface disturbance and, presumably, forage abundance.

The significance of increased forage availability on linear features for primary ungulate prey abundance is unclear. Some have hypothesized that browse response on linear features can serve to redistribute these ungulates, reducing the spatial separation with caribou that is important in mitigating predation risk; however, empirical support for this effect is inconsistent (Mumma et al., 2018). Browse response in lower productivity caribou refugia[14] should be less than in more productive uplands, and therefore might not be as significant an attractant. Tattersall et al. (2020) found that seismic lines in lowland habitats following restoration treatments were more frequently used by caribou but less frequently by white-tailed deer.

Linear development > ungulates

Regardless of browse response, linear developments may still serve as travel corridors and allow ungulates to penetrate caribou habitat, thereby reducing spatial separation and increasing predation risk for caribou. Evidence for this pathway and for the *linear development > browse* pathway are observationally equivalent; that is, whether ungulates are on linear features because of the forage provided, because the features facilitate travel, or both, cannot be distinguished from observational data. But as noted above, empirical support for this mechanism is currently limited (Mumma et al., 2018). Habitat use studies demonstrate inconsistent attraction of moose to linear features (Finnegan et al., 2023) and landscape density of features (Mumma et al., 2019; Pattison et al., 2020). Variation might be due to vegetation characteristics on features, with moose use of lines related to advanced regeneration of preferred forage (Tattersall et al., 2023).

The most significant redistribution of primary ungulate prey has been the northward expansion of the range of white-tailed deer. This has been attributed to both climate changes and landscape development (Darlington et al., 2022; Dawe et al., 2014; Dawe and Boutin, 2016; Fisher and Burton, 2021). Fisher and Burton (2021) concluded that linear features are playing a significant role in facilitating northward

[14] Caribou "refugia" here is used a conceptual term to refer to conditions that allow caribou to maintain spatial separation from the predators of primary ungulate prey.

expansion, although Darlington et al. (2022) found that deer selected only roads and trails and avoided seismic lines and pipelines. Even in the absence of linear features, deer can “spillover” from adjacent, more productive habitats into caribou refugia (Latham et al., 2011).

Linear development > wolves

The role linear development plays in redistributing wolves is considered a major pathway; linear features in lower productivity boreal caribou refugia can turn unsuitable wolf habitat (due to the low density of their primary prey) into suitable wolf habitat and presumably increase predation risk on caribou (DeMars and Boutin, 2018; Mumma et al., 2018). Wolves travel faster and farther where these features are available, which is assumed to increase encounter frequencies with potential prey (Dickie et al., 2017). The same effect is assumed to occur in low-elevation winter ranges of southern mountain caribou (Environment Canada, 2014), although this has not been confirmed in research. Outside lower productivity refugia, the effects of linear development are less clear. While these features could increase the hunting efficiency of wolves in productive upland habitat, this has only a second-order effect on caribou, because greater hunting efficiency afforded by the linear features (independent of primary prey population size or density) leads to a denser wolf population that in turn increases predation risk on caribou (Dickie et al., 2022). Dickie et al. (2022) found such a relationship between wolf density (via smaller pack territories) and linear feature density, but only in lower-productivity regions; in higher productivity areas wolf density was high regardless of linear feature density. Lochhead et al. (2021) proposed this as an important mechanism operating in the "matrix" habitat of mountain caribou range in BC.[15]

Linear features linking lower elevation primary ungulate prey habitat to higher-elevation southern mountain caribou habitat have recently been targeted for restoration in BC, on the assumption that these features facilitate travel of wolves into caribou habitat and increase predation risk (Schilds and Spencer, 2023). The importance of this pathway is unclear because telemetry studies have demonstrated that wolves generally remain at low elevations in winter (Ehlers et al., 2016; Whittington et al., 2005), likely because prey are more abundant there. Deep, unconsolidated snow, more common at higher elevations, restricts wolf movements (Droghini and Boutin, 2018a), while packed trails and roads, which are more common at low elevations (Apps et al., 2013; Lochhead et al., 2021), facilitate wolf movements (Droghini and Boutin, 2018b; Keim et al., 2021; Whittington et al., 2011, 2005).

As noted above, predation of southern mountain caribou (at least among the southern group) is relatively rare in winter (Wittmer et al., 2005) and occurs most often at lower elevations (Apps et al., 2013). During

[15] I have been critical of these authors' failure to address the confounding factor of time in their results. All mountain caribou subpopulations included in their study were declining during the time covered by their analysis and all of the disturbance factors they tested were increasing during the same time period. That the road density in matrix habitat showed the strongest correlation with caribou declines might just mean that it is the factor among those examined that had the strongest correlation with time, regardless of any causal relationship with caribou declines. Further, there was no discernible dose-response relationship; that is, the strongest caribou declines were not associated with the largest increases in matrix road density. In fact, some of the largest declines in caribou abundance occurred where increases in road density were very small. From this I conclude that there is no evidence of a causal relationship and disagree with their conclusions and their recommendation that road densities in matrix habitat should be reduced to benefit caribou.

summer, travel into high elevation habitat is less restricted, and wolves benefit less from the presence of linear features.

Collectively, this evidence suggests that linear features in refugia habitats are likely increasing predation pressure on caribou by facilitating movements of wolves; however, evidence supporting this mechanism in high-elevation, mountain caribou habitat is lacking.

Synthesis

The literature review above summarizes the major pathways to decline affecting boreal and southern mountain caribou subpopulations in Alberta. Of course, caribou habitat use, and ultimately their reproductive success and survival, is dependent on behaving in a manner that minimizes a risk function that integrates all of these different pathways. As an example, Avgar et al. (2015) found that caribou movements in northern Ontario were driven by forage abundance, as well as by avoidance of high wolf density, and avoidance by some individuals of moose habitat. Research generally points to three major caribou forest management goals that are directly relevant to forestry (Figure 6):

1. Minimize early seral habitat and therefore primary prey and predator abundance;
2. Minimize predator access; and,
3. Maintain/recover caribou forage.

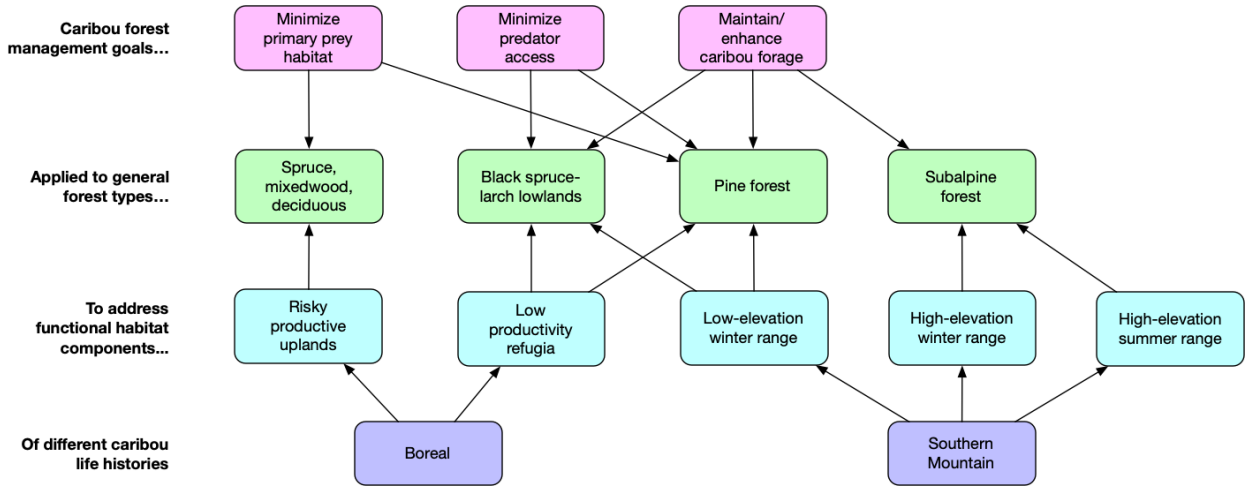

Figure 6. Relationship between functional habitat requirements of boreal and mountain caribou and proposed caribou forest management goals, by general forest types.

Implementing strategies in forested landscapes to address these goals are likely to directly benefit caribou. But it is clear from the literature review that these goals are not all equally relevant to all forest types considered to comprise caribou habitat, nor to different caribou subpopulations. In general, caribou habitat use in Alberta is concentrated in relatively low productivity environments that serve as refugia from predators. Predators tend to remain close to their primary prey, and those prey prefer more productive forests because of the abundant forage they provide. Altering habitat in a manner that affects this spatial separation (e.g., linear features that penetrate caribou refugia) or generates a numerical

response in primary prey and therefore predators in/and or near suitable caribou habitat, is expected to increase predation pressure (James et al., 2004; Latham et al., 2011).

As a result, minimizing primary prey habitat is likely more important in productive forests, while minimizing predator access is likely more important in lower productivity caribou refugia, although loss of suitable forage via forest harvesting or fire in refugia could alter caribou habitat use in a way that could compromise anti-predator strategies, even in the absence of a numerical response by primary prey (Leblond et al., 2016; Peters et al., 2013).

Of course, these goals are not absolute; forestry activity can enhance primary prey habitat in lower productivity forests and caribou forage and travel through more productive areas. The management goals are also not independent. Predator access is not a concern if predators are absent, so intervening to remove predators directly but temporarily reduces predator access as a stressor. Similarly, predator impacts on caribou survival can be additive to condition-related risks caused by forage limitation (Cook et al., 2021; Denryter et al., 2022).

But spatial separation via differential habitat selection by caribou and primary prey and their predators appears to be a key factor in restoring and maintaining self-sustaining caribou subpopulations. And differential habitat selection is evident at the scale of generalized forest types, which serve different functional roles for caribou, both in boreal forests and in montane ecosystems (Figure 2).

Minimizing primary prey habitat is the principal concern in productive upland spruce, mixedwood, and deciduous stands, because disturbances in these habitats are expected to generate the strongest forage response and therefore the strongest numerical response in primary prey and their predators. In forest types where forage responses are weaker, minimizing predator access becomes key, but adjacency and interspersion of early seral conditions in more productive upland habitats can drive unsustainable predation even in lower productivity habitats (Latham et al., 2011).

Outside of the driest pine-lichen stands, pine more broadly requires a dual strategy that includes reduction in primary prey habitat because post-harvest shrub and therefore moose and deer response can be substantial.

Maintaining and recovering caribou forage in low predation refugia are also important for ensuring the use of these habitats by caribou. This includes ground lichens in black spruce-larch forests and pine-lichen winter ranges, as well as arboreal lichens, which are important to both southern mountain and boreal populations, particularly during periods of deep snow. Shrub-forb forage resources are equally critical for caribou in other seasons, but enhancing their abundance is contraindicated because of the effect of increasing forage for other ungulates.

Minimizing direct sensory disturbance is not included as a goal because evidence of avoidance is inconsistent and confounded by coincident predation and forage effects. Managing habitat to minimize predator access and primary prey enhancement could also mitigate caribou avoidance of linear features and cutblocks.

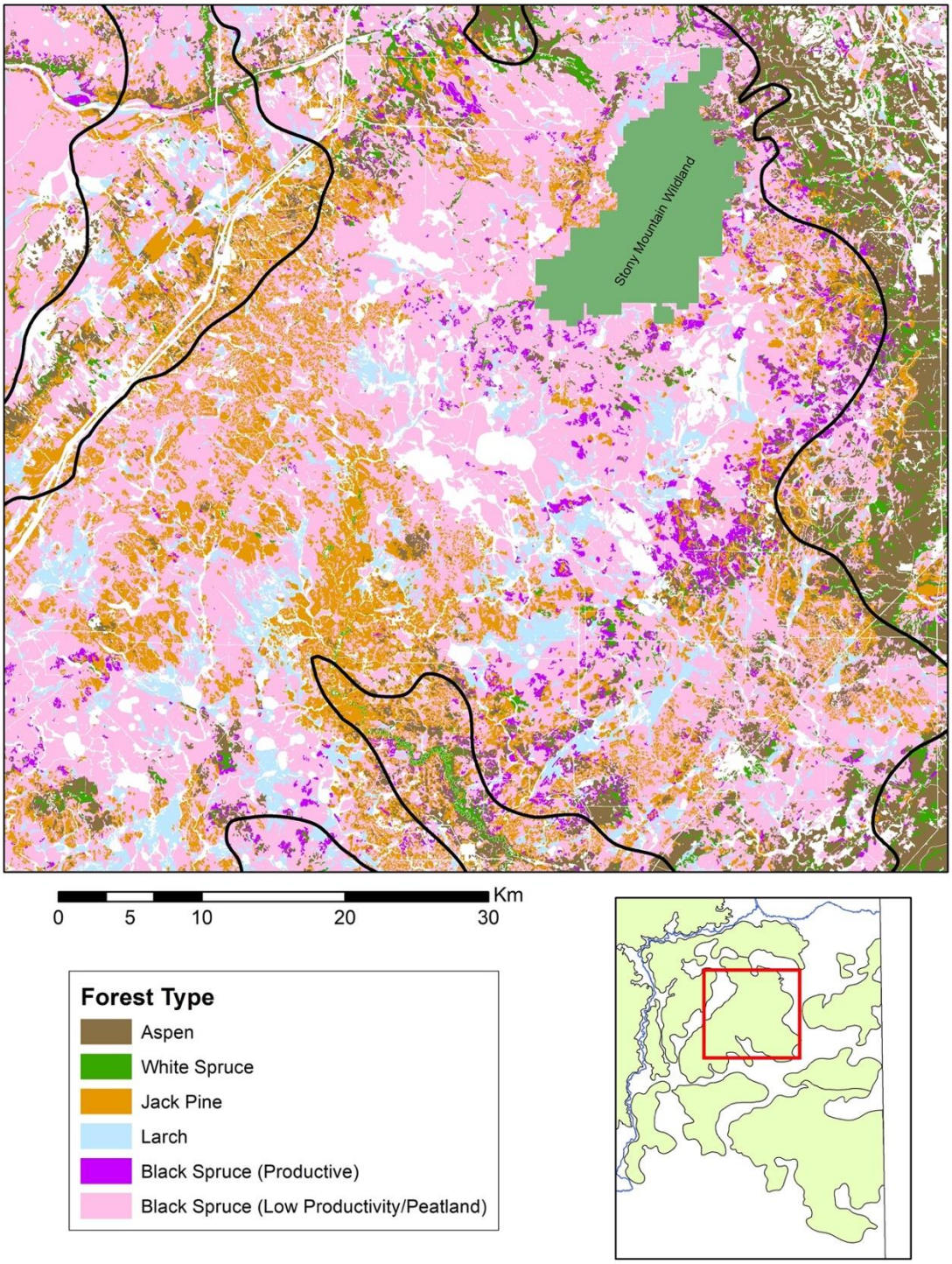

Figure 2. Example of the distribution of forested habitat in the Egg-Pony local population of the East Side Athabasca River (ESAR) subpopulation range. Caribou use occurs throughout the lower productivity unforested and forested peatlands (i.e., bogs and fens) dominated by black spruce. Jack pine stands occur both interspersed in the matrix of peatland habitat and more contiguously. Caribou use of jack pine overall is less than expected in relation to availability (approximately 7.7% use 11.5% availability in ESAR). Spruce and aspen forest are used relatively little. Map prepared and provided by T. Habib (Alberta-Pacific Forest Industries Inc.).

Empirical support for the ecological roles of these forest types is further supported by summaries of habitat selection for different forest types generated from radio telemetry studies of caribou in boreal and mountain caribou ranges in Alberta (Table 1). These summaries indicate that caribou strongly avoid productive deciduous, mixedwood, and spruce-balsam forests in nearly all ranges studied. Selection and avoidance of pine is more variable and complicated by the strong response of moose and deer to early seral stands generated by forestry (Figure 4). In contrast, all caribou in all ranges for which data were available select mid-late seral, lower productivity habitats dominated by black spruce and larch.

The caribou forest management goals are defined in direct relation to the life history functions served by the different forest types. This is in contrast, but is compatible with, the broader goals of reducing habitat fragmentation and retaining and restoring biophysical attributes (Environment and Climate Change Canada, 2020). Current evidence suggests that habitat fragmentation is a concern for caribou only to the extent that it leads to suitable conditions for primary prey (e.g., more edge habitat), facilitates predator access (e.g., linear features), reduces foraging opportunities (e.g., direct habitat loss, microclimate changes), or increases sensory disturbance that directly displaces caribou or disrupts movements (e.g., roads and trails). In other words, habitat fragmentation is a correlate of caribou decline that is conditional on other causal factors, which are captured in the caribou forest management goals presented here.

Caribou biophysical attributes are defined by Environment and Climate Change Canada (2020) as broad habitat features that generally speak to the life history requirements of caribou (e.g., open, mature-old forest with abundant arboreal and/or terrestrial lichens, treed bogs, etc.). The caribou forest management goals are consistent with managing to the federal guidance.

Alberta's approach to managing biophysical attributes for caribou refines the federal approach by first identifying stand types selected by caribou and then using the age class at which caribou switch from avoiding to selecting a stand type to identify stands comprising suitable biophysical attributes (Government of Alberta, 2018). Heavily used stands are also considered biophysical habitat even if positive selection is not demonstrated. This results in a finer stratification of stand types than the broad forest types used for this report, but both are based on the same data and are generally consistent. As a result, the forest management goals presented here are compatible with Alberta's approach to reducing habitat disturbance and restoring caribou biophysical habitat attributes.

Caribou Forest Management Goals and Defining Undisturbed Habitat

The federal boreal and southern mountain caribou recovery strategies provide definitions of disturbed habitat that reference only how disturbance is to be measured (i.e., anthropogenic features visible on 30-m Landsat imagery buffered by 500 m plus fire footprints <40 years old). Alberta reinterpreted this definition and uses a 40-year age threshold for anthropogenic disturbances.

If the current approaches were to be augmented with a definition:

Undisturbed habitat, for the purpose of caribou recovery planning, is the return of important functional components of habitat, following a natural or anthropogenic disturbance, to a condition that is consistent with a self-sustaining caribou population.

Conditions consistent with a self-sustaining caribou population need to be defined by desired outcomes that are linked to the forest management goals defined above (Table 2).

Table 2. Proposed qualitative definitions of undisturbed habitat conditions to meet desired outcomes inferred from caribou habitat management goals.

Caribou forest management goals	Desired outcome	Undisturbed habitat condition
Minimize primary prey habitat	Predator-prey populations consistent with self-sustaining caribou subpopulations.	Sparse cover of herb, shrub, and deciduous tree forage preferred by primary ungulate prey.
Minimize predator access	Permeability of the landscape for predators does not result in unsustainable predation rates on caribou.	Travel rates of predators and use of linear features are similar to those in the surrounding forest.
Maintain/recover caribou forage	Forage is sufficient to meet the nutritional needs of self-sustaining caribou subpopulations.	Abundant terrestrial and/or arboreal lichens for winter forage, *ad libitum* preferred forage in other seasons.

Defining undisturbed habitat conditions functionally can provide a basis for evaluating current age thresholds and an opportunity to explore alternative strategies to meet desired outcomes more effectively and/or efficiently.

Based on these proposed definitions, what is considered an undisturbed habitat condition from a functional perspective will vary by forest type, and sometimes within forest types (Table 3). It follows that not all undisturbed habitat conditions need apply to all forest types for caribou recovery because not all forest types are associated with all functional habitat components (Figure 2). Alberta's current approach, identifies a subset of stand types as being capable of generating biophysical habitat for caribou and provides minimize stand age criteria. The proposal here is to provide functional guidance not only for forest types capable of generating suitable biophysical habitat for caribou but also for other forest types contributing to the broader predator-prey community affecting caribou.

Seral trajectories that ultimately generate undisturbed habitat conditions are influenced by specific site conditions. As a result, the draft metrics presented in Table 3 provide only general guidance. Significant uncertainty and knowledge gaps remain.

Table 3. Structural characteristics and draft metrics proposed to meet undisturbed habitat conditions, by forest type.

Undisturbed habitat conditions	Forest type	Undisturbed stand structure characteristics	Draft default metric	Rationale
Sparse cover of herb,shrub, and deciduous tree forage preferred by primary ungulate prey.	Spruce, mixedwood, deciduous	From onset of stem exclusion phase of stand development, unless site conditions severely limit	>40 years of forest growth, although this can occur earlier in productive ecosystems and might not apply in very cold and/or dry conditions (e.g., some	Disturbance in this forest type is a driver of disturbance-mediated apparent competition because of its high productivity, and stem exclusion generally causes a significant drop in herb and shrub abundance (Hart and

Undisturbed habitat conditions	Forest type	Undisturbed stand structure characteristics	Draft default metric	Rationale
		shrub/herb responses.	conditions in taiga ranges, although this requires additional research).	Chen, 2006; Oliver and Larson, 1996). The marginal forage benefit provided by these stands is highest in harvested stands <40 (Figure 4; Figure 5).
	Black spruce-larch	Does not apply.	N/A, but treatments should encourage a rapid return to conifer cover.	There is a limited response of preferred forage in these lower-productivity ecosystems to disturbance, and little evidence of a significant response by primary ungulate prey.
	Pine	Mature mesic stands and all xeric sites	40-100 years of forest growth for mesic stands and all ages for xeric stands.	Some older mesic stands will succeed to spruce-shrub stands, while others will maintain a pine overstorey. Forage enhancement for moose resulting from harvest can be substantial (Figure 4) in all but the most xeric sites, which are relatively rare.
	Subalpine forest	From onset of stem exclusion phase of stand development in lower elevations dominated by continuous forest cover.	>40 years of forest growth in closed forest stands at lower elevations, does not apply in higher elevation habitats.	Low response of herb/shrubs to disturbance is expected here because of cold-dry conditions, although lower elevations in this zone can exhibit significant shrub responses. Consequently, population responses by primary ungulate prey is not expected to be as significant as in lower elevation forest types.
Travel rates of predators and use of linear features are similar to those in the surrounding forest.	Spruce, mixedwood, deciduous; black spruce-larch; pine-lichen	Impediment to travel similar to surrounding forest.	>1 m tall vegetation	Dickie (2015) found that 1-m tall vegetation was sufficient to slow down wolves in summer, when most predation occurs (5-m in winter). Other treatments that create physical barriers can also serve this purpose (e.g., mounding, tree-felling) but might not be permanent. Restoration treatments usually involve dense plantings, 1200-2000 stems/ha, depending on site (Melanie Dickie et al., 2022).
	Subalpine forest	Does not apply.	N/A	There is currently very limited evidence that linear features in high elevation caribou habitats generate a significant risk to caribou via enhancing predator

Undisturbed habitat conditions	Forest type	Undisturbed stand structure characteristics	Draft default metric	Rationale
				movements. These features are generally rare in this habitat type because much of the habitat is either protected or is associated with limited development pressure. A correlation between linear feature density in high-elevation habitats and caribou demographic rates has not been demonstrated. Ploughed roads are favourable to wolf travel but winter mortality of caribou by predators is relatively rare.
Abundant terrestrial and/or arboreal lichen for winter forage, *ad libitum* preferred forage in other seasons.	Spruce, mixedwood, deciduous	Does not apply.	N/A	Most stands are generally avoided by caribou, presumably because of predation risk. The primary goal in this forest type is to mitigate the early seral forage response to disturbance.
	Black spruce-larch	Mature-old forest conditions.	>40 years of forest growth	Lichens dominate ground cover in mature forest conditions, but like pine-lichen stands, ground lichens can be succeeded by moss as the canopy closes. (Dunford et al., 2006) found that lichens in northern Alberta peatlands that recovered 40-years post-fire, but that lichen cover was low in stands that had not been disturbed for at least 70 years. In NWT, (Maikawa and Kershaw, 1976) found that the phase of ground lichen dominance spanned 60-130 years. Evidence from other jurisdictions suggests that arboreal lichen abundance peaks later (100-200 years; (Boudreault et al., 2009; Proceviat et al., 2003).Lichens dominate ground cover in mature and old forest conditions, but like pine-lichen stands, is succeeded by moss as the canopy closes in old stands (Maikawa and Kershaw, 1976). This condition is relatively rare because of frequent fires.

Undisturbed habitat conditions	Forest type	Undisturbed stand structure characteristics	Draft default metric	Rationale
	Pine	Mature mesic stands and all xeric sites.	40-100 years of forest growth for mesic stand and all ages for xeric stands.	Ground lichens can recover in a few decades following fire or forest harvesting, if ground disturbance is minimized (Lafleur et al., 2016). But in mesic conditions lichens can be outcompeted by feathermoss as canopies close in older stands. In low-productivity, xeric stands, suitable lichen mats can persist for hundreds of years (Cichowski et al., 2022).
	Subalpine forest	Mature and old forest conditions.	>60 years	Arboreal lichens require defoliated lower branches for a substrate and are present 60 years after stand initiation; however, older and more ventilated stands are associated with higher lichen loads (Goward and Campbell, 2005).

Beneficial Management Practices

Having now established:

1. caribou forest management goals with respect to different functional habitat components;
2. cross-walked the goals with general forestry types, and,
3. defined qualitatively and quantitatively (where possible) undisturbed habitat conditions for the forest types in the context of their functions as caribou habitat,

the next step is to identify forest management objectives and practicable strategies that can generate undisturbed habitat conditions as rapidly as possible following disturbance, or that can support caribou habitat management goals indirectly.

The following sections present proposed objectives and strategies, stratified by general forest types. These have been drawn and adapted from a number of sources; in particular, a recent draft compilation of beneficial management practices for caribou developed for BC caribou subpopulations (BC Caribou Recovery Program and BC Provincial Forestry Forum, 2021). This joint government-industry collaboration expanded on earlier work by Hamilton (2011), Cichowski and McNay (2016), and other references cited there-in. Several of these strategies have already been adopted as guidelines or regulatory requirements in Alberta.

Note that strategies to benefit caribou might be contrary to other biodiversity goals (e.g., moose abundance) and might not be consistent with current policy requirements. Implementation will need to be balanced with competing objectives based on legislation, Forest Management Agreement commitments, and obligations under Sustainable Forest Management certifications.

Spruce, mixedwood, and deciduous forests

As noted above, these forests are generally avoided by both boreal and southern mountain caribou subpopulations (Table 1). As a result, management in this forest type is less about mitigating direct impacts to biophysical habitat characteristics preferred by caribou and more about mitigating the increase in early seral habitat that often follows forest harvesting or other disturbances.

The response of early seral forage to forest harvesting varies by subregion and ecosite. Submesic-medium to subhygric-rich moisture-nutrient regimes in warmer and wetter subregions are expected to generate the strongest responses in early seral vegetation post-harvest. As subregions and ecosites become progressively drier and colder, harvesting is expected to produce a weaker response in shrubs and forbs, to the point that the implications for populations of primary ungulate prey and their predators are not a significant concern and mitigations might not be necessary (Neufeld et al., 2021). The extent to which these conditions occur in Alberta is not known but would likely be limited to some areas in taiga ranges. Where there is a significant response, forest management should consider implementing actions that reduce shrub and forb response to harvesting and shorten the post-harvest window of forage enhancement (Table 4).

Table 4. Proposed forest management objectives and possible strategies to achieve caribou habitat management goals in spruce-mixedwood forests.

Caribou habitat management goals	Forest management objectives	Rationale	Possible strategies
Minimize primary prey habitat.	Minimize edge.	Primary ungulate prey often select habitat near forest edges for access to both abundant forage and adjacent security and snow interception cover (Courtois et al., 2002; Dussault et al., 2005; Williamson and Hirth, 1985).	Harvest in large blocks with simple shapes that minimize edge and “strand” available forage far from the edge habitats.
	Minimize forage response.	A positive forage response following disturbance is the main mechanism assumed to drive disturbance-mediated apparent competition (Neufeld et al., 2021).	Retain hardwoods to discourage suckering.
			Employ mechanical brushing or chemical treatments.
	Encourage stem exclusion as rapidly as possible and maintain as long as possible.	The stem exclusion phase of stand development shades the forest understorey and suppresses understorey growth (Oliver and Larson, 1996).	Reforest as soon as practicable.
			Plant large and/or genetically enhanced stock.
			Plant at high densities.
			Re-harvest stands before multi-storied canopies emerge.
	Encourage high hunter use and success.	Access and forest openings near roads encourages hunting pressure to lower primary prey populations	Maintain roads and related infrastructure to a standard suitable for subsistence and recreational access.

Caribou habitat management goals	Forest management objectives	Rationale	Possible strategies
		(Lebel et al., 2012; Rowland et al., 2021).	Minimize visual screening from roads.

Black spruce-larch

This forest type is selected by both boreal and southern mountain caribou, at least when the latter are ranging at low elevations in winter and the habitat type is available (Table 1). These forests provide terrestrial and arboreal lichens for winter caribou forage, as well as shrub and forb forages for other seasons. But these stands are generally avoided by moose and deer because site productivity is low and suitable forage relatively limited. Note however that there could be "spillover" of primary ungulate prey into these areas where there is high interspersion or adjacency with higher-productivity habitats (Latham et al., 2011).

Post-harvest or post-fire shrub response is expected to be less in these habitats than in upland forest because of the generally low site productivity (although this requires further study). Forest harvest pressure also tends to be low, again due to low productivity, although there is some pressure to access isolated but productive timber, often located in patches of upland habitat. These are fire-adapted ecosystems with relatively frequent disturbances, and their lichen forage value is not necessarily maintained indefinitely; succession to bryophytes is a risk in older stands (Dunford et al., 2006; Maikawa and Kershaw, 1976).

Access by predators is a significant concern in these areas, because linear features can alter this forest type from one that is avoided by wolves to one that is selected (DeMars and Boutin, 2018). Therefore, management is focused on minimizing access and maintaining or recovering lichen forage for wintering caribou, given that forestry is limited in these habitats and the majority of the forage subsidy generated by forestry activity is likely to be associated with roads and trails (Table 5).

Table 5. Forest management objectives and possible strategies to achieve caribou habitat management goals in black spruce-larch forests.

Caribou management goals	Forest management objectives	Rationale	Possible strategies
Minimize predator access.	Minimize roads and trails.	Wolves use linear features to access caribou habitat and increase predation pressure on caribou (DeMars and Boutin, 2018; Dickie et al., 2017).	Use existing access.
			Route necessary access through upland habitats to the extent practicable.
			Deactivate/debuild roads promptly following entries.
			Build access to the lowest practicable standard.
Maintain/recover caribou forage.	Minimize ground disturbance.	Minimizing ground disturbance can maintain forage resources for caribou (Lafleur et al., 2016)	Restrict activities to frozen conditions.

Caribou management goals	Forest management objectives	Rationale	Possible strategies
	Encourage rapid return to conifer cover.	Early seral responses should be discouraged to prevent forage enhancement.	Replant where practicable with large stock.
	Retain suitable stands known to be selected by caribou.	Retention of stands exhibiting high use by caribou minimizes risk of predation and provides persistent lichen forage resources, particularly in stands 40-70 years.	Defer harvest.
			Address forest health concerns with minimum interventions.

Pine forests

Lodgepole pine (*Pinus contorta*) stands can be important winter ranges for southern mountain caribou but are generally avoided by boreal caribou in the taiga subregion (Table 1; Figure 3). Jack pine (*Pinus banksiana*) stands are selected by caribou when adjacent to black spruce-larch lowlands (Proulx and Gillis, 2017).

Like black spruce-larch forests, dry pine habitats can provide abundant winter forage for caribou in the form of extensive ground lichens but harvesting in more mesic stands can generate a shrub response sufficient to attract moose and deer until stem exclusion is reached and shrub cover is reduced.

Pine stands are assumed to provide a predator refuge for caribou when maintained in suitable condition (low shrub but high lichen). The driest pine forests can maintain productive lichen mats at any age, barring natural disturbances (Cichowski et al., 2022).

In more common, mesic conditions, pine stands tend to lose lichen to feathermoss (*Pleurozium schreberi*), which are more shade-tolerant and hold more moisture. Lodgepole pine itself is a shade-intolerant species adapted to establish rapidly after stand-replacing fires and can be replaced by Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) at higher elevations (Gendreau-Berthiaume et al., 2016) and white spruce (*Picea glauca*) at lower elevations (Krakowski and El-Kassaby, 2005).

The timing of the transition away from ground lichens is site-dependent, beginning at stand ages as early as 70 years (Finnegan et al., 2021) to about 150 years (Sulyma and Coxson, 2001). Forest harvesting is recommended to re-establish suitable conditions for abundant terrestrial lichens (Cichowski et al., 2022) and lichens can recover quickly following harvest (Nobert et al., 2020). Partial harvest has also been suggested to increase feathermoss mortality and encourage regrowth of lichens (Coxson, 2015; McNay, 2011)

The trajectory for jack pine is similar, with rapid recolonization following fire and the maximum total cover of lichen reportedly occurring as early as 21-30 years (Skatter et al., 2014) or up to approximately 45 years after disturbance (Carroll and Bliss, 1982). Older, sandy and well-drained upland sites become more open but in wetter sites black spruce becomes co-dominant and lichens are lost to bryophytes. Schaefer and Pruitt (1991) found that caribou in Manitoba returned to jack pine stands approximately 50 years after fire when foraging conditions improved, but that the oldest stands (160 years) had the lowest lichen productivity. Skatter et al. (2014) reported a second peak in abundance of ground lichens in jack pine stands at ages 101-150.

Proulx and Gillis (2017) found that in deep snow or crusted conditions, caribou lost access to the ground lichens abundant in jack pine stands and moved into black spruce muskegs to access arboreal lichens. Selection of black spruce-larch forests by southern mountain caribou in west-central Alberta might suggest a similar behaviour.

Shrub response following harvest in mesic conditions can attract moose, often more than disturbance from fire, and therefore requires mitigation to limit risk to caribou. In addition, linear features presumably provide predator access into pine-lichen winter ranges as they do into black spruce-larch forests; however, the relative advantage may be less because sparsely forested upland pine might provide relatively easy travel for wolves, even in the absence of roads.

Despite the impacts of the mountain pine beetle outbreak and subsequent salvage on caribou habitat over the past 30 years, research demonstrating that caribou-supporting lichens are at risk of being lost due to forest succession in both lodgepole and jack pine stands, and an escalating risk of catastrophic fire, consistent management policies and practices to rapidly recover and maintain terrestrial lichens have not been articulated nor implemented in pine forests. The federal recovery strategy for southern mountain caribou adopts the boreal requirement to manage ranges to achieve 65% undisturbed habitat (Environment Canada, 2014); however, simply allowing these forests to age is likely suboptimal for maintaining caribou biophysical attributes in the long term, and is inconsistent with the natural disturbance characteristics of these ecosystems (e.g., Cichowski et al., 2022; Schaefer and Pruitt, 1991).

Here, the proposed management emphasis is to minimize predator access, suppress early shrub response in mesic conditions to discourage a strong predator-prey response, and to maintain or recover forage resources in pine-lichen forests (Table 6).

Table 6. Forest management objectives and potential strategies to achieve caribou habitat management goals in pine forests.

Caribou management goals	Forest management objectives	Rationale	Potential strategies
Minimize predator access.	Minimize roads and trails.	Wolves presumably use linear features to access caribou habitat and increase predation pressure on caribou.	Use existing access.
			Deactivate/debuild roads promptly following entries.
			Build access to the lowest practicable standard.
Minimize primary prey habitat (mesic conditions and/or where a strong shrub response is expected).	Minimize edge.	Primary ungulate prey often select habitat near forest edges for access to both abundant forage and adjacent security and snow interception cover (Courtois et al., 2002; Dussault et al., 2005; Williamson and Hirth, 1985).	Harvest in large blocks with simple shapes that minimize edge and “strand” available forage far from the edge habitats.
	Minimize forage response.	A positive forage response following disturbance is the main mechanism assumed to drive disturbance-mediated apparent competition (Neufeld et al., 2021).	Retain hardwoods to discourage suckering.
			Employ mechanical brushing or chemical treatments.

Caribou management goals	Forest management objectives	Rationale	Potential strategies
	Encourage stem exclusion as rapidly as possible and maintain as long as possible.	The stem exclusion phase of stand development shades the forest understorey and suppresses understorey growth (Oliver and Larson, 1996).	Reforest as soon as practicable.
			Plant large and/or genetically enhanced stock.
Maintain/recover caribou forage (in more xeric conditions where terrestrial lichens dominate understories).	Minimize ground disturbance.	Minimizing ground disturbance can lead to faster lichen recovery in harvested stands than on fire-disturbed sites (Coxson and Marsh, 2001), which can take 50 years (Russell and Johnson, 2019). Nobert et al. (2020) found that lichen abundance was lower in clearcuts and burns than in undisturbed forest for only 10 and 20 years post-disturbance, respectively.	Restrict activities to frozen conditions.
			Avoid mechanical site prep, except for light scarification where herbaceous shrubs have succeeded lichen.
	Target xeric/low productivity sites for retention.	Lichens can dominate in old stands conditions on very low-productivity, xeric sites (Brulisauer et al., 1996; Cichowski et al., 2022).	Defer harvest.
	Maintain mature conditions in mesic pine forest.	These stands are likely to lose lichen to feathermoss if left untreated (Cichowski et al., 2022).	Harvest mature pine on rotations that optimize lichen abundance.
			Salvage promptly and replant stands affected by forest health issues.
			Replant at low densities, avoiding extant lichen clumps.
	Minimize slash	Downed wood can limit access by caribou (Apps, 2020; Wilson et al., 2023).	Process logs and pile slash off lichen-suitable sites.
			Treat sites by burning or light scarification.

Subalpine forest

Subalpine forest provides calving and summer range habitat for southern mountain caribou, as well as winter range habitat for some fraction of most subpopulations (Environment Canada, 2014). Access to arboreal lichens on the lower, dead branches of large, live trees, as well as ground lichens on exposed windswept ridges, are considered limiting in winter. Summer forage is generally assumed to be abundant and not limiting (c.f., Denryter et al., 2017).

The high-elevation habitats preferred by southern mountain caribou are often considered unmerchantable, so forestry impacts are generally limited to the lower elevations of suitable habitat. Research investigating the impact of high-elevation forestry on forage enhancement and subsequent responses by primary ungulate prey is limited but high elevation cutblocks have not been found to increase the time moose spend at high elevations (Anderson et al., 2018). Given the observed decline of southern mountain caribou throughout much of their range, even in high-elevation protected areas, prey enrichment in low-elevation matrix habitat alone appears sufficient to cause caribou declines and the additive effect of high-elevation habitat disturbance is unclear. Apps et al. (2013) found that southern mountain caribou were not more likely to die in landscapes with abundant early-seral and edge habitat, but were at higher risk of predation at lower elevations, a conclusion supported by Ehlers et al. (2016).

As noted above, that linear features facilitate the movement of primary ungulate prey and their predators into subalpine caribou habitat is the motivation for some projects in BC that are restoring linear features that lead from low to high elevations.[16] However, evidence that these features pose a significant risk, and that caribou would benefit from their restoration is generally lacking. Snow limits mobility and access to forage at higher elevations and consequently early seral ungulate prey and their predators are more common in lower elevations during winter. In summer, dispersal of prey and predators into higher elevations is common, regardless of the presence of roads, and this loss of spatial separation between caribou and their predators coincides with when most southern mountain caribou mortalities occur (Apps et al., 2013; Wittmer et al., 2007). While restoring high-elevation roads may have some benefit, managing the drivers of apparent competition caused by low-elevation habitat change is likely to generate a more positive impact for caribou (Apps et al., 2013).

The management emphasis proposed here is on maintaining and restoring forage resources (Table 7).

Table 7. Forest management objectives and strategies to achieve caribou habitat management goals in subalpine parkland forests.

Caribou management goals	Forest management objectives	Rationale	Strategies
Maintain/recover caribou forage.	Retain or recruit stands with high arboreal lichen loading.	Arboreal lichens provide an important food source for southern mountain caribou wintering at high elevations (Environment Canada, 2014).	Defer harvest.
			Implement partial harvest strategies to retain or enhance lichen-bearing stems by improving stand ventilation.
			Address forest health concerns with minimum interventions.

Recommended Workflow

The sections above infer a general workflow for companies operating in boreal or southern mountain caribou ranges. Harvesting and silviculture planning can be informed by answering specific questions in the context of caribou recovery:

[16] https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/caribou/management-activities#habitat

1. **What is the general forest type proposed for development and what function is it serving for caribou?** The federal boreal recovery strategy identifies subpopulation boundaries but does not stratify ranges into habitats of different functions within those boundaries, while the southern mountain caribou strategy does stratify habitats by function, but often without defining boundaries among the different functional types. The generalized forest types identified here provide a starting point for understanding how areas proposed for development are functioning as caribou habitat and Table 2 provides overall caribou forest management goals, desired conditions, and qualitative definitions of undisturbed habitat. These functions are not absolute, particularly in areas of interspersion of forest types and ages.
2. **How is "undisturbed" habitat provisionally defined for the forest?** Table 3 provides general guidance for managing to undisturbed habitat conditions, but there is uncertainty in the metrics and in some cases, there may be a mismatch between the proposed metrics and the descriptions of undisturbed habitat conditions. The latter should be the focus when planning development activities.
3. **What are the practicable harvesting and silviculture practices that can be applied to generate undisturbed habitat conditions as quickly as possible?** This report provides beneficial management practices designed to address caribou management goals, stratified by forest type, that can help guide planning. Within the direction provided by current legal and policy requirements, innovative prescriptions are encouraged to address current knowledge gaps and to accelerate the development of conditions favourable to caribou more quickly following harvest.
4. **How can outcomes be monitored and management improved over time?** Monitoring should include components focusing on *implementation* (i.e., were planned prescriptions implemented successfully?) and *effectiveness* (i.e., did the prescriptions generate, or are they likely to generate, the expected undisturbed habitat conditions within the intended timeframe?).

Outcomes should be summarized and shared with governments to support caribou recovery planning and forestry's role in promoting positive outcomes.

Knowledge Gaps

This report highlights a number of knowledge gaps that need to be addressed to improve management of caribou habitat and further recovery efforts in Alberta, Specifically, research and adaptive management trials are required to:

1. **Develop a more precise definition of early seral forage conditions that are inconsistent with caribou recovery.** What indicates a shrub response that is likely to enhance primary ungulate prey populations and ultimately affect caribou populations? This is particularly important in pine and black spruce-larch forests which comprise the majority of suitable habitat for caribou. Could we develop guidelines with respect to biomass, cover, and/or species? How can such conditions best be prevented or minimized over the forest rotation?
2. **Develop detailed planning guidance for pine-leading forests to optimize conditions for caribou.** Not all pine stands >40 years old are necessarily suitable caribou habitat. Harvesting and

silviculture treatments provide the opportunity for earlier recruitment and longer retention of lichen forage.

3. **Assess the effect of forest interspersion on managing caribou refugia from predation.** While differential habitat use by caribou and primary ungulate prey generally maintains spatial separation and increases the probability of caribou persistence, forest types occur in mosaics at various scales. Does interspersion at some scale(s) challenge caribou recovery efforts and should management guidance be altered to address the challenge?
4. **Determine the extent to which subalpine refugia for mountain caribou are compromised by linear features.** While this mechanism is relatively well-studied in boreal environments, roads from low- to high-elevation habitats are being targeted for restoration based on little evidence that these features are increasing predation risk.
5. **Better integrate caribou habitat management goals with those for other species or biodiversity in general.** Aggressive strategies associated with advancing undisturbed habitat for caribou might conflict with goals for other species (e.g., moose densities). How can competing objectives best be optimized? Should we be trying to meet multiple goals on the same land base or zone objective spatially, and at what scale?

Next Steps

This report presents several broad concepts as well as proposed goals and strategies that can form the basis for further dialogue with the Governments of Alberta and of Canada on strengthening the evidence considered in range planning. Chief among the broad concepts I present is that different forest types broadly serve different functional roles in the caribou system and therefore no single "undisturbed" metric is likely to drive caribou recovery efforts effectively or efficiently. Rather, different strategies could be applied in different areas to ensure that limited conservation resources are allocated most beneficially.

Secondly, I argue that, for some forest types and some habitat functions, an older forest is not necessarily a better forest for caribou. In fire-adapted ecosystems it is logical that disturbance will be required to maintain functional components of ecosystems on which caribou have evolved to depend, and how best to manage these dynamics for the benefit of caribou, in the context of competing goals and the challenges of climate change, requires a more nuanced approach.

As a result, the proposed strategies are not all consistent with current federal and provincial direction, and some carry economic or ecological risks. All require careful review by stakeholders and rights-holders prior to implementation.

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