BOREAL CARIBOU HABITAT RESTORATION PRACTICES: APPLICATION AND OUTCOMES

A synthesis for the National Boreal Caribou Knowledge Consortium

National Boreal Caribou Knowledge Consortium

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The Habitat Restoration Working Group of the National Boreal Caribou Knowledge Consortium (NBCKC-HRWG) is a composition of representatives from federal, provincial and territorial governments, Indigenous communities and organizations, industry, academia, ENGOs and consultants with a working knowledge of habitat restoration. This report was prepared by NBCKC-HRWG member Dr. Steven F. Wilson (EcoLogic Research) under contract to Environment and Climate Change Canada and on behalf of the NBCKC-HRWG. We wish to extend our thanks to all the HRWG members for providing valuable discussions, comments and edits to earlier versions.

National Boreal Caribou Knowledge Consortium

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Executive Summary

The Habitat Restoration Working Group of the National Boreal Caribou Knowledge Consortium (HRWG-NBCKC) developed a conceptual model for understanding the impacts of habitat restoration on woodland caribou (*Rangifer tarandus caribou*). The model was based on the current scientific understanding of the caribou system; however, habitat restoration projects have been ongoing and there is a need to review management actions that have been taken to date and their outcomes. Learnings from these projects can be used by jurisdictions, Indigenous communities, industry, and other groups in the planning and delivery of restoration programs. The purpose of this report is to present these actions and outcomes in relation to the pathways described in the model, and to recommend best practices and opportunities for further development and research.

Here, restoration is defined as management actions that intervene to alter habitat in a way that is expected to improve conditions for caribou. The predation and nutrition pathways of the ecological model are the two main pathways that have been addressed in habitat restoration projects. Most of the projects focused on the predation pathway have aimed to accelerate revegetation on linear features in order to physically disrupt movements of bears, ungulates, and wolves. Because most projects have been recent, monitoring has been limited to measuring short-term responses of vegetation and wildlife. The broader pathways associated with habitat-mediated apparent competition remain largely untested. Projects are needed to test whether interventions could alter the abundance, distribution, and/or composition of available browse and whether this would alter the habitat use or population responses of predators and primary prey.

These restoration projects have generally employed a variety of different treatments within the same study to adapt to variable site conditions. Generally, treatments have been pooled in analyses to gauge effectiveness. This is understandable but makes detailed evaluations of specific treatments difficult.

Experience gained in the field from these projects is rarely captured in scientific papers and only partially in management reports. Knowledge sharing occurs primarily among practitioners and is being learned through trial and error in the field. As a result, developing an effective community of practice to share best practices and train field staff will be important to scale restoration activity efficiently and to avoid costly errors.

Projects related to the nutrition pathway have been focused on small scale trials to accelerate the recovery of lichens following disturbance from surface mining or fire. Post-treatment monitoring of these studies has been restricted to <5 years. While these projects have been well designed and have generated important learnings, scaling such treatments to have a measurable effect on the caribou system will be challenging.

As habitat restoration projects continue, there will be a need to shift from relatively small-scale treatments and short-term monitoring of immediate benefits to significantly larger-scale treatments that can be expected to have demonstrable effects at the subpopulation range scale in the medium and long term. This creates a challenge for monitoring and approaches will need to be developed that can shorten the adaptive management feedback loop and inform changes to future restoration projects before results from previous trials are fully realized. It will also require the development of new approaches to measure the effect of site level treatments on range-scale ecology.

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1. Introduction

The Amended Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada (Environment and Climate Change Canada 2020) identified habitat restoration as a key requirement for recovery of declining caribou subpopulations. In response, the Habitat Restoration Working Group of the National Boreal Caribou Knowledge Consortium (HRWG-NBCKC) developed a conceptual model for understanding the impacts of habitat restoration on the caribou system. The model, referred to as the Boreal Caribou Ecological Model, presents a hypothesized causal structure for different pathways currently leading to caribou decline (Figure 1).

HRWG-NBCKC (2022) provided the scientific rationale for the structure of the model; however, a more operationally oriented report is required to describe management actions that have been taken to date and their outcomes. Learnings from these projects can be used by jurisdictions, Indigenous communities, industry, and other groups involved in restoration programs throughout the boreal range of caribou in Canada. With habitat restoration actions currently being planned and implemented, a review of outcomes in the context of the ecological model is timely.

The purpose of this report was to review the various management actions taken to date and their outcomes, in relation to the pathways described in the model, and to recommend best practices and opportunities for further development and research.

The following sections review the major pathways (i.e., predation, nutrition, and hunting), the outcomes of projects completed to date, and considerations for the design, implementation, and monitoring of future projects.

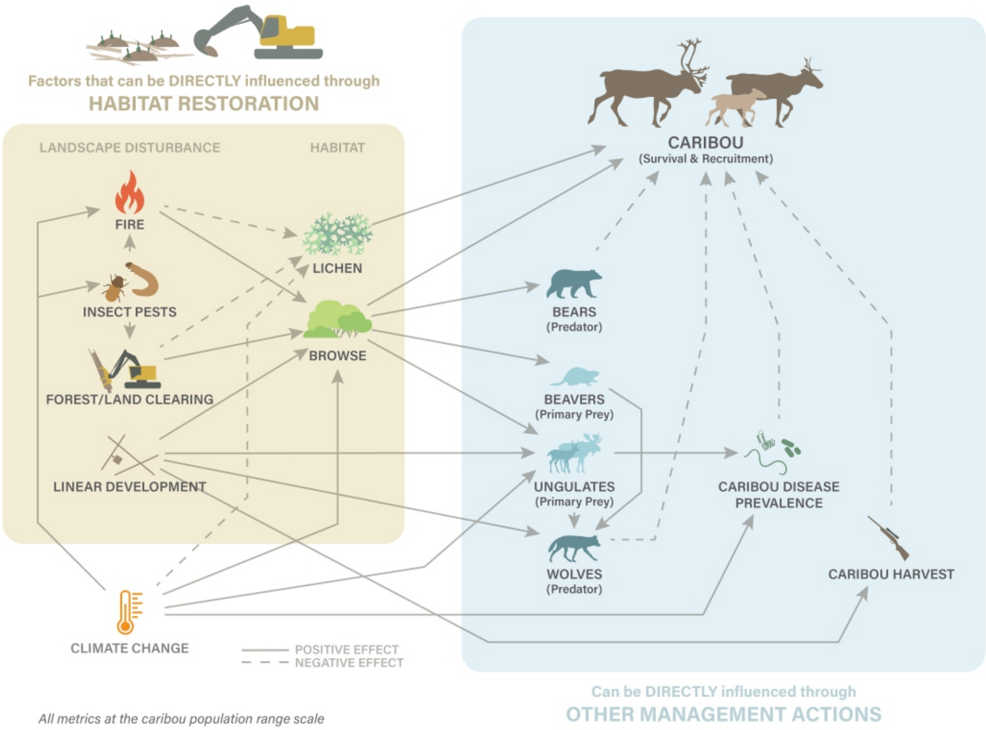

Figure 1. Conceptual ecological model of the boreal caribou system in Canada (HRWG-NBCKC 2022).

2. Methods

This report is a compilation of available scientific and management literature, focusing on documented habitat interventions (i.e., direct manipulation of habitats to improve conditions for caribou). Non-habitat related interventions (e.g., predator management) were not reviewed.

3. Predation Pathways

Unsustainable predation is considered the most significant, proximal cause of caribou declines throughout much of their range (e.g., Festa-Bianchet et al. 2001) but habitat change is cited as the ultimate cause (e.g., Frenette et al. 2020). High predation rates are believed to be the result of abundant predators that have benefitted from increasing populations of their primary prey, such as moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*). Primary prey populations are generally increasing because of habitat alteration and climate change effects that tend to improve the suitability of forage for these species (Figure 2). In addition to improving forage suitability, a second major pathway links an increase in linear features with risk to caribou by increasing the hunting efficiency of predators (primarily wolves, *Canis lupus*). Consequently, habitat restoration focused on reversing habitat changes that enhance primary prey are expected to benefit caribou. The complex causal pathways manifest as an overall statistical association between habitat disturbance and caribou recruitment and adult female survival (Johnson et al. 2020).

Of all the pathways, this one has received the most attention, with projects treating linear features to change the short-term behaviour of primary prey and wolves (Table 1). Keim et al. (2019) focused entirely on disrupting animal movements while the other studies were aimed at habitat recovery but measured the behavioural responses of species using treated and control features.

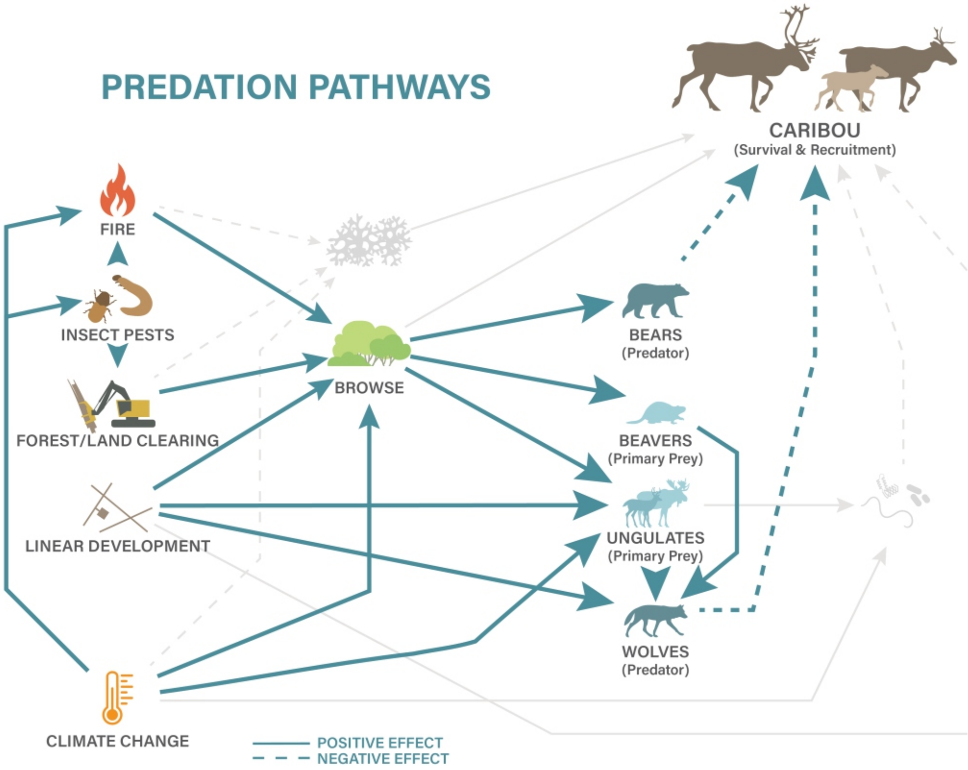

Figure 2. Components of the conceptual ecological model related to predation stressor (HRWG-NBCKC 2022).

Table 1. Projects focused primarily on restoring linear features to alter behaviour of wolves and primary prey.

Reference	**Keim et al. (2019)**	**Tattersall et al. (2019)**	**Dickie et al. (2021)**	**Keim et al. (2021)**	**Hervieux et al. (2021)**
Geographic location	Northeastern Alberta	Northeastern Alberta	Northeastern Alberta & Northwestern Saskatchewan	Northeastern British Columbia	Northeastern British Columbia
Caribou subpopulation	East Side Athabasca	East Side Athabasca	Cold Lake, SK2 (west)	Parker	Snake-Sahtenah
Study design	Replicated treatment-control	Post-treatment monitoring of treated (active and passive restoration) versus untreated (human use and control)	Single control-single treatment, large scale	Pre- and post-treatment monitoring of treated lines and untreated game trails	Treatments and control (for wildlife camera monitoring)
Treatment(s)	200-m^3 downed wood treatments at 200 m intervals	Mounding, downed wood, planting	Mounding, scalping, bending/felling, yarding, transplanting, planting. Post-hoc classification of intensity as either high or low	Mounding, tree planting, tree felling	Whole hummock transplantation, scraping and planting, tree-felling
Monitoring	Camera traps post-treatment	Camera traps 3- 6 years post-treatment	Camera traps, GPS collaring during and post-treatment	Camera traps pre- and post-treatment	Winter track surveys (study area scale), camera traps (treatment and control lines), treatment vegetation plots
Outcomes	Use by wolves and white-tailed deer was lower on treated sites.	Restoration reduced white-tailed deer use; wolves did not avoid treated lines.	Wolves and bears were less likely to be found on treated than untreated lines, individuals were less likely to use treated lines. No significant decline in line use within the treatment area.	Wolf-caribou encounters and bear-caribou encounters were reduced by treatments in treatment area.	Early results variable, but monitoring is ongoing.
Challenges/ recommendations	Confounded by human use, snow conditions	Assessed only shortly after treatment	Restoration progressed over several years, heterogeneous treatments	Strongly influenced by packed snow conditions	Not provided

Another set of restoration projects have addressed the same pathways but have measured primarily vegetation responses, assuming that more vegetation growth will lead to physical disruption of movements of ungulates and predators (Table 2). This list includes two retrospective studies of previous treatments to assess their effectiveness.

Table 2. Projects focused primarily on restoring linear features to recover vegetation.

Reference	**Golder Associates (2015)**	**Hall et al. (2016)**	**Filicetti et al. (2019)**	**Lacerte et al. (2021)**
Geographic location	West-central Alberta	Northwestern Ontario	Northeastern Alberta	Akumunan, Saguenay, Québec
Subpopulation	Little Smoky	Various	Cold Lake	Québec
Study design	9 –13-year post-treatment monitoring	Observational study of post-treatment and untreated vegetation responses on roads (123 road segments)	Paired plots (treated versus untreated seismic lines) in three study areas	Post-treatment monitoring of incrementally treated roads and controls
Treatment(s)	Mounding and planting, wooden fencing on seismic lines	Cross-berming, decompaction, water-crossing removal, tree-planting, aerial seeding, passive regeneration (varied by site)	Mounding and ripping, planting	Road closure, decompaction, tree planting, soil enrichment
Monitoring	Stand height and leader growth of planted and naturally ingressing trees in treatment and naturally regenerating plots, lowland versus upland sites.	Tree species and height class in 16 m^2 circular plots, ease-of-travel on segments.	Vegetation sampling 4 years post-treatment.	Vegetation sampling 3-4 years post-treatment.
Outcomes	Treated lines had little ATV use, >50% of fences intact. Planted black spruce taller than ingress, particularly on lowland sites. Time since treatment, shrub cover and depth to water did not affect height. Mounding and planting accelerated recovery times by 5-10 years in lowland sites but not upland sites.	Time since abandonment the most significant factor. Less aggregate and lower compaction resulted in better growth. Road surface variables had limited effect.	Treated lines had 1.6x more stems than untreated lines.	Closing, decompacting and planting was most effective in reducing shrubs and deciduous trees.
Challenges/ recommendations	Treatments need to be targeted to site conditions (i.e., moisture, nutrients, shade) to achieve better results.	Many outcomes possible due to the large number of factors involved.	Poor fens do not respond as positively to treatment.	Closing or decompacting without planning increased forage for moose and bears.

3.1. Monitoring Outcomes

Most habitat restoration projects have occurred only recently, and monitoring has generally been restricted to short-term vegetation responses and post-treatment wildlife and human use. The first project aimed specifically at restoring caribou habitat occurred as part of the *Caribou Protection and Recovery Program* (CPRP) in Alberta, which began in 2005 (Golder 2011). Returning to sites 9-13 years post-treatment, conditions suggested that there had been modest improvements resulting from treatments, with an acceleration of 5-10 years of tree growth on lowland sites. However, techniques have improved since these early treatments and long-term monitoring of more recent projects may reveal better performance.

The scale and recency of treatments to date has been insufficient to expect changes in caribou survival and recruitment, although these continue to be monitored in most ranges. Area-level effects of treatments on behaviour of bears, ungulates and wolves were detected by Keim et al. (2021) but not by Dickie et al. (2021).

3.2. Project Gaps

The pathways of the ecological model addressed by restoration projects to date have been restricted to *linear development > ungulates* and *linear development > wolves* and have focused on physical impediments to movements of bears, ungulates and wolves caused by regenerating vegetation, mechanical treatment of substrates, and woody debris. Projects have also measured caribou use of treated lines, although impeding caribou is not considered an objective.

Photo Credit: Ryan Dickie

No projects have yet addressed the pathways mediated by browse. These pathways are expected to alter habitat use but, more importantly, are expected to influence population-level responses of bears, beavers, and ungulates. These pathways represent habitat-mediated apparent competition (Frenette et al. 2020) and comprise the primary hypothesis advanced to explain the proximate decline of caribou.

Projects aimed at addressing the browse pathways would test interventions aimed at altering the abundance, distribution, and/or composition of available browse and testing the habitat use and population responses of bears and primary prey. Current restoration guidance encourages treatments that favour conifer regrowth over deciduous, based on research demonstrating that deciduous regrowth encourages habitat use or leads to population responses by primary prey (e.g., Labadie et al. 2021). Possible treatments could include planting bigger conifer stock to shade out deciduous vegetation more quickly, leaving deciduous trees to avoid suckering, or mechanical or chemical treatment of brush.

3.3. Project Design Considerations

The ecological model identifies possible confounding factors that need to be addressed in the design of projects to test the effectiveness of habitat interventions. For example, climate change is expected to increase browse, independent of other landscape changes. Although not a short-term monitoring concern, this creates a long-term concern regarding the effectiveness of habitat restoration because climate change pressures might counter treatments to limit browse. Designing treatments to be resilient to such changes could mitigate this.

Where habitat restoration treatments are intended to both impede movements of ungulates and dissuade use by reducing browse, studies should be designed to allow the independent estimation of these effects. Knowing the relative strengths of different drivers can help optimize restoration effort. For example, if physically blocking lines has a greater effect than reducing browse, then restoration actions should shift to those that mechanically disrupt movements and lead to the rapid revegetation of woody species, regardless of composition. If the browse pathway is more important, then restoration should emphasize suppression of browse and the establishment of a conifer overstorey.

Similarly, wolf movements on treated lines may decline because they are physically impeded and because their prey are found on lines less commonly. Separating these pathways has important implications for population management actions. For example, if the main driver of wolf habitat change following treatment is physical disruption, then reductions in primary prey populations (e.g., through increased hunting) would not be expected to significantly reduce use of linear features by wolves nor re-establish spatial separation with caribou. Alternatively, if wolf use declines because prey are less abundant, then primary prey reductions could augment or perhaps replace habitat restoration in some instances.

Finally, while reducing browse is expected to discourage habitat use by primary prey or negatively affect their populations, browse suppression might also affect caribou, given that outside the winter season they have broad diets (e.g., Thompson et al. 2015, Denryter et al. 2020) and like other ungulate species can select habitats that provide abundant forage (e.g., Hins et al. 2009). Therefore, browse manipulation studies need to consider both primary prey and caribou impacts.

Photo Credit: Ryan Dickie

4. Nutrition Pathways

Caribou feed primarily on terrestrial lichen in winter and on a wider variety of forages in the snow-free season (e.g., Thompson et al. 2015, Denryter et al. 2020). Because of the critical role of nutrition in reproductive performance (Cook et al. 2021), habitat changes via disturbance and climate change could affect caribou population growth rates (Figure 3). Implementing restoration projects to increase lichen or the abundance of other forage could benefit caribou survival and reproduction.

There have been several studies focused on restoring lichen communities following disturbance (Table 3), particularly from land clearing associated with surface mining or following fire.

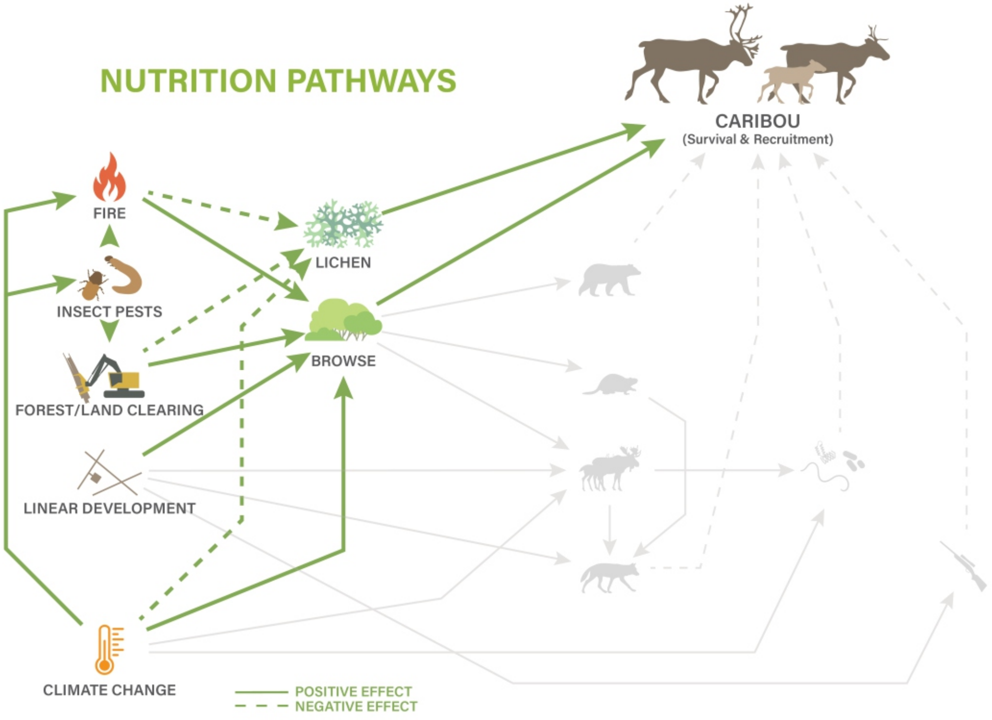

Figure 3. Components of the conceptual ecological model related to caribou nutrition (HRWG-NBCKC 2022).

Photo Credit: Ryan Dickie

Table 3. Projects focused on restoring lichens following land clearing (primarily mining) or fire.

Reference	**Roturier et al. (2007), Roturier and Bergsten (2009)**	**Duncan (2011), Duncan (2015)**	**Hugron et al. (2013)**	**Rapai et al. (2018)**	**Ronalds and Grant (2018)**
Geographic location	Northern Sweden	Northeastern Alberta	Parc national des Grands-Jardins, Québec	Northeastern Ontario	Northwestern British Columbia
Subpopulation	Not applicable	Not applicable	Charlevoix	Cochrane	Tweedsmuir (Southern Mountain Caribou)
Study design	Unbalanced randomized block with 2 blocks and 3 dispersal methods; 48 experimental plots of 1 m^2 each	6 blocks of 3 plots (1 m^2) with randomized treatments at 3 sites	Complete randomized block with 2 levels of 3 treatments and 4 blocks (1 m^2 each)	Randomized block with 3 blocks and 12 treatment combinations with 5 replicates of each treatment within blocks (1 m^2 each)	Four treatment and 2 control transects (20-40 x 50-100 m) among two study areas
Treatment(s)	Patch planting or scattering lichens, control	Lichen fragments applied to moss, pine needle litter, and soil substrates	Spreading diaspores, mulching, peat amendment	No lichen, lichen mat, lichen fragments x moss, no moss, wood chips, no wood chips, erosion blanket, no erosion blanket	Manual application, leaf blower or aerial application of lichen fragments
Monitoring	Photographic inventory over 5 years to determine lichen area	Thalli survival and vigour, hyphae growth, photo analysis of cover, 2-year trial	Vegetation survey after 3 years measuring percent cover	Ocular estimates of lichen percent cover over 23 months	100-m^2 ecosystem plots with 4, 1x1-m monitoring plots for substrate and vegetation cover
Outcomes	Treatments increased cover, patch planting was more effective.	Moss and litter were better substrates than bare soil in young forest, no difference in older forest.	Spreading diaspores and mulching generated positive effects, mulching was negative.	Supports use of *Cladina* fragment and mat transplants on roadways capped with a coarse substrate.	In progress
Challenges/ recommendations	Initial treatments were grazed heavily by reindeer, natural colonization was evident. Bark, twig and moss substrates were positive for thalli fastening compared to bare mineral soil.	50% of fragments applied were lost and image analysis was difficult.	Other organic matter additions should be tested.	Sandy loam is a poor substrate and micro topography is important (e.g., avoid pooling).	Manual distribution led to higher cover than arial and was less expensive. Leaf blowers became clogged. Lichen handling is important.

There is an additional, related study that intervened in the nutritional pathways by supplementally feeding caribou on winter range (Table 4). Rather than native browse or lichens, the food provided was commercial pellets.

Table 4. Project focused on supplemental feeding to address forage limitation on managed landscapes.

Reference	**Heard and Zimmerman (2021)**
Geographic location	Northern BC
Subpopulation	Kennedy Siding (Southern Mountain Caribou)
Study design	Before-after treatment and control (unreplicated)
Treatment(s)	Supplemental feeding with food pellets
Monitoring	Lambda (survival and recruitment)
Outcomes	Lambda was higher after than before treatment and higher than in control herd.
Challenges/ recommendations	Should be replicated elsewhere but could be used in conjunction with other treatments.

4.1. Monitoring Outcomes

Monitoring the outcomes of lichen transplant studies has usually been limited to 2-3 years and no more than 5 years. Most treatments were easily disturbed by wind and debris and even by grazing caribou, which challenged monitoring. Some studies are still in progress. Because the trials have all been small scale, experimental designs, data collection, and analyses have been comprehensive.

Photo Credit: Ryan Dickie

4.2. Project Gaps

The nutrition-related pathways addressed by these studies have been *forest/land clearing > lichen > caribou* and *fire > lichen > caribou*. Treatments to recover lichen in logged areas have not been attempted, although there are recommended forestry practices designed to minimize ground disturbance and mitigate impacts on lichen mats (e.g., winter logging in frozen and snow-covered conditions, avoiding scarification post-harvest; Cichowski et al. 2022). This can lead to faster recovery of lichens in harvested stands than in burned areas (Coxson and Marsh 2001).

The main drawback of studies completed to date is their small scale. Using small plots enables a rigorous experimental design and leads to strong inferences; however, it would be challenging to scale lichen transplant projects to the point that they could provide a significant and detectable benefit to caribou. Projects have relied on manual collection of lichen stock and most studies also apply lichen to treatment blocks by hand. Ronalds and Grant (2018) tested leaf-blowers and aerial application by helicopter for broad-scale application and concluded that aerial application might be effective but costly.

Supplemental feeding is a unique intervention to address lichen loss due to disturbance and results suggested that food might be limiting in the Southern Mountain Caribou winter range of the Kennedy Siding herd. Although feeding does not restore habitat, investing in supplemental feeding while lichens naturally recover might be more practicable than treatments to accelerate lichen re-establishment.

Photo Credit: Ryan Dickie

4.3. Project Design Considerations

As noted in the predation pathways section, both lichen and browse abundance can generate positive nutritional consequences for caribou, but their management tends to be competing. Actions to maintain or improve lichen productivity can involve reducing competition with invading shrubs and mosses, particularly in transitional pine-lichen stands (Cichowski et al. 2022). The assumption has been that lichens are more limiting because they comprise the majority of caribou diets in winter when nutritional stress is at its greatest, while browse is generally not limiting in other seasons. However, this logic has been challenged (Denryter et al. 2022). Designing restoration trials to distinguish between these two pathways would generate important information about their relative effects.

The biggest challenge facing these types of treatments is scaling them to a point where they could be expected to generate a detectable benefit to caribou compared to untreated areas. Moving to larger scales presents logistical challenges because large volumes of lichen need to be collected, manual distribution is impractical, treatment intensity (i.e., L/ha) will be lower than studied previously, substrates will be variable, and any caribou responses could be confounded by a variety of factors unrelated to treatments.

Photo Credit: Ryan Dickie

5. Hunting Pathways

Licensed hunting of boreal caribou is prohibited in many parts of their range, but caribou continue to be an important species for many Indigenous communities. Habitat alteration can increase caribou vulnerability by improving access by humans (Plante et al. 2017; Figure 4). As a result, restoration projects that reduce access can benefit caribou by reducing hunting pressure; however, this pathway has not been specifically tested.

5.1. Project Design Considerations

Controlling human access is often an objective of habitat restoration projects conducted on linear features. Ongoing motorized access can impair natural regeneration by compacting soils and damaging new vegetation. In areas where caribou are hunted, this means that restoration treatments that restrict human access also remove hunting as a population stressor. While this might ultimately be positive for caribou, it also adds another pathway that can bias the measured effects of physical disruption to predator-prey movements and forage changes. Project designs that try to separate these effects experimentally (e.g., by establishing treatment and control areas both where hunting is allowed and where it is prohibited) will yield the most knowledge about the system.

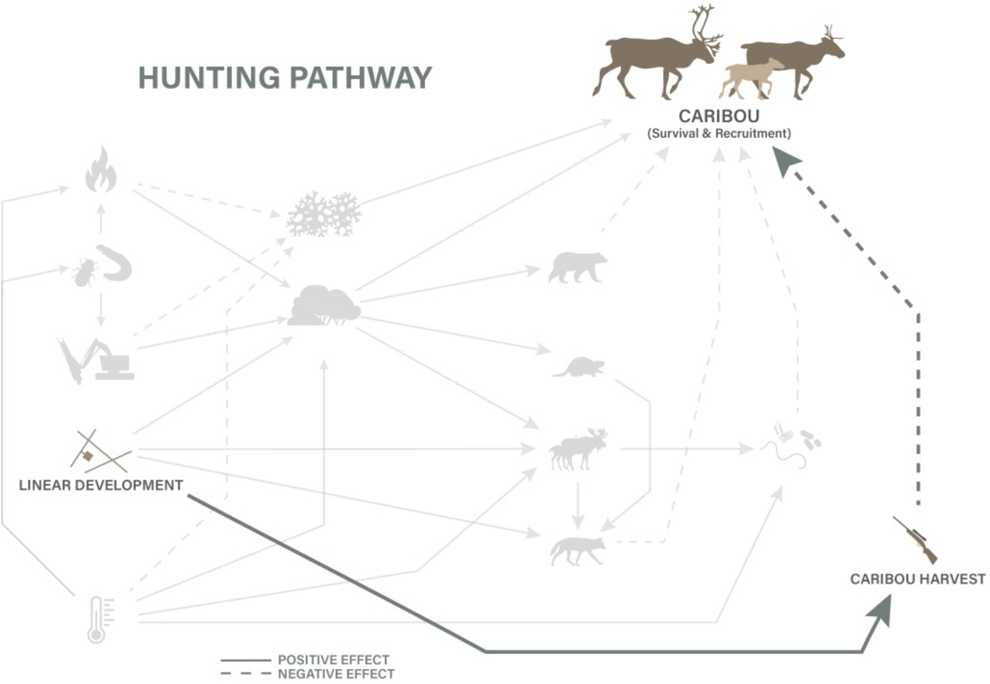

Figure 4. Components of the conceptual ecological model related to caribou hunting (HRWG-NBCKC 2022).

6. Synthesis

6.1. Summary of Outcomes and Gaps

Habitat restoration projects aimed at accelerating vegetation regrowth on linear features have scaled up considerably in recent years and hundreds of kilometres have been treated, mostly in Alberta and British Columbia, but also in Québec. Most published studies of these projects include statistical analysis of short-term outcomes in comparison with controls. However, in most of these studies, multiple treatments have been used, based on conditions encountered in the field. Sites that are recovering naturally are left untreated while other areas are subject to a variety of treatments. The most common technique employed is a combination of substrate preparation (mounding, ripping) followed by planting of conifer stock. Less common are tree-felling, hinging, yarding of coarse woody debris and transplanting. Standard treatments for road deactivation (e.g., ripping and planting, culvert/bridge removal, signage) have also been applied, although not necessarily specifically to benefit boreal caribou.

The variation in treatments is understandable, given variability in site conditions that are often not confirmed until detailed field reconnaissance. To evaluate effectiveness, different treatments are often pooled and compared against controls, preventing detailed evaluation of specific treatments.

Experience gained in the field from these programs is rarely captured in scientific papers and only partially in management reports. Knowledge sharing occurs primarily among practitioners and is being learned through trial and error in the field.

While the benefit of habitat restoration treatments on disrupting the short-term use of linear features by wildlife is now well-studied, the broader pathways associated with habitat-mediated apparent competition remain largely untested. Adaptive management projects are needed to determine whether interventions could alter the abundance, distribution, and/or composition of available browse and whether this would alter the habitat use or population responses of bears and primary prey.

Photo Credit: Krysia Tuttle

In contrast to projects focused on the predation pathways, restoration projects testing lichen transplantation have been restricted to small-scale trials, which have rigorously tested different lichen applications on different substrates. However, the likelihood that such treatments can be scaled sufficiently to deliver a measurable benefit to caribou seems remote. Projects are labour intensive because large volumes of lichen have to be collected by hand, carefully stored, and then distributed over large areas.

6.2. Recommended Best Practices

As habitat restoration projects continue, there will be a need to shift from relatively small-scale treatments and short-term monitoring of immediate benefits to significantly larger-scale treatments that can be expected to have demonstrable effects at the subpopulation range scale in the medium- and long-term. But committing to long-term monitoring is challenging and larger- and longer-scale monitoring data are inherently noisier, making differences between treatments and controls more difficult to detect.

Forecast models could offer a partial solution by taking short-term monitoring results and extrapolating performance into the future. For example, Golder (2015) used growth and yield models to forecasts the future growth of trees planted during restoration trials based on growth characteristics 9-13 years after treatment. Approaches such as this can shorten the adaptive management feedback loop and inform changes to future restoration projects before results from previous trials are fully realized.

Shifting from measuring site effects (i.e., whether wildlife use treated lines) to area effects (whether treatments shift the predator-prey community in the area and reduce predation pressure on caribou) requires the development of new monitoring approaches. For example, camera traps have been very effective for indexing short-term changes in wildlife use on treated versus untreated linear features; however, inferring area effects based on camera trap data, even when augmented with radio-collared moose, bears, and wolves, is challenging (Dickie et al. 2021). Keim et al. (2021) monitored area effects by placing cameras on both linear features and game trails and found that predator-prey use declined on game trails when nearby linear features were treated.

To maximize learning, restoration projects should be designed as active adaptive management experiments to isolate and estimate the effect size of different pathways. This could involve multiple treatment and control areas. Statistical analysis can be relied on for some adjustment to the same end if appropriate experimental designs are infeasible. However, this approach needs to be balanced with efficiency because a single treatment might disrupt multiple pathways and therefore have a higher chance of generating positive outcomes for caribou, but without the opportunity to understand exactly why. Current land use policies and approval processes might also limit or restrict how restoration treatments are implemented.

Finally, sharing among practitioners is key because many operational field techniques require "learning by doing" and adaptation based on local conditions. Developing a "community of practice" that connects those with direct field experience and are willing to teach, with those who are willing to learn, can facilitate knowledge exchange and reduce costly errors as new projects are launched.

Photo Credit: Ryan Dickie

6.3. Research and Development Opportunities

Important research questions remain, and restoration projects can play a role in disentangling multiple effects. Perhaps most importantly, the question of functional versus numerical predator-prey responses to habitat change, and in turn to habitat restoration, remains unresolved. The reason this is such an important question is that the two responses are associated with different pathways in the ecological model (direct linear development to predator prey, versus mediated through browse) and therefore associated with different potential treatments. Theoretical (e.g., Serrouya et al. 2020) and recent observational studies (e.g., Dickie et al. 2022) are starting to reduce our uncertainty, but deliberate adaptive management experiments in the context of restoration projects would advance our understanding.

As mentioned in the previous section, as we shift from a short-term to a longer-term focus, different tools will be required. Habitat restoration was never intended to "fix" the caribou problem in the short-term, but many of our projects and monitoring regimes are designed as if that was the intention. A longer-time horizon will demand a clearer focus on the issue of natural regeneration and its contribution to habitat recovery. This could lead to different types of extensive treatments that may not have measurable short-term effects but generate long-term, incremental benefits to ecosystems that are expected to change over time, with or without treatment.

Finally, there are strategies that could be developed to ensure that research findings and outcomes from trials are adopted in operational practices, as restoration activities continue to roll out. These include: including key stakeholders in project designs and partnering with Indigenous communities to increase the likelihood of generating directly applicable results, ensuring that findings are disseminated to key audiences, and working to align policies to support implementation.

Photo Credit: Ryan Dickie

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