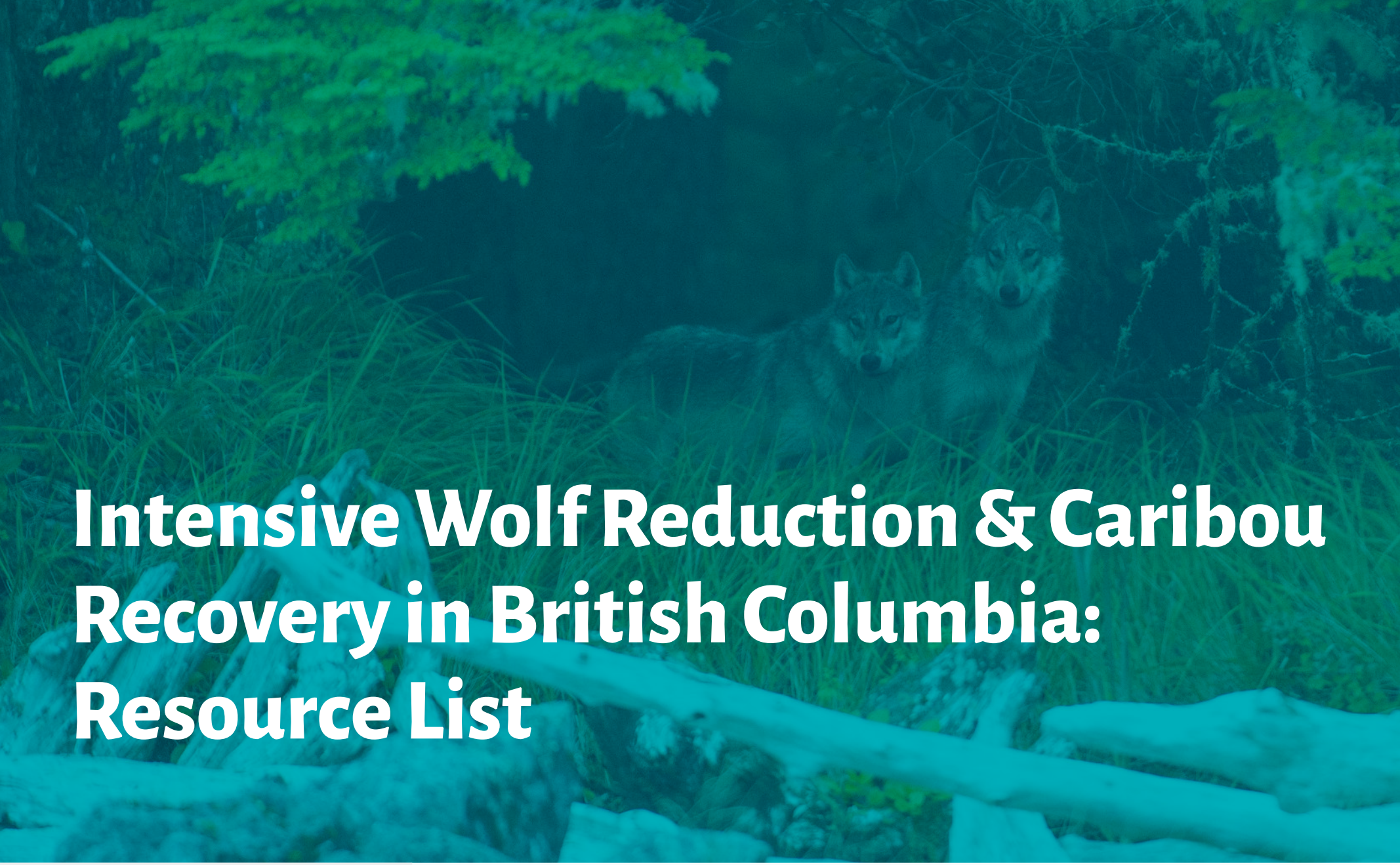

Intensive Wolf Reduction & Caribou Recovery in British Columbia: Resource List

PACIFICWILD

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OCTOBER 2025
- VERSION 2

Contents

Introduction:

This resource list, which Pacific Wild has compiled based on a file review and a literature review, includes research articles, government reports, books, and other references pertinent to the decline of woodland caribou (*Rangifer tarandus caribou*) and the intensive reduction of the grey wolf (*Canis lupus*) in British Columbia (B.C.). While this document is not an exhaustive list of references related to caribou decline, habitat destruction, and the wolf cull program, it is a substantial collection of over 100 research summaries.

The resource list highlights the scientific evidence for the urgent need to protect and restore caribou habitat and challenges the prevailing narrative that attributes caribou decline primarily to wolf predation. The Government of British Columbia is using the grey wolf as the scapegoat for caribou decline, but the literature collected here substantiates the cull as ineffective long-term, unsustainable, and unethical.

Woodland caribou depend on intact, mature, and often old-growth forest ecosystems for forage, cover, and predator avoidance. These habitats have been fragmented and degraded by industrial activities such as logging, mining, oil and gas exploration, and the creation of linear features like roads and seismic lines. Such alteration reduces nutritionally-important forage like terrestrial lichens, increases vulnerability to predation by enhancing predator access and movement, and facilitates competition from other ungulates such as moose and deer, which thrive in disturbed areas and may attract more predators into caribou range. Although grey wolves are natural predators of woodland caribou, elevated predation risk is largely a consequence of human-caused habitat disturbance.

Wolves are apex predators and a keystone species that plays a vital role in maintaining ecosystem health, regulating prey populations, and shaping trophic dynamics. Their removal can cause altered ungulate behaviour and density, and ecological imbalance. British Columbia's wolf culls, conducted via aerial gunning, have shown limited short-term success while contributing to these disruptions. Even where wolf removal has temporarily stabilized populations, habitat loss—the fundamental driver of caribou decline—remains inadequately addressed.

Chapter topics include threats to caribou, Indigenous-led conservation, current wolf management, insufficient habitat protection, and the scientific debate over predator control effectiveness. Additional chapters cover ecological consequences of predator removal, preferred non-lethal recovery strategies, ethical considerations, public disapproval, caribou ecology, historical abundance, climate change impacts, industrial pressures, and relevant legal and policy frameworks.

1 Historical Abundance of Woodland Caribou in British Columbia

1.1 The Historical Abundance of Woodland Caribou in British Columbia

1.1.1 The early history of woodland caribou (*Rangifer tarandus caribou*) in British Columbia

This report provides a historical overview of the caribou population in British Columbia, based on written sources such as explorers' accounts, scientific articles, and archival records. Spalding presents results by ecoprovince for northern, mountain, and boreal caribou, including their current geographic distribution and historic population trends. Spalding describes major threats to these populations—such as habitat loss, predation, hunting, weather and disease, and land-use impacts—and discusses the difficulty of accurately estimating historical caribou populations. Notwithstanding this difficulty, it is known that at the time of European settlement, caribou were widespread and numerous across the landscape and have since experienced significant declines. The author believes that there were approximately 30–35,000 caribou in what is now known as British Columbia when Europeans arrived. Numbers declined into the 1940s with a steep drop-off after the 1970s that left just 16,500 animals at the time of this document (2000). Changing land-use practices have put growing pressure on caribou habitat, especially in the south, since the mid-twentieth century, rendering caribou populations to low numbers.

Spalding, D. J. (2000). *The early history of woodland caribou (Rangifer tarandus caribou) in British Columbia*. BC Minist. Environ., Lands and Parks, Wildl. Branch, Victoria, BC. Wildl. Bull, (100), 5. https://www.for.gov.bc.ca/hfd/library/documents/bib88026.pdf https://www.sciencebase.gov/catalog/item/572a2a58e4b0b13d391a06f4

1.1.2 Recovery strategy for the woodland caribou, southern mountain population (*Rangifer tarandus caribou*) in Canada

The southern mountain caribou recovery strategy (2014) states:

At the turn of the 20th century, the estimated number of caribou in all of B.C was 30,000–40,000 (Spalding 2000). Aboriginal traditional knowledge holders stated that prior to the arrival of Europeans in north-eastern B.C., caribou populations were so high that they were described to be "like bugs on the land" (Willson 2014). Historical records and more recent survey information suggest a general declining trend until about the 1940s, followed in some cases by an increase in numbers through to the 1960s, a subsequent decline in the late 1970s, an increase in the mid-late 1990s, and a decline to the present (Bergerud 1978, Stevenson & Hatler 1985, Seip & Cichowski 1996, Spalding 2000, Thomas & Gray 2002).

Environment Canada. (2014). *Recovery strategy for the woodland caribou, southern mountain population (Rangifer tarandus caribou) in Canada*. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. viii + 103 pp. https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_woodland%20caribou_bois_s_mtn_0614_e.pdf

1.1.3 Caribou recovery program strategy

This strategy guides the Caribou Recovery Program's actions and reflects the successes, challenges, and lessons learned from its first five years. The program's vision is "resilient ecosystems and thriving caribou populations" that sustain Indigenous rights and the well-being of all British Columbians. The strategy is organized around four interconnected goals:

- **Goal 1:** Caribou recovery focuses on stabilizing and recovering threatened caribou herds by prioritizing those with the highest likelihood of near-term recovery (20–40 years), particularly in areas with existing herds and habitat protections. Short-term actions include population management and disturbance reduction, while long-term goals involve restoring high-quality habitat. Progress is monitored and adaptively managed. Protections remain for non-prioritized herds to support biodiversity and future recovery options.
- **Goal 2**: Inclusive stewardship promotes shared responsibility through transparent engagement with Indigenous Nations, governments, and other stakeholders. The program emphasizes trust-based, interest-driven collaboration and recognizes First Nations as essential partners, aligning with the UN Declaration of Rights of Indigenous Peoples and provincial legislation.
- **Goal 3:** Durable provincial program emphasizes accountability and transparency to build public trust and deliver effective caribou recovery. Grounded in strong teams, leadership, and communication, the program ensures clear governance, tracks and reports progress, and develops accessible communication tools to support public awareness and accountability.

- **Goal 4:** Well-informed decisions support decision-making through the best available science, Indigenous knowledge, and shared expertise. It focuses on closing knowledge gaps, maintaining accessible and centralized data, and providing decision-makers with clear, coordinated tools and information.

B.C. Ministry of Water, Land and Resource Stewardship. (2024). *Caribou recovery program strategy*. Government of British Columbia. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/bccaribourecoveryprogram_strategy.pdf

1.1.4 Boreal caribou protection and recovery plan

Released in July 2025, the BCPRP is a co-developed initiative between the Province of British Columbia and the Fort Nelson First Nation (FNFN), with input from the Northern Rockies Regional Municipality. It integrates western science with Indigenous and local knowledge to support the recovery of four boreal caribou herds: Calendar, Maxhamish, Snake-Sahtahneh, and Westside Fort Nelson (excluding Chinchaga). The plan's primary goal is to restore caribou populations to self-sustaining levels within 40 years to enable Indigenous sustenance harvesting. It focuses on two core objectives: (1) establishing a positive habitat trend by protecting high-value areas and restoring degraded ones; and (2) stabilizing and reversing population declines across all herd ranges.

Habitat management is central to the plan. It identifies Core Habitat Zones and two new Areas of Interest (AOIs) — Hay River/Shekilie and Muskwa-Westside Connection — informed by FNFN knowledge. The plan defines four Habitat Management Types:

- Type 1: Full protection from industrial activity; highest restoration priority.
- Type 2: No forest harvest; conditional petroleum and natural gas (PNG) development.
- Type 3: Conditional forestry and PNG development with limits on disturbance.
- Type 4: Similar to Type 3 but applied to more developed or accessible areas.

Legislative tools like Wildlife Habitat Areas (WHAs), Ungulate Winter Ranges (UWRs), and Resource Review Areas (RRAs) will be used to restrict future tenures and industrial activities. Habitat restoration will focus on reducing habitat disturbance and accelerating habitat regeneration with habitat offsetting as a last resort. Caribou habitat and protection information will be provided to the B.C. Wildfire Service to inform response and risk reduction plans. Wildlife population management targets wolf control, with provincial procedures aiming for a density of less than three wolves per 1,000 km². Predator reduction is expected to stabilize herds within 1–3 years but must be sustained for long-term results.

Adaptive management requires five-year reviews and monitoring. Indicators include:

- Habitat trend: aiming for <1 km/km² of linear disturbance.
- Population trend: target is a stable or increasing population ($\lambda \geq 0.99$).

Priorities include legal habitat protections, updated industry guidelines, restoration planning, predator management assessments, and filling monitoring/data gaps. Forestry may see an annual harvest reduction of ~489,497 m³, though actual impacts may be lower. Existing PNG tenures are maintained, but future development viability remains uncertain.

B.C. Ministry of Water, Land and Resource Stewardship, & Fort Nelson First Nation. (2025). *Boreal caribou protection and recovery plan*. Government of British Columbia. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/boreal_caribou_protection_and_recovery_plan.pdf

1.1.5 Summary of B.C. caribou population estimates, trends, and recovery actions up to March 31, 2023

This document provides an assessment of caribou herds across British Columbia. It draws on aerial surveys, demographic monitoring, and scientific and Indigenous knowledge to present long-term (21–27 years) and short-term (5–9 years) population trends. Despite several herd extirpations, integrated recovery actions have prevented further losses, with estimates showing an increase in over 1,500 more caribou since recovery efforts commenced. Caribou are classified into Designatable Units (DUs). For Southern Mountain Caribou, populations are estimated as follows: DU7 (Northern Group) with over 1,971 individuals in 9 herds, DU8 (Central Group) with over 534 caribou across 8 herds, and DU9 (Southern Group) with over 1,384 individuals across 18 herds. Boreal Caribou (DU6) comprise over 1,074 individuals in 6 herds. While the Calendar, Maxhamish, and Snake-Sahtahneh herds are in decline, the Chinchaga herd shows short-term growth. Northern Mountain Caribou (also DU7), federally listed as a species of Special Concern, comprise over 12,319 individuals across 21 herds, though trend data remain largely unavailable. Key recovery actions include wolf culls, used broadly across

Southern Mountain herds. Maternal penning and captive breeding have been implemented in herds like Klinse-Za and Columbia North, while transplants have been used in Purcells South. Habitat planning and protection, often co-developed with First Nations, are ongoing. However, recovery efforts face persistent challenges: several herds lack recent survey data, trend data are incomplete for many, and proposed boundary changes remain under consultation. Addressing data gaps and continuing adaptive management are essential to guide recovery effectively.

Zimmerman, K., Munro, R., & Ernst, B. (2025). *Summary of B.C. caribou population estimates, trends, and recovery actions up to March 31, 2023*. B.C. Caribou Recovery Program. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/bc_caribou_herds_population_estimates.pdf

2 Habitat Requirements of Woodland Caribou

2.1 Habitat Requirements of Woodland Caribou

2.1.1 Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia

This research, conducted around the time woodland caribou were listed under the Species at Risk Act (SARA), describes seasonal habitat requirements. Habitat selection for varying forest overstory and terrain characteristics were assessed at different spatial scales based on radio-collared caribou in the north Columbia Mountains of British Columbia between 1992 and 1999. Generally, results confirmed that caribou are closely associated with old-growth forests and seasonal relationships can be accounted for in forestry models.

Apps, C. D., McLellan, B. N., Kinley, T. A., & Flaa, J. P. (2001). Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia. *The Journal of Wildlife Management*, 65–77. https://www.jstor.org/stable/3803278

See also:

Serrouya, R., McLellan, B. N., & Flaa, J. P. (2007). Scale-dependent microhabitat selection by threatened mountain caribou (*Rangifer tarandus caribou*) in cedar–hemlock forests during winter. *Canadian Journal of Forest Research*, *37*(6), 1082–1092. https://doi.org/10.1139/X06-279

See also:

Wilson, S. F., Nudds, T. D., Green, P., & de Vries, A. (2022). Effect of Forest Understorey Stand Density on Woodland Caribou Habitat Use. *EcoEvoRxiv*. https://doi.org/10.32942/osf.io/m382v

2.1.2 Factors influencing the dispersion and fragmentation of endangered mountain caribou populations

The researchers contend that mountain caribou, a subspecies of woodland caribou, are endangered due to the loss and fragmentation of the old forests on which they rely. Understanding the natural and human factors which may limit caribou persistence and isolate populations can help stop or reverse population declines. The research analyzed caribou location data from 235 radio-collared animals across 13 subpopulations to identify landscape variables affecting their persistence and occupancy at both the metapopulation and subpopulation level. Factors such as the extent of wet climatic conditions, the distribution of old forests, remoteness from human presence, low road density, and little motorized access were found to be important. Additionally, the study provides a prediction model for mountain caribou population persistence, isolation, and restoration. The findings provide insights into range-wide caribou population connectivity and conservation.

Apps, C. D., & McLellan, B. N. (2006). Factors influencing the dispersion and fragmentation of endangered mountain caribou populations. *Biological Conservation*, *130*(1), 84–97. https://doi.org/10.1016/j.biocon.2005.12.004

2.1.3 Effect of forest understorey stand density on woodland caribou (Rangifer tarandus caribou) habitat selection

Wilson et al. investigated how various forest structural characteristics affect woodland caribou habitat selection in two geographically and biophysically distinct regions: Northwestern Alberta and Northwestern Ontario. The authors assessed forest understory stand density and performed multivariate analyses to identify and quantify the independent influences of ecological factors on caribou habitat selection. Wilson et al. found that caribou in the Bistcho range (Alberta) exhibited a clear preference for non-forest or sparsely forested areas. This is likely because they provide increased visibility of potential predators and decreased structural barriers that could impede movement, which facilitates foraging. Caribou in the Trout Lake region (Ontario)

predominantly selected for forested habitats, which emphasizes the dual need for both the availability of forage and cover to mitigate predation risk. Forests that provide space and visibility while still offering protective cover were deemed optimal habitats. Both populations demonstrated a shared underlying principle of predator avoidance, despite differing habitat structures. Both populations favoured habitats characterized by lower understory stand density which likely facilitates mobility, promoting efficient foraging and improving predator evasion. Wilson et al. stress the need for regionally-tailored caribou habitat management. Management strategies should be revised and updated with new ecological data findings.

Wilson, S. F., Nudds, T. D., Green, P. E. J., & de Vries, A. (2024). Effect of forest understorey stand density on woodland caribou (*rangifer tarandus caribou*) habitat selection. *Canadian Journal of Forest Research*, *54*(2), 158–167. https://doi.org/10.1139/cjfr-2023-0105

3 Threats to Caribou

3.1 Health Stressors (Nutritional Inadequacies and Disease)

3.1.1 Animal-defined resources reveal nutritional inadequacies for woodland caribou during summer–autumn.

This study fills research gaps related to the role of nutrition in the decline of woodland caribou populations. In particular, Denryter et al. assessed the adequacy of habitat to support nutritional demands during lactation for caribou in northeastern B.C.. The researchers used tame caribou to quantify dietary quality and intake rates (digestible protein and energy) among predominant B.C. plant communities, with focus on requirements during lactation. Findings demonstrated that tame caribou could not satisfy protein and energy requirements during lactation. The magnitude of nutritional inadequacies was severe. More than 33% of sites failed to meet 50% of protein and energy needs and >60% did not meet 80% of daily requirements. Simulations applied to wild caribou provide evidence of widespread nutritional inadequacies from their habitat ranges. Due to the low availability of vegetation communities having high nutritional value (i.e., old growth forests), calf production, growth, and maternal body fat replenishment is likely suppressed. This study, in conjunction with documented caribou body fat measurements, established that the nutritional environment does not meet the needs of lactating caribou. The researchers point to another study indicating widespread low body condition for caribou in southern and central mountains of B.C., adding that 30% of the reported female caribou carcasses had marrow and body fat levels indicative of vulnerability to predation, disease, and parasites. The study concludes that "Bottom-up and top-down forces undoubtedly act simultaneously on prey populations, and thus either-or perspectives regarding both forces are unduly limited and probably artificial" (p. 25). Nutritional deprivation in lactating caribou has consequences for caribou populations, recovery, and conservation. The authors assert that this work adds to a growing body of literature illuminating nutrition as a limiting factor for caribou populations.

Denryter, K., Cook, R. C., Cook, J. G., & Parker, K. L. (2022). Animal-defined resources reveal nutritional inadequacies for woodland caribou during summer–autumn. *Journal of Wildlife Management* 86:e22161. https://doi.org/10.1002/jwmg.22161

See also:

Cook, J. G., Kelly, A. P., Cook, R. C., Culling, B., Culling, D., McLaren, A., Larter, N.C., & Watters, M. (2021). Seasonal patterns in nutritional condition of caribou (*Rangifer tarandus*) in the southern Northwest Territories and northeastern British Columbia, Canada. *Canadian Journal of Zoology*, *99*(10), 845–858. https://doi.org/10.1139/cjz-2021-0057

3.1.2 Seasonal patterns of mortality for boreal caribou (Rangifer tarandus caribou) in an intact environment

Kelly investigates seasonal variation of boreal caribou vulnerability to mortality by using survival and mortality data on radio-collared adult female caribou to evaluate patterns across the year. Results showed a trimodal mortality pattern, characterized by three peaks across the year. The two highest mortality peaks occurred in late spring (pre-calving) and mid-summer, followed by a smaller peak in late autumn. Generally, the risk of mortality was elevated from late spring (pre-calving) to mid-summer. The mid-summer peak could not be explained by increased predator encounter rate as may be predicted for the other peaks due higher caribou movement rates during those times. Kelly found evidence that mortalities during the mid-summer peak were driven by caribou nutritional conditions, as the greatest depletion of body reserves occurs from spring to mid-summer. Mortalities identified as predation followed the same trimodal pattern across the year, while those definitively attributed to starvation (i.e., carcass intact) were clustered between the calving and mid-summer period. Bone marrow fat has been found to be lower in caribou killed due to predation. The researchers suggest a variety of factors interact to display the seasonal pattern of mortality. Seasonal changes in both predator and prey movements and encounter rates likely contribute to variation in the pattern. However, this study expands on research demonstrating that other non-pred-

ator factors mediate and contribute to predation. Specifically, prey vulnerability (i.e., malnutrition and demanding reproductive stages of late gestation and lactation) is a significant factor to caribou mortality. Seasonal variations in the dominant pressures to caribou (predator encounters, energy demands, and nutrition) all need to be considered when attempting the difficult task of discerning bottom-up and top-down mechanisms.

Kelly, A. (2020). Seasonal patterns of mortality for boreal caribou (*Rangifer tarandus caribou*) in an intact environment. https://doi.org/10.7939/r3-qgdp-kh61

See also:

Brown, G. S., Landriault, L., Sleep, D. J. H., & Mallory, F. F. (2007). Comment arising from a paper by Wittmer et al.: hypothesis testing for top-down and bottom-up effects in woodland caribou population dynamics. *Oecologia*, *154*(3), 485–492. https://doi.org/10.1007/s00442-007-0855-3

The above in response to / refuting:

Wittmer, H. U., Sinclair, A. R., & McLellan, B. N. (2005). The role of predation in the decline and extirpation of woodland caribou. *Oecologia*, *144*(2), 257–267.

3.1.3 British Columbia boreal caribou health program, progress report: Year 2

Health of caribou is an indicator of vulnerability that represents the capacity to cope with external stressors such as natural and human disturbance. Therefore, the health status of species-at-risk such as caribou have important implications to conservation and management decisions. The Boreal Caribou Health Research Program (BCHRP) reported the health status of boreal caribou in northeastern B.C.. Bacterial, viral, and parasitic diseases along with other health indices (i.e., chronic physiological stress, immunity, and nutrition) were evaluated. Notable health threats included pathogenic bacterium *E. rhusiopathiae*, the protozoan parasite *N.caninum*, and severe winter tick (*D. albipictus*) infestations. Schwantje et al. also identified changes in bone marrow fat and nutrient deficiencies. Evidence demonstrated that the pathogen *E. rhusiopathiae* may have contributed to unusually elevated mortality observed in 2013. Findings determined that health and disease could be of great importance to the long-term sustainability of boreal caribou.

Schwantje, H., Macbeth, B., Kutz, S., & Elkin, B. (2016). British Columbia boreal caribou health program, progress report: Year 2 (February 1, 2015–March 31, 2016) (British Columbia Boreal Caribou Health Research Program Working Group). 49. Available online at http://www.bcogris.ca/sites/default/files/bcip-2014-05-boreal-caribou-health-study-final-report-year-2.pdf

See also:

Forde, T. L., Orsel, K., Zadoks, R. N., Biek, R., Adams, L. G., Checkley, S. L., Davison, T., De Buck, J., Dumond, M., Elkin, B. T., Finnegan, L., Macbeth, B. J., Nelson, C., Niptanatiak, A., Sather, S., Schwantje, H. M., van der Meer, F., & Kutz, S. J. (2016). Bacterial Genomics Reveal the Complex Epidemiology of an Emerging Pathogen in Arctic and Boreal Ungulates. *Frontiers in Microbiology*, 7. https://doi.org/10.3389/fmicb.2016.01759

See also:

Bondo, K. J., Macbeth, B., Schwantje, H., Orsel, K., Culling, D., Culling, B., Tryland, M., Nymo, I. H., & Kutz, S. (2019). Health Survey of Boreal Caribou (*Rangifer tarandus caribou*) in Northeastern British Columbia, Canada. *Journal of Wildlife Diseases*, *55*(3), 544–562. https://doi.org/10.7589/2018-01-018

3.1.4 Combining stable isotope ratios with elemental concentrations to improve the estimation of terrestrial carnivore diets

Mowat et al. (2023) aim to improve the accuracy of estimating terrestrial carnivore diets, particularly for detecting rare prey like endangered caribou, by exploring and testing novel elemental tracers (e.g. strontium, cesium) in addition to traditional stable isotopes (e.g. carbon, nitrogen). The authors found that traditional stable isotopes were ineffective in estimating predator diets because prey species, especially caribou and other herbivores, had very similar isotope signatures, making it hard to distinguish them. Elemental tracers showed potential for separation with strontium isotope ratios, and strontium and cesium concentrations showing clear separation between caribou and other prey, but when used in diet models, they greatly overestimated caribou consumption. While promising for distinguishing caribou, elemental tracers need further investigation, particularly regarding their turnover times in animal tissues.

Mowat, G., Heard, D. C., & Curtis, P. J. (2023). Combining stable isotope ratios with elemental concentrations to improve the estimation of terrestrial carnivore diets. *Global Ecology and Conservation*, 45, e02507. https://doi.org/10.1016/j.gecco.2023.e02507

3.2 Habitat Disturbance and Linear Features

3.2.1 Witnessing extinction—Cumulative impacts across landscapes and the future loss of an evolutionarily significant unit of woodland caribou in Canada

Research on Central Mountain caribou showed that the cumulative effects of industrial development strongly influenced patterns of caribou habitat selection and availability. Using 11 years of Central Mountain caribou location data, Johnson et al. characterized the relationship between disturbance and caribou response to develop species distribution models. Caribou habitat avoidance was modelled as zones of influence (buffer areas of avoidance around disturbance features) for roads, seismic and pipelines, oil and gas features, cut blocks, burns, and coal mines. Using the models, the researchers calculated habitat loss over a period of 22 years based on a loss of functional habitat (reduction in the relative probability of use due to avoidance of zones of influence). Habitat change was then correlated with measured population decline. Results demonstrated a maximum loss in high-quality habitat of 66%. The accelerated loss of habitat was strongly correlated with caribou population decline. Habitat selection by caribou was impacted as the availability and quality of habitat diminished. Studies on boreal woodland caribou had similar findings. Considering these dramatic declines and herd extinctions, there is an immediate need for habitat protection and restoration. Further extinctions are imminent at the current rates of habitat alteration and population declines.

Johnson, C. J., Ehlers, L.P.W., & Seip, D.R. (2015). Witnessing extinction—Cumulative impacts across landscapes and the future loss of an evolutionarily significant unit of woodland caribou in Canada. *Biological Conservation* (186). 176–186. https://www.sciencedirect.com/science/article/abs/pii/S0006320715001160?via%3Dihub

See also:

Polfus, J. L., Hebblewhite, M., & Heinemeyer, K. (2011). Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. *Biological Conservation*, *144*(11), 2637–2646. https://doi.org/10.1016/j.biocon.2011.07.023

See also:

Courtois, R., Ouellet, J. P., Breton, L., Gingras, A., & Dussault, C. (2007). Effects of forest disturbance on density, space use, and mortality of woodland caribou. *Ecoscience*, *14*(4), 491–498. http://www.jstor.org/stable/42902586

See also:

Lochhead, K. D., Kleynhans, E. J., & Muhly, T. B. (2022). Linking woodland caribou abundance to forestry disturbance in southern British Columbia, Canada. *The Journal of Wildlife Management*, *86*(1). https://doi.org/10.1002/jwmg.22149

3.2.2 Boreal caribou (*Rangifer tarandus*) in British Columbia: 2017 science review

This science review summarizes research results on British Columbia's boreal woodland caribou and habitat between 2010 and 2016. Boreal caribou are listed as threatened under the federal Species at Risk Act and provincially (B.C.) are on the red list (S1: Imperiled).[1] Research results demonstrated that B.C.'s boreal caribou population is in decline. The report indicated adult caribou mortality was primarily from changes to predator-prey dynamics caused by human footprint. Specifically, increased density of wolves, however information on distribution and abundance of wolves was noted to be lacking. Further, "no formal studies of causes of calf mortality have been conducted in B.C.'s Boreal Caribou Ranges" (p. 15) and calf mortality to date was best explained by black bear predation. Health threats to boreal woodland caribou included parasite and bacterial infections, winter tick infestations causing hair loss, nutrient deficiencies, and high levels of cortisol indicating physiological stress. Additional threats include fire, weather and climate change. Cumulative and interacting factors impacting boreal caribou population dynamics are depicted in Figure 1. As shown, landscape level habitat alterations including linear features and changes to habitat vegetation are the ultimate main drivers of caribou declines. The report identified knowledge gaps including wolf abundance and diet, the primary cause of calf mortality, and level of habitat restoration requirements.

1 Northern mountain caribou are assessed under SARA as special concern (2005). Southern mountain caribou (which under SARA also includes the central mountain populations) are listed as threatened (2003).

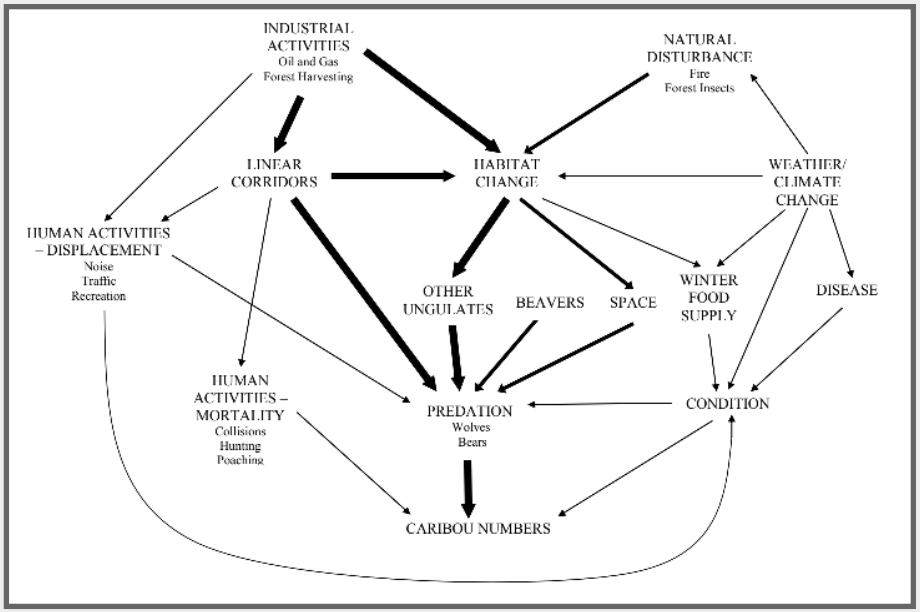

Figure 1: *Cumulative impacts to boreal caribou and linkages between interacting factors. Adopted from Culling and Cichowski (2017), pp. 63. Thickness of arrows is intended to represent relative contribution.*

Culling, D. E., & Cichowski, D. B. (2017). *Boreal caribou* (Rangifer tarandus) *in British Columbia: 2017 science review. 141*. Prepared for the BC Oil and Gas Research and Innovation Society, Victoria, BC. Available online at: http://www.bcogris.ca/sites/default/files/bcip-2016-21-science-review-2017-final.pdf

See also:

B.C. Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, & B.C. Ministry of Environment and Climate Change Strategy. (2018). *Science review for the South Peace Northern Caribou* (Rangifer tarandus *caribou pop. 15 and pop. 18) in British Columbia*. Victoria, BC. 71pp. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/2018_science_review_for_the_south_peace_northern_caribou.pdf

See also:

Government of British Columbia. (n.d). *Caribou in British Columbia*. Retrieved June 6. 2022, from https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/caribou

See also:

Government of Canada. (2021). *Caribou in Canada*. https://www.canada.ca/en/environment-climate-change/services/species-risk-education-centre/caribou.html

3.2.3 Behavioral and demographic effects of open-pit mining on central mountain caribou in British Columbia—Plain language summary

This study was prepared to satisfy requirements of an environmental assessment for an application for the proposed Sukunka Coal Mine within the Quintette caribou herd range. Using analytical models, scientists examined the impact of mining operations on caribou populations in two separate areas of High Elevation Winter Range (HEWR). The caribou in the treatment area (Roman) responded differently to those in the Control area (Bullmoose) in terms of behavior and demographics. Roman caribou spent more time away from HEWR, resulting in larger areas of use and longer movements away from core areas, and increased predation risk. These behavioral responses led to lower vital rates and population abundance decreasing to zero in the treatment area. The impacts of mining on caribou took time to become apparent, but once they did, caribou were displaced from critical range, faced higher mortality rates, and decreased population abundance. The study suggests that mining disturbance compromises or irreparably harms critical habitat, leading to the eventual abandonment of the area by caribou. The findings have implications for other mines in the Quintette caribou range, and future extinction of the population is likely without intensive recovery measures, which are cost-prohibitive under the proposed mitigation measures.

McNay, R. S., Lamb, C., Sutherland, G., Thompson, M., Jones, J., & Milakovic, B. (2022). *Behavioral and demographic effects of open-pit mining on central mountain caribou in British Columbia—plain language summary*. https://www.projects.eao.gov.bc.ca/api/public/document/63a3661d67bf5d0022a9a5d3/download/McNay%20et%20al.%202022_plain%20language%20summary.pdf

3.2.4 Nowhere to hide: Effects of linear features on predator-prey dynamics in a large mammal system

Researchers demonstrate how linear features (e.g., roads, pipelines) and resource exploration/seismic lines reduce the ability of boreal woodland caribou to successfully find refuge from predators (i.e., grey wolves and black bears). Linear features can facilitate predator movement to increase special overlap of predator and prey species. Peatlands such as bogs provide refuge for caribou and are therefore a preferred habitat. However, linear features were found to increase predator selection for peatlands. Results showed despite attempts, most caribou are unable to entirely avoid high-density linear feature peatlands. Furthermore, it was demonstrated that use of linear features by female caribou increased mortality of newborn calves. Mitigation efforts should be focused on limiting or restoring linear features that contribute to predator–prey spatial overlap.

DeMars, C. A., & Boutin, S. (2018). Nowhere to hide: Effects of linear features on predator-prey dynamics in a large mammal system. *Journal of Animal Ecology*, *87*(1), 274–284. https://doi.org/10.1111/1365-2656.12760

3.2.5 Predation risk for boreal woodland caribou in human-modified landscapes: evidence of wolf spatial responses independent of apparent competition

For caribou in northeast British Columbia, modeling research found stronger support for direct effects of linear features to caribou-wolf co-occurrence and predation risk than for the commonly held hypothesis of apparent competition. In order to understand the human-mediated decline of boreal caribou, three hypotheses were evaluated: (1) numeric apparent competition/increased moose prey density; (2) spatial apparent competition/altered moose prey distribution; and (3) wolf spatial responses/altered wolf distribution independent of prey. Findings demonstrated no relationship between disturbances, moose density, and caribou survival. Further, both positive and negative relationships were evident between disturbance and caribou-moose co-occurrence. By contrast, positive correlations were demonstrated between wolf-caribou co-occurrence with predation risk and linear features. Recommendations suggest limiting future and restoring existing linear features for caribou recovery in northeastern British Columbia. The need for region-specific solutions is highlighted for recovery of wide-ranging species.

Mumma, M. A., Gillingham, M. P., Parker, K. L., Johnson, C. J., & Watters, M. (2018). Predation risk for boreal woodland caribou in human-modified landscapes: Evidence of wolf spatial responses independent of apparent competition. *Biological Conservation*, 228, 215–223. https://doi.org/10.1016/j.biocon.2018.09.015

See also:

Mumma, M. A., Gillingham, M. P., Johnson, C. J., & Parker, K. L. (2017). Understanding predation risk and individual variation in risk avoidance for threatened boreal caribou. *Ecology and Evolution*, *7*(23), 10266–10277. https://doi.org/10.1002/ece3.3563

See also (independent summary below):

Johnson, C. J., Mumma, M. A., & St-Laurent, M. H. (2019). Modeling multispecies predator–prey dynamics: Predicting the outcomes of conservation actions for woodland caribou. *Ecosphere* (Washington, D.C), *10*(3), e02622–n/a. https://doi.org/10.1002/ecs2.2622

See also:

Droghini, A., & Boutin, S. (2017). Snow conditions influence grey wolf (Canis lupus) travel paths: The effect of human-created linear features. *Canadian Journal of Zoology*, *96*(1), 39–47. https://doi.org/10.1139/cjz-2017-0041

See also:

Dickie, M., Serrouya, R., McNay, R. S., & Boutin, S. (2017). Faster and farther: Wolf movement on linear features and implications for hunting behaviour. *Journal of Applied Ecology*, *54*(1), 253–263. https://doi.org/10.1111/1365-2664.12732

See also:

Finnegan, L., Pigeon, K. E., Cranston, J., Hebblewhite, M., Musiani, M., Neufeld, L., Schmiegelow, F., Duval, J., & Stenhouse, G. B. (2018). Natural regeneration on seismic lines influences movement behaviour of wolves and grizzly bears. *PLoS ONE*, *13*(4). https://doi.org/10.1371/journal.pone.0195480

See also:

Dabros, A., Pyper, M., & Castilla, G. (2018). Seismic lines in the boreal and arctic ecosystems of North America: Environmental impacts, challenges, and opportunities. *Environmental Reviews*, *26*(2), 214–229.

3.2.6 Modeling multispecies predator–prey dynamics: Predicting the outcomes of conservation actions for woodland caribou

Johnson et al. attribute the decline of caribou in many parts of Canada to "human-mediated predation." Focusing on the Chinchaga caribou (boreal caribou Designatable Unit) population in British Columbia, multispecies modelling of predator-prey dynamics was applied to explore the effectiveness and cost of various conservation actions and then contrasted with a different boreal caribou population in Quebec. The decline in the Chinchaga population was found to be due to seismic lines and resource roads, thereby mediating the risk of wolf predation. Wolf density alone does not have a significant impact on population decline but does have an effect when linear features are present. Long-term wolf-culling was identified (via modeling) as the most cost-effective recovery action for the Chinchaga caribou ($25,665/caribou), followed by a large-scale predator exclosure ($170,767/caribou), and the aggressive restoration of roads, seismic lines, power lines, pipelines, railroads, cut lines, and recreational trails ($531,675/caribou). The model did support the general principle of first addressing the root cause of decline before insecurely investing in short-term stop-gap measures that are intensive, invasive and expensive. The model shows that an increase in linear features (roads etc.), lead to extirpation (local extinction) of caribou within a year while removal of linear features was effective in reducing population decline; however, this method is very expensive and would require long-term commitment to be successful. The results indicated that a high degree of variation in recovery actions should be expected for woodland caribou; a one-size solution will not fit all populations.

Johnson, C. J., Mumma, M. A., & St-Laurent, M. H. (2019). Modeling multispecies predator–prey dynamics: Predicting the outcomes of conservation actions for woodland caribou. *Ecosphere (Washington, D.C)*, *10*(3), e02622–n/a. https://doi.org/10.1002/ecs2.2622. Retrieved from https://esajournals.onlinelibrary.wiley.com/doi/10.1002/ecs2.2622

3.2.7 Habitat alterations and population isolation: The caribou case

This article discusses the threat of human-induced habitat alterations to biodiversity, particularly habitat fragmentation leading to population isolation. Population isolation describes a population that has little to no gene flow or exchange of genetic material with other populations of the same species, increasing the risk of extinction. Caribou in Western Canada have been experiencing population isolation and the study aims to discover the drivers of this isolation. The authors tested three hypotheses: lack of food and shelter, predation pressure and human infrastructure, and physical barriers to dispersal, in addition to Isolation by Distance (IBD). The study found that genetic patterns of isolation in caribou can be explained by a combination of IBD and Isolation by Environment (IBE), specifically based on forest stand age, slope, and land cover type. Habitat preferences also differed seasonally. The study allows for a better understanding of the relationship between loss of critical habitat, habitat fragmentation, and isolation of populations, and provides insight into targeted conservation measures for caribou.

Hughes, M., Cavedon, M., Michalak, A., Neufeld, L., Schwantje, H., Thacker, C., Poissant, J., & Musiani, M. (2022). Habitat alterations and population isolation: The caribou case. In *Ecological Society of America & Canadian Society for Ecology and Evolution-PROGRAM/BOOK OF ABSTRACT* (p. 1). https://cris.unibo.it/handle/11585/905690

3.2.8 Quantifying forest disturbance regimes within caribou (Rangifer tarandus) range in British Columbia

Maltman et al. examined the effects of forest disturbances on woodland caribou habitat in B.C. between 1985 and 2019 using Landsat-derived satellite imagery. The authors assessed disturbance rates before and after key conservation milestones such as the full implementation of the Species at Risk Act (SARA) in 2004, which designated boreal and southern mountain caribou as threatened, and the release of caribou recovery strategies in 2012 and 2014. The analysis focused on three primary types of forest disturbance: wildfire, forest harvesting (e.g., logging), and non-stand-replacing disturbances, defined as changes in vegetation caused by insect outbreaks, disease, or drought that do not result in a complete shift in land-cover class. A noted limitation of the study is its exclusion of linear disturbances, such as roads and seismic lines, as it focused solely on polygonal disturbance types. More specifically, the level of forest disturbance within re-

spective caribou herd range boundaries, termed in the paper as "caribou herd polygons" (p. 4). Maltman et al. analyzed data at herd and ecotype levels and found that 16.4% of forested area was disturbed. Southern mountain caribou were most impacted with 22.8% disturbed area overall and 31.15% area disturbed for the central group. Boreal and northern mountain ecotypes had lower disturbance with 6.6% and 9%, respectively. For southern mountain caribou, the most threatened ecotype, the authors found no significant decrease in forest harvesting levels after both the implementation of SARA (2004) and the publication of recovery strategies. Conversely, between 2010–2019, harvesting increased in this ecotype's habitat. This study highlights the need for habitat protection and effective caribou management strategies in B.C..

Maltman, J. C., Coops, N. C., Rickbeil, G. J. M., Hermosilla, T., & Burton, A. C. (2024). Quantifying forest disturbance regimes within caribou (*Rangifer tarandus*) range in British Columbia. *Scientific Reports*, *14*(1), 6520. https://doi.org/10.1038/s41598-024-56943-0

3.2.9 In search of evidence-based management targets: A synthesis of the effects of linear features on woodland caribou

Dickie et al. developed a framework to link anthropogenic linear features to woodland caribou declines, and to identify specific thresholds of linear feature densities that correlate with significant changes in caribou population dynamics. Through a systematic literature review, the authors found that approximately 65% of studies examined how linear features impact the movements or habitat use of caribou, their predators and competion. Most studies focused on broad relationships without assessing the mechanistic pathways linking changes in space use to demographic outcomes (e.g. survival, population growth). For example, while many studies showed that linear features increase the efficacy of wolf movement, very few measured whether this led to higher encounter or kill rates between wolves and caribou. The findings indicated that linear features generally exert negative effects on caribou, with studies reporting negative impacts approximately 2.3 times more than neutral or positive effects combined. Linear features tended to facilitate predation, with roads closely associated with increased predator access. Moreover, peer-reviewed studies rarely addressed thresholds for linear feature density. Dickie et al.'s proposed framework translates the established area-based maximum disturbance target of 35% habitat disturbance into a linear feature-based management target. A road density of 0.18 km/km² (based on Environment and Climate Change Canada data) or 0.63 km/km² (based on a supplementary dataset) could align with this disturbance threshold. The results highlight that several southern mountain caribou herds exceed these proposed road density thresholds, suggesting that urgent management interventions are necessary. Caribou conservation efforts require developing targeted, evidence-based goals for managing linear features with formally established thresholds for impact assessment.

Dickie, M., Love, N., Steenweg, R., Lamb, C. T., Polfus, J., & Ford, A. T. (2023). In search of evidence-based management targets: A synthesis of the effects of linear features on woodland caribou. *Ecological Indicators*, 154, 110559. https://doi.org/10.1016/j.ecolind.2023.110559

See also:

Benoit-Pépin, A., Feldman, M. J., Imbeau, L., & Valeria, O. (2024). Use of linear features by mammal predators and prey in managed boreal forests. *Forest Ecology and Management*, 561, 121911.

3.2.10 Automated linear disturbance mapping via semantic segmentation of Sentinel-2 imagery

Nager et al. developed an automated, cost-effective mapping approach to identify and monitor linear disturbances (e.g. roads and seismic lines) in Canada's boreal woodland caribou habitat. Using deep learning methods and Sentinel-2 (S2) satellite imagery, Nager et al. created an algorithm for identifying linear disturbances in Alberta's Boreal and Taiga Plains. The model accurately segmented broad linear features but had difficulty detecting narrow disturbances, showing better accuracy in residential areas than forests. Despite these limitations, it produced detailed, multi-class disturbance maps. This approach allows for automated mapping that can be updated regularly, improving the ability to monitor and manage habitat fragmentation, and predict zones of elevated predation. In turn, updated and accurate maps of linear disturbances can support decision-making for caribou habitat restoration.

Nagel, A. M., Webster, A., Henry, C., Storie, C., Sanchez, I. S.-M., Tsui, O., Duffe, J., & Dean, A. (2024). Automated linear disturbance mapping via semantic segmentation of Sentinel-2 imagery (No. arXiv:2409.12817). arXiv. https://doi.org/10.48550/arXiv.2409.12817

3.3 Cumulative Impacts to Caribou: Climate, Fire, Mountain Pine Beetle, and Recreation

3.3.1 The impact of mountain pine beetle outbreaks and their treatment methods on the abundance of plant-foods important to caribou and grizzly bears

McClelland et al. investigated how mountain pine beetle (MPB) outbreaks and their treatment methods affect the abundance and distribution of 25 specific understory shrub and forb plants. Shrubs are defined as woody understory plants that often produce leaves, twigs, or berries, while forbs are non-woody, herbaceous flowering plants that grow in the understory. Both plant types serve as important food sources for threatened caribou and grizzly bears in Alberta. The study area covered two main regions in Alberta: (1) west-central, which included ranges for central mountain and boreal caribou, and (2) north-west, which included ranges for Chinchaga boreal caribou. The researchers selected transects within five different types of forest conditions: (1) MPB kill (forest naturally killed by beetles), (2) MPB control (where single-tree cut and burn occurred), (3) fire (areas burned by wildfire, used as a proxy for prescribed burns), (4) cut (clear-cut harvested areas), and (5) uncut (old growth, undisturbed forest, >50 years old). In west-central, abundance of 13 of the 25 plant species differed among forest stratum, while in north-west, abundance of 5 of the 13 species differed among strata. Many plants showed a positive response to less intense disturbances: areas affected by MPB, single-tree cut and burn, and wildfires. For caribou forage, birch abundance increased after fires, and grasses increased in clear-cut areas, but caribou tend to avoid clear-cut areas due to other associated risks, like increased predation. Fireweed, a less desirable competitor plant, increased significantly in clear-cut areas and MPB-affected sites. This is concerning for caribou because fireweed is a food source for other ungulates, increasing competition and predation risk. The authors suggest that less intense MPB treatments (like single-tree cut and burn) or prescribed fires might be more compatible with caribou conservation as they minimize habitat disruption.

McClelland, C. J., Nobert, B., Larsen, T. A., Pigeon, K. E., & Finnegan, L. (2023). The impact of mountain pine beetle outbreaks and their treatment methods on the abundance of plant-foods important to caribou and grizzly bears. *Forest Ecology and Management*, 532, 120841.

3.3.2 Effects of helicopter skiing on mountain goats and woodland caribou in British Columbia

Wilson assessed the effects of helicopter skiing activities on mountain goats and woodland caribou in B.C. through a literature review. The included studies assessed the physiological and behavioural responses of caribou, and whether caribou were displaced or exhibited increased movement rates in response to approaches by helicopters and skiers. In general, caribou exhibited low behavioral responses to helicopter encounters, but there was still a dose-response relationship with closer encounters causing higher responses. Contact with skiers elicited stronger behavioural responses in caribou than helicopters. Research focusing on physiological stress displays inconsistent results when fecal cortisol is measured. However, caribou pellets from areas with helicopter skiing activity contain higher cortisol levels than areas without it, suggesting it does elicit physiological stress. The reviewed literature did not find evidence that helicopter skiing activities displace caribou from their preferred habitats or increase their overall movement rates within heli-skiing tenures. This differs from unguided backcountry ski touring which displaces caribou to lower elevations and increases their movement rates. The authors highlight a significant research gap: no studies have assessed the long-term demographic consequences of helicopter skiing on caribou. While helicopter skiing elicits short-term behavioral responses in woodland caribou, there is no strong evidence that it leads to sustained displacement from their preferred habitats. The long-term impacts on caribou survival or reproduction are unknown, thus the authors cannot conclude whether helicopter skiing contributes to caribou population declines.

Wilson, S. F. (2022). *Effects of helicopter skiing on mountain goats and woodland caribou in British Columbia*. https://ecoevorxiv.org/repository/view/3701/

3.3.3 Habitat alteration or climate: What drives the densities of an invading ungulate?

Dickie et al. leveraged Alberta and Saskatchewan's differing degrees of habitat alteration to determine the relative importance of anthropogenic habitat alteration versus climate in white-tailed deer densities. While Alberta has significantly more habitat alteration for a given latitude, the climate does not vary significantly across the provincial border. Enabling Dickie et al. to determine whether climate or habitat alteration more strongly influenced white-tailed deer density. Dickie et al. estimated deer densities over five years (2017–2021) using remote cameras while monitoring habitat alteration, climate, and habitat productivity. Winter severity was the primary factor limiting white-tailed deer densities. Habitat alteration, while present, had a much smaller and

statistically insignificant effect. As climate change leads to milder winters, white-tailed deer are expected to continue expanding northward and increasing in population size. As white-tailed deer population increases in boreal caribou habitat, the deer are expected to attract more wolves, increasing incidental predation events on caribou. Habitat restoration alone may be insufficient for caribou recovery and the authors suggest that complementary management strategies be employed such as predator or prey reduction. The authors highlight that further research is needed to understand the demographic mechanisms linking climate to deer density.

Dickie, M., Serrouya, R., Becker, M., DeMars, C., Noonan, M. J., Steenweg, R., Boutin, S., & Ford, A. T. (2024). Habitat alteration or climate: What drives the densities of an invading ungulate? *Global Change Biology*, *30*(4), e17286. https://doi.org/10.1111/gcb.17286

3.3.4 Trophic rewilding can expand natural climate solutions

Schmitz et al. advocate for trophic rewilding, the restoration and protection of wild animals and their functional roles in ecosystems. The authors argue that trophic rewilding is a key natural climate solution that is ignored by most climate policies. Natural climate solutions often focus on forests, which cover only 9% of the Earth's surface. Wild animals exist in all ecosystems, offering vast potential expansion. Wild animals contribute to carbon capture and storage through their outsized control over carbon in plants, soils, and sediments (15–250%). This carbon capture occurs through seed dispersal, herbivory, and soil engineering. In the Serengeti, restoring wildebeest (from 300 thousand to 1.2 million) reduced wildfires by increasing grazing pressure, which in turn reduced fuel loads (grass biomass), lowered carbon emissions from fires, and converted the Serengeti back into a carbon sink. Schmitz et al. focus on larger-bodied vertebrates (e.g. marine fish, grey wolves, and sea otters), which have significant impacts on carbon storage. The authors note that animal impacts can vary with ecosystem type, population density and functional traits (e.g. herbivory) such as wolves which have positive effects in boreal forests. Schmitz et al. conclude that trophic rewilding can expand natural climate solutions and contribute to achieving the Paris Climate Agreement target of limiting global warming to 1.5 .

Schmitz, O. J., Sylvén, M., Atwood, T. B., Bakker, E. S., Berzaghi, F., Brodie, J. F., Cromsigt, J. P. G. M., Davies, A. B., Leroux, S. J., Schepers, F. J., Smith, F. A., Stark, S., Svenning, J.-C., Tilker, A., & Ylänne, H. (2023). Trophic rewilding can expand natural climate solutions. *Nature Climate Change*, *13*(4), 324–333. https://doi.org/10.1038/s41558-023-01631-6

3.3.5 Cut vs. fire: A comparative study of the temporal effects of timber harvest and wildfire on ecological indicators of the boreal forest

Best et al. compared the effects of timber harvesting and wildfires on the recovery of forest stand attributes and the availability of forage for caribou, moose and bears in Alberta. The study area included nine caribou populations of boreal and central mountain caribou herds. The authors measured four stand attributes related to timber supply to assess forest structure, and counts of coarse woody debris (CWD) to assess stand-level biodiversity. Comparisons were made between areas impacted by timber harvesting, wildfires, and areas designated as caribou use sites, considering various timeframes since disturbance. Forest stand attributes including basal area and stems per hectare recovered more rapidly in timber harvest sites compared to wildfire sites; however, after >40 years post disturbance, forest stand attributes became similar across timber harvest, wildfire, and older caribou use sites. CWD was most abundant in recently burned sites but decreased over time, reaching levels akin to harvested and older forest stands. For foraging availability, terrestrial lichens were predominantly found in older caribou use sites, whereas younger timber harvest and wildfire areas supported greater availability of forage for moose and bears. Overall, timber harvesting fostered quicker timber volume recovery, but was less advantageous for developing habitats suitable for caribou compared to natural disturbances like wildfires. The differing impacts of timber harvest and wildfire emphasize the need for forest management strategies that consider these trade-offs to maintain ecological integrity.

Best, I. N., Brown, L., Elkin, C., Finnegan, L., McClelland, C. J. R., & Johnson, C. J. (2024). Cut vs. fire: A comparative study of the temporal effects of timber harvest and wildfire on ecological indicators of the boreal forest. *Landscape Ecology*, *39*(4), 81. https://doi.org/10.1007/s10980-024-01882-4

See also:

Mackey, B., Campbell, C., Norman, P., Hugh, S., DellaSala, D. A., Malcolm, J. R., Desrochers, M., & Drapeau, P. (2023). Assessing the cumulative impacts of forest management on forest age structure development and woodland caribou habitat in boreal landscapes: A case study from two Canadian provinces. *Land*, *13*(1), 6.

3.3.6 Mixed evidence for disturbance-mediated apparent competition for declining caribou in western British Columbia, Canada

Tjaden-McClement et al. investigated the causal mechanisms behind the decline of the Itcha-Ilgachuz caribou population in the low-productivity Chilcotin Plateau region of west-central B.C.. The authors examined the role of disturbance-mediated apparent competition (DMAC) and its impact on caribou predation risk and population dynamics. Vegetation productivity and relative abundances of primary ungulate prey, predators and caribou were measured. Following forest harvest and fire, vegetation productivity increased, but overall productivity was lower compared to other caribou ranges where DMAC has been supported. Both moose and mule deer showed weak positive responses to cutblocks but strong positive responses to fire. The increased ungulate presence in burned areas attracted more predators, supporting the DMAC hypothesis. Predators were more abundant in areas with increased prey populations. Linear features facilitated predator movement, potentially increasing predation risk for caribou. Caribou had weak positive associations with cutblocks at lower elevations, suggesting attraction to forage, but this may create an ecological trap by drawing caribou to areas with higher predator density. During calving, caribou avoided high-productivity areas, possibly to minimize predator encounters. Caribou also showed some weak positive associations with predators at lower elevations, challenging DMAC's assumption of spatial segregation. Proximity to water sources and other habitat features significantly affected the relative abundance and movement patterns of both prey and predator species. Overall, the results provided partial support for DMAC as a driver of caribou decline in the Itcha-Ilgachuz range:

- Increased productivity and primary prey abundance post-disturbance.
- Predator abundance followed prey availability, aligning with DMAC mechanisms.

However, caribou did not consistently avoid areas with predators or primary prey, weakening the case for DMAC as a sole explanation. Tjaden-McClement et al. advocate for adaptive management based on context-specific data to optimize conservation efforts. The authors also emphasized the need for improved fire management practices and the role of cultural burning by Indigenous populations to maintain habitat safety for caribou.

Tjaden-McClement, K., Gharajehdaghipour, T., Shores, C., White, S., Steenweg, R., Bourbonnais, M., Konanz, Z., & Burton, A. C. (2025). Mixed evidence for disturbance-mediated apparent competition for declining caribou in western British Columbia, Canada. *The Journal of Wildlife Management*, *89*(6), e70040. https://doi.org/10.1002/jwmg.70040

3.3.7 Mapping interactions between winter recreationists and an endangered ungulate

Gill et al. investigated spatial overlap between winter heli-skiing activities and late-winter habitat use by endangered southern mountain caribou in British Columbia. Using GPS collar data from 114 female caribou and Strava-derived spatial data on heli-ski use, the researchers modeled habitat suitability for both caribou and skiers. The authors found that approximately 10% of the study area represents potential conflict zones where high-quality caribou habitat overlaps with terrain desirable for heli-skiing. While most heli-ski tenures include terrain that is not critical to caribou, some areas of overlap likely reduce the functional availability of habitat due to behavioural avoidance driven by human disturbance. Encouragingly, the study identified over 3,100 km² of heli-skiable terrain with low potential for conflict, suggesting that operators could substantially reduce their impact by avoiding high-risk zones. The authors recommend collaborative management approaches such as rolling closures and careful tenure planning to protect critical caribou winter habitat.

Gill, R., Serrouya, R., Simms, J., DeMars, C., Ernst, B., & Noonan, M. J. (2025). Mapping interactions between winter recreationists and an endangered ungulate. *The Journal of Wildlife Management*, *89*(6), e70042. https://doi.org/10.1002/jwmg.70042

See also:

Gill, R., Serrouya, R., Calvert, A. M., Ford, A., Steenweg, R., & Noonan, M. J. (2024). Movement ecology of endangered caribou during a COVID-19 mediated pause in winter recreation. *Animal Conservation*, *27*(3), 350–363. https://doi.org/10.1111/acv.12912

3.3.8 The role of federal guidelines in the evolution of cumulative effects assessment research in the Canadian forest ecosystem

Kwabena Antwi et al. examined the progression of cumulative effects assessment (CEA)

research in Canadian forestry and its alignment with federal government guidelines under the 2019 Impact Assessment Act (IAA), particularly in relation to engaging Indigenous communities and applying a gender-based analysis (GBA) plus framework. The authors performed a systematic review of CEA research in Canada since 1992 and a thorough document analysis of the 2012 Canadian Environmental Assessment Act (CEAA) and the 2019 IAA, focusing on their respective practitioners' guides. Kwabena Antwi et al. found that CEA research in Canadian forestry has evolved to align with the guidelines set out in the 2019 Impact Assessment Act (IAA). Of the 65 articles reviewed, 61.5% of articles focused on regional-scale assessments, primarily aimed at determining sustainable levels of cumulative effects for species such as caribou. A majority (73.8%) of the studies performed long-term impact assessments over 10 years. Over 76% addressed the impacts of disturbances on forest ecosystems, with logging identified as the most frequently cited disturbance type (41.5%). 92.3% of studies identified the specific pathways through which disturbances occurred, including soil degradation, climate effects, and construction activities. Four main forms of cumulative effects were identified: additive (~43% of articles), synergistic (~ 21.5% of articles), compensatory, and masking. Only 21.5% proposed mitigation strategies to alleviate cumulative effects. Modeling was the most commonly used analytical tool, employed in 44.6% of studies. Geographically, most of the CEA research was concentrated in Alberta and British Columbia (27 of 65, around 41.6% of articles), with relatively fewer studies conducted in Ontario and Quebec (19 of 65, around 29% of articles), considering that the latter provinces have the greatest forest cover. The remaining provinces and territories were not exclusively captured in the assessments reviewed. Despite the IAA's emphasis on Indigenous and public participation, only 3 of the 65 articles published after 2019 incorporated Indigenous knowledge or involved Indigenous communities in the CEA process.The authors concluded that while there has been meaningful progress in aligning CEA research with legislative expectations, there remains a clear gap in the integration of Indigenous perspectives and broader public engagement.

Kwabena Antwi, E., Toloo Yohuno (Apronti), P., Boakye-Danquah, J., Abolina, E., Dabros, A., & Nyamekye Darko, A. (2024). The role of federal guidelines in the Evolution of cumulative effects assessment research in the Canadian forest ecosystem. *Ecological Indicators*, 166, 112333. https://doi.org/10.1016/j.ecolind.2024.112333

3.3.9 The erosion of threatened southern mountain caribou migration

Lamb et al. investigated long-term changes in the migratory patterns of southern mountain caribou. Telemetry data, collected over 35 years (1987–2022), was analyzed to assess how the duration, distance, and elevation change of migratory behaviours have evolved. To determine potential drivers of changes in migration patterns, the authors analyzed relationships between migratory behaviour and disturbance as well as weather variables. Caribou were classed into two distinct migratory behaviour types: "conventional migrants" (p. 3), characterized by long horizontal migrations (15–70 km) between winter and summer ranges, and "elevational migrants" (p. 3), characterized by shorter horizontal migrations (5–20 km) with more vertical movement (200–650 m) twice per year. Overall, Lamb et al. found that both migratory behaviours declined over the study period. Caribou showed a reduction in migratory duration of approximately two to three days per decade. Migration distance decreased by 6-8 km per decade, equivalent to a 15–25% decline over the study period. Migration elevation change diminished by around 120–150 m per decade for elevational migrants, translating to a 7–23% reduction. The authors noted a strong correlation between changes in migratory behaviour and increased human disturbances, particularly in low-elevation winter ranges. For every 10% increase in human-caused disturbance, migration distance declined by 10.7 km, and caribou shifted their winter ranges upslope by roughly 60.8 m. Changes in weather conditions did not appear to significantly influence the observed declines in migration, indicating that anthropogenic factors are the primary concern affecting migratory patterns. The reduction in migratory behaviours coincided with population declines, suggesting that these trends may be interconnected. These changes pose serious concerns in balancing anthropogenic activity and conservation, as migratory behaviours are essential for the caribou's access to vital resources and their overall fitness.

Lamb, C. T., Steenweg, R., Serrouya, R., Hervieux, D., McNay, R. S., Heard, D. C., McLellan, B. N., Shores, C., Palm, E., Giguere, L., Hubner, J., Polfus, J., Klaczek, M., Crosland, N., White, S., Russel, M., & Ford, A. (2025). The erosion of threatened southern mountain caribou migration. *Global Change Biology*, *31*(3), e70095. https://doi.org/10.1111/gcb.70095

3.3.10 The umbrella value of caribou management strategies for biodiversity conservation in boreal forests under global change

Labadie et al. evaluated the effectiveness of boreal caribou as an umbrella species for conserving bird and beetle diversity in boreal forests, particularly under the impacts of climate change and land-use change. The study aimed to determine whether management strategies targeting caribou can simultaneously support other species, highlighting the benefits of single-species conservation approaches for overall biodiversity. The authors developed predictive models for 31 bird species and 77 beetle species to assess their responses to varying land-use and climate scenarios. Labadie et al. found that

land-use change had a more pronounced effect on biodiversity than climate change. The results indicate that strategies designed to decrease caribou mortality—such as reduced forest harvesting rates or the establishment of protected areas—benefit caribou populations and promote the conservation of associated bird and beetle species. The authors also observed a significant shift in forest composition, with an increase in deciduous vegetation from disturbances threatening the integrity of boreal ecosystems. While the occurrence of bird species associated with mature forests declined, those linked to early-to-mid succession forests may increase. Labadie et al. conclude that strategies aimed at reducing forest harvesting and promoting boreal caribou conservation can significantly mitigate biodiversity loss by preserving associated bird and beetle assemblages, underscoring the critical role of boreal caribou in sustaining regional biodiversity amidst climate and land-use changes.

Labadie, G., Bouderbala, I., Boulanger, Y., Béland, J.-M., Hébert, C., Allard, A., Hebblewhite, M., & Fortin, D. (2024). The umbrella value of caribou management strategies for biodiversity conservation in boreal forests under global change. *Science of The Total Environment*, 907, 168087. https://doi.org/10.1016/j.scitotenv.2023.168087

See also:

Micheletti, T., Haché, S., Stralberg, D., Stewart, F. E. C., Chubaty, A. M., Barros, C., Bayne, E. M., Cumming, S. G., Docherty, T. D. S., Dookie, A., Duclos, I., Eddy, I. M. S., Gadallah, Z., Haas, C. A., Hodson, J., Leblond, M., Mahon, C. L., Schmiegelow, F., Tremblay, J. A., … McIntire, E. J. B. (2023). Will this umbrella leak? A caribou umbrella index for boreal landbird conservation. *Conservation Science and Practice*, 5(4), e12908. https://doi.org/10.1111/csp2.12908

4 Indigenous Knowledge and Management

4.1 Indigenous Knowledge and Management

4.1.1 Intergovernmental partnership agreement for the conservation of the central group of the southern mountain caribou

Signed in February 2020 under SARA section 11, the Saulteau First Nations and West Moberly First Nations partnered with both the Government of British Columbia and the Government of Canada to advance a collaborative approach for the protection of southern mountain caribou in the northeastern extent of their range. The Partnership Agreement commits to protect over 700,000 hectares of caribou habitat through moratoria on resource development and permanent protection. For Indigenous partners, Saulteau and West Moberly First Nations continue to lead recovery actions for the central group and the agreement enhances their decision-making with regards to lands and resources related to caribou recovery. The Partnership Agreement establishes a Caribou Recovery Committee with officials from the four governments. Long-term financial support will be provided for recovery efforts, including funding for maternal penning, habitat restoration, collaborative knowledge sharing and research, and an Indigenous Guardians program.

Government of Canada, Government of BC, Saulteau First Nations, & West Moberly First Nations. (2020). *Intergovernmental partnership agreement for the conservation of the central group of the southern mountain caribou*. Retrieved from https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/conservation-agreements/intergovernmental-partnership-conservation-central-southern-mountain-caribou-2020.html. Also available from: https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/Ca-SthnMtnCaribouMtgnsSud-AccordPartnAgrmt-v00-2020Feb-Eng.pdf

4.1.2 Support for B.C. First Nations' territorial management and protection of caribou and wolf populations

The Union of B.C. Indian Chiefs (UBCIC) passed a resolution calling for First Nations' management and protection of caribou and wolf populations by territory. The resolution emphasizes that First Nations have long protected and managed their territories and that the endangered status of caribou is due to mismanagement of caribou habitat by the provincial government. The resolution states the importance of wolves as a keystone species as well as sacred animals with spiritual connection to Indigenous peoples. The Province has targeted wolves with inhumane aerial killings while failing to protect caribou habitat. The resolution outlines commitments under the United Nations Declaration on the Rights of Indigenous Peoples. First Nations uphold the right to make decisions regarding land and wildlife management. Due to lack of Provincial priorities to restore habitat, remove linear features, and reduce development, the only option for many First Nations is to move forward with their own caribou recovery plans. The resolution calls for a stop to unilateral state decisions on wolf culling and caribou recovery. Finally, the UBCIC Chiefs Council directs members to work with organizations to ensure the provincial government undertakes a selective approach that respects First Nations jurisdiction and territorial management.

Union of British Columbia Indian Chiefs Council. (2022, February 23-24). Resolution no. 2022-09 Support for BC First Nations' territorial management and protection of caribou and wolf populations [Virtual meeting]. Final Resolutions of UBCIC Chiefs Council February 23rd-24th, 2022. Retrieved from https://assets.nationbuilder.com/ubcic/pages/132/attachments/original/1646354635/2022_02_UBCIC_CC_FinalResolutions_Combined.pdf?1646354635

See also:

Union of British Columbia Indian Chiefs Council. (2021, February 25). *Ending the wolf cull program and addressing misguided wildlife management policy.* Letter to Minister of Forests, Lands and Natural Resources. Retrieved from https://pacificwild.org/wp-content/uploads/2021/10/Union-of-BC-Indian-Chiefs-Letter-of-Support.pdf

4.1.3 Indigenous-led conservation: Pathways to recovery for the nearly extirpated Klinse-Za mountain caribou

This research paper reviews the success of Indigenous leadership in conservation in the case of the West Moberly and Saulteau First Nations' impact on short-term and long-term recovery efforts on the Klinse-Za mountain caribou subpopulation. The Klinse-Za population declined from 250 individuals in the 1990s to 38 in 2013, leading to a non-viable Indigenous caribou harvest with implications for treaty rights to subsistence living. In 2014, the West Moberly First Nations and Saulteau First Nations implemented a maternal penning program as a short-term recovery measure since they suspected that calf mortality was limiting caribou population growth. The recovery program included wolf reductions (trapping by First Nations and helicopter culling by the Provincial government). The Kilnse-Za caribou population rapidly increased in eight years by more than double, with 101 individuals in 2021. The authors credited the population increase to both maternal penning and predator reduction. The success of this initiative underscores the integral role of Indigenous governance and leadership in stimulating meaningful conservation for endangered species recovery. In 2020, the two First Nations implemented a partnership agreement with the Provincial and Federal governments based on the understanding that a self-sustaining caribou population required long-term habitat protection and restoration (see section 5.1). The framework of decentralized co-management and Indigenous-led conservation demonstrates the effectiveness of merging Indigenous treaty rights, traditional knowledge, and endangered species recovery to advance synergistic goals. Collaboration and Indigenous leadership creates a greater opportunity to restore ecosystems and cultural connections to the land, which has many positive implications for reconciliation and wildlife conservation.

Lamb, C.T., Willson, R., Richter, C., Owens-Beek, N., Napoleon, J., Muir, B., McNay, R.S., Lavis, E., Hebblewhite, M., Giguere, L., Dokkie, T., Boutin, S. & Ford, A.T. (2022). Indigenous-led conservation: Pathways to recovery for the nearly extirpated Klinse-Za mountain caribou. *Ecological Applications*. Accepted Author Manuscript e2581. https://doi.org/10.1002/eap.2581.

See also (related paper discussed in section 8.5.1):

McNay, R. S., Lamb, C. T., Giguere, L., Williams, S. H., Martin, H., Sutherland, G. D., & Hebblewhite, M. (2022). Demographic responses of nearly extirpated endangered mountain caribou to recovery actions in Central British Columbia. *Ecological Applications*, *32*(5). https://doi.org/10.1002/eap.2580

See also:

Harold, S. (2023). Indigenous-led recovery. N*ature Ecology & Evolution*, *7*(1), 8-8. https://www.nature.com/articles/s41559-022-01961-2

See also:

Spencer, B.J. (2022). *Bickford Caribou Maternity Pen Construction: Annual Report*. Wildlife Infometrics Inc. Report No. 789. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada. https://wildlifeinfometrics.com/wp-content/uploads/2022/10/Spencer_2022_WII_Report789_BickfordPenConstruction.pdf

4.1.4 Medzih action plan: Fort Nelson First Nation boreal caribou recovery plan

Fort Nelson First Nation (FNFN) implemented the Medzih Action Plan (MAP), founded on the principle of habitat protection for caribou recovery. FNFN developed this recovery strategy due to the current state of caribou, as well as little or no change and overall lack of faith in federal and provincial governments. The MAP clearly outlines several strategies including: protection zones, restoration zones, restoration actions, fund establishment, moratorium, an ecosystem management approach to development, improving population trends, management paradigm that ensures decisions are precautionary, habitat protection that meets SARA, appropriate monitoring (habitat, population, and restoration success), and building a stable economic future (not boom/

bust approach). FNFN developed this plan based on traditional knowledge, science, and mapping, and aims to work with provincial and federal governments for implementation.

Fort Nelson First Nation. (2017). *Medzih action plan: Fort Nelson First Nation boreal caribou recovery plan*. http://www.fortnelsonfirstnation.org/uploads/1/4/6/8/14681966/2017-sept-29_fnfn_medzih_action_plan_final_medres.pdf

4.1.5 Comparing traditional ecological knowledge and western science woodland caribou habitat models

This article discusses the importance of using a combination of traditional ecological knowledge (TEK) and western science to improve wildlife management decisions, particularly in cases where data is limited. The study compares predictions of habitat selection for woodland caribou in northern British Columbia using both resource selection function (RSF) models based on western science and habitat suitability index models based on TEK developed from interviews with Taku River Tlingit members. Both models were tested and compared regarding their ability to spatially predict the occurrence of collared caribou locations. The study found that the TEK and RSF model predictions were overall in high agreement. When applying complementary knowledge sources, important information can be revealed where models differ. In this case, the RSF model (western science) underestimated the use of frozen lakes where TEK captured this overlooked but important habitat type. Further, only the TEK model identified burned areas as low habitat quality, an important habitat relationship necessary for understanding caribou distribution. The results demonstrate the effectiveness of TEK-based habitat models in informing recovery planning for imperiled species, such as woodland caribou.

Polfus, J. L., Heinemeyer, K., Hebblewhite, M., & Taku River Tlingit First Nation. (2014). Comparing traditional ecological knowledge and western science woodland caribou habitat models. *The Journal of Wildlife Management*, *78*(1), 112–121. https://doi.org/10.1002/jwmg.643

See also:

Jessen, T. D., Ban, N. C., Claxton, N. X., & Darimont, C. T. (2022). Contributions of Indigenous Knowledge to ecological and evolutionary understanding. *Frontiers in Ecology and the Environment*, *20*(2), 93–101. https://doi.org/10.1002/fee.2435

4.1.6 Braiding Indigenous rights and endangered species law (recovery targets fall short of culturally meaningful abundance)

This policy-oriented, scholarly commentary argues for further integration of Indigenous rights and knowledge into endangered species law. The authors highlight the insufficiency of current endangered species laws in Canada (SARA) and the U.S. (ESA,) which primarily focus on preventing extinction by using Minimum Viable Population (MVP) targets. MVP targets tend to leave species in a state of reduced abundance compared to their historical baselines, and often ignore "constitutionally protected Indigenous rights to sustain a culturally meaningful way of life" (p. 694). A culturally meaningful recovery target often requires greater abundance and/or different distribution than those prescribed by MVP approaches. The authors discuss the recovery efforts of three culturally important species including woodland caribou. In the past century, caribou populations have declined extensively, especially in the southern range, with 11 of 38 populations extirpated, and an overall population decline of more than 40% in the last 20 years. Indigenous knowledge has greatly contributed to the conservation of caribou. In B.C., following caribou decline in 1970, West Moberly First Nation imposed a moratorium on caribou harvest that is still in place today. West Moberly and Saulteau Nations' recovery efforts more than tripled the Klinse-Za caribou abundance in eight years, from 38 (2013) to 114 (2022). While the current caribou population meets the Canadian government's MVP target, it is significantly less than the abundance needed for a culturally meaningful harvest (~3,000 caribou). This commentary underlines the need for policies that "center Indigenous perspective and people in the design and implementation of restorative actions" (p. 694).

Lamb, C. T., Willson, R., Menzies, A. K., Owens-Beek, N., Price, M., McNay, S., Otto, S. P., Hessami, M., Popp, J. N., Hebblewhite, M., & Ford, A. T. (2023). Braiding Indigenous rights and endangered species law. *Science*, *380*(6646), 694–696. https://doi.org/10.1126/science.adg9830

4.1.7 Who is local and what do they know? Braiding knowledges within carnivore management in Europe

Pettersson et al.'s perspective paper aimed to advance the recognition of local knowledge (LK) in biodiversity conservation, specifically in the context of managing human-carnivore interactions in Europe. The authors performed a literature review of existing studies and frameworks that highlight the role of LK in biodiversity conservation. The authors demonstrated the benefits of integrating local knowledge with scientific

knowledge, showing that this fusion often leads to more effective and culturally relevant carnivore management policies. Empowering local communities by recognizing their cultural heritage and values leads to more sustainable agricultural practices and biodiversity conservation. Pettersson et al. call for the development of policies that are informed by both scientific data and local experiences to promote equitable coexistence strategies that acknowledge the complexities of human-wildlife interactions. By braiding scientific and local knowledge, Pettersson et al. advocate for more equitable and sustainable conservation practices that are sensitive to the needs and contexts of local communities.

Pettersson, H., Lécuyer, L., Young, J., Stringer, L., Calla, S., Juhász, E., & Molnár, Z. (2025). Who is local and what do they know? Braiding knowledges within carnivore management in Europe. *People and Nature*, pan3.10797. https://doi.org/10.1002/pan3.10797

4.1.8 Identifying Indigenous knowledge components for Whudzih (Caribou) recovery planning

Priadka et al. explore how Indigenous Knowledge (IK) can be effectively integrated into caribou recovery planning in British Columbia. The authors conducted a survey among non-Indigenous government professionals involved in caribou conservation initiatives to gather insights on the specific IK they believe would aid in caribou recovery planning. Survey responses informed semi-structured interviews with Lhtako Dene knowledge holders, covering 40 questions on participants' experiences with caribou, socio-ecological values, demographics, and management strategies. The interviews revealed that IK is often holistic, blending ecological and cultural insights. However, some of the IK sought by professionals was not available, highlighting complexities in traditional knowledge transfer. Participants expressed a strong preference for autonomous community-based caribou monitoring, emphasizing the importance of involving Indigenous communities in recovery actions to enhance the relevance and effectiveness of species conservation efforts. The authors advocated for clarity of expectations and outcomes in IK sharing, and for structured processes that facilitate respectful collection and integration of IK. Overall, Priadka et al. provide a framework for integrating IK into conservation strategies, highlighting both the benefits and challenges of such collaborations for caribou recovery in B.C..

Priadka, P., Suzuki, N., & Nation, L. D. (2025). Identifying Indigenous knowledge components for Whudzih (Caribou) recovery planning. *FACETS*, 10, 1–11. https://doi.org/10.1139/facets-2023-0139

4.1.9 Setting a foundation for Indigenous knowledge systems-guided boreal caribou (tǫdzı) conservation planning in the Western Boreal Region of Canada: A systematic map protocol

Saturno et al. conducted a literature review of both peer-reviewed and grey literature to examine how Indigenous Knowledge (IK) has been incorporated into wildlife conservation research. Grey literature refers to research or information produced by organizations such as governments, NGOs, and universities that has not gone through the peer-review process. The authors aimed to assess methods used to bridge IK with Western science, particularly in spatial mapping for caribou management. The literature review revealed patterns and trends in how past research has engaged IK holders in caribou studies, including the frequency and nature of their involvement. The authors compiled a list of best practices that enhance engagement between Indigenous peoples and Western researchers. These practices included ensuring Indigenous participation throughout the research process, respecting knowledge ownership through frameworks like OCAP (Ownership, Control, Access, and Possession), and encouraging the inclusion of Indigenous contributors as co-authors. The findings indicated that successful collaborations that integrate IK can contribute positively to the self-determination of Indigenous communities. Research co-led by Indigenous peoples has shown greater alignment with community needs and values. Overall, Saturno et al. found that combining Western and IK systems led to more holistic management strategies for conservation.

Saturno, J., Boeckner, M., Haché, S., Hodson, J., McAuley, E., McIntire, E., Micheletti, T., Polfus, J., Sliwa, S., Teed, T., & Westwood, A. R. (2023). Setting a foundation for Indigenous knowledge systems-guided boreal caribou (Tǫdzı) conservation planning in the Western Boreal Region of Canada: A systematic map protocol. *Ecological Solutions and Evidence*, 4(1), e12211. https://doi.org/10.1002/2688-8319.12211

4.1.10 Amendments to the Intergovernmental Partnership Agreement for the Conservation of the Central Group of Southern Mountain Caribou

The 2022 and 2024 amendments, along with the 2024 Replacement Supplemental Agreement, collectively advance and operationalize the commitments made in the 2020 Intergovernmental Partnership Agreement for the Conservation of Central Southern Mountain Caribou. The 2022 Amending Agreement clarifies the Government of British Columbia's obligation to implement enforceable regulatory measures—such as land use orders, legislative designations, and planning tools—to protect key caribou

habitat zones (A and B), ensuring these actions align with provincial legal frameworks. Building on this, the 2024 Amending Agreement enables formal habitat protection through the use of the Park Act and Environment and Land Use Act, allowing the creation of legislated protected areas. It also addresses the interaction between habitat protections and previously approved infrastructure projects, including natural gas pipelines, by providing for temporary park use permits and outlining restoration requirements to ensure no long-term net loss of habitat. The 2024 Replacement Supplemental Agreement gives legal effect to these mechanisms by formally designating the Klinse-za/Twin Sisters Park and Protected Area, covering the high-value caribou habitat in Zone A, and establishes conditions for access, exclusions for essential infrastructure, and a pathway for full restoration of temporarily impacted areas. It reflects the leadership of West Moberly and Saulteau First Nations in stewarding these lands and affirms their rights and roles in long-term conservation. Together, these agreements mark a major milestone in implementing legally-binding habitat protection, reconciling conservation with existing land use, and embedding Indigenous governance into caribou recovery and land management in northeastern British Columbia.

Government of Canada, Government of BC, Saulteau First Nations, & West Moberly First Nations. (2020). *Intergovernmental partnership agreement for the conservation of the central group of the southern mountain caribou*. Retrieved from https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/conservation-agreements/intergovernmental-partnership-conservation-central-southern-mountain-caribou-2020.html.

Government of Canada, Government of BC, Saulteau First Nations, & West Moberly First Nations. (2022). *Amending agreement: Intergovernmental partnership agreement for the conservation of the central group of the Southern Mountain Caribou*. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/2022_amending_agt_smc_partnership_agreement.pdf

Government of Canada, Government of BC, Saulteau First Nations, & West Moberly First Nations. (2024). *Second amending agreement to the Intergovernmental Partnership Agreement for the Conservation of the Central Group of the Southern Mountain Caribou*. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/2024_amending_agmt_smc_partnership_agreement.pdf

Government of Canada, Government of BC, Saulteau First Nations, & West Moberly First Nations. (2024). *Replacement Supplementary Agreement on Protected Areas and Related Matters under the Intergovernmental Partnership Agreement for the Conservation of the Central Group of Southern Mountain Caribou*. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/replacement_supplemental_agmt_smc_partnership_agmt.pdf

5 Wolf Management in British Columbia

5.1 Wolf Management in British Columbia

5.1.1 Management Plan for the grey wolf (*Canis lupus*) in British Columbia

In this document, the B.C. Ministry of Forests, Lands and Natural Resource Operations describes the status and management of the grey wolf in British Columbia. The Ministry characterizes population trends as likely stable or increasing and notes the purpose of wolf management as species-at-risk (caribou) recovery. Wolf reductions that had occurred to date (2014) fell short of this goal, as caribou populations continued to decline. Although wolf densities were reduced, "a correlation between wolf densities and caribou recovery could not be substantiated" (p. 17). Furthermore, the Ministry notes that fragmentation of packs can lead to high birth rates (also see section 6.1). The document recommends that future actions related to mitigation of wolf populations should be constrained to areas as small as possible in order to minimize conservation risks to (a) the broader wolf population and (b) unintended ecological consequences (e.g., trophic cascades) (also see section 6.2 and 6.3). In addition, management actions need to align with expectations of the public (also see section 8.0); maintain transparency; and continually be monitored, reassessed, and adjusted as necessary.

B.C. Ministry of Forests, Lands and Natural Resource Operations. (2014). *Management Plan for the grey wolf (Canis lupus) in British Columbia. B.C.* Ministry of Forests, Lands and Natural Resource Operations, Victoria, BC. 48 pp. Retrieved from: https://www.env.gov.bc.ca/fw/wildlife/management-issues/docs/grey_wolf_management_plan.pdf

5.1.2 Predator management to support caribou recovery: 2020–2021 summary

This report summarizes predator management over the 2020–2021 winter. Aerial shooting of wolves occurred in 13 of 54 caribou populations in British Columbia. Ground tracking and hunting of cougars also occurred in two of the 13 caribou population

ranges. In total, government contractors killed 237 wolves and eight cougars. Costs were approximately $1.6 million that year and are summarized by caribou herd within the report. Intensive wolf reduction aims for annual removal of >80% of wolves to achieve government targets of less than three wolves per 1000 km2 in caribou recovery areas. Contractors remove entire wolf packs using GPS/VHF radio collars. The figure below depicts predator reduction areas and number of predators killed. The report states the Caribou Recovery Program assesses the effectiveness of predator reduction on caribou herds during the following year and adapts if necessary. Wolf populations have shown to recover at rates ranging between 30–100% by the following winter. The wolf kill program is intended to be a short term recovery action for woodland caribou. This document acknowledges that the "ultimate cause" of the decline in caribou is landscape modifications, due primarily to forestry and that the wolf kill program "will not address the ultimate cause of caribou population declines if habitat protection and restoration does not occur concurrently" (p. 3).

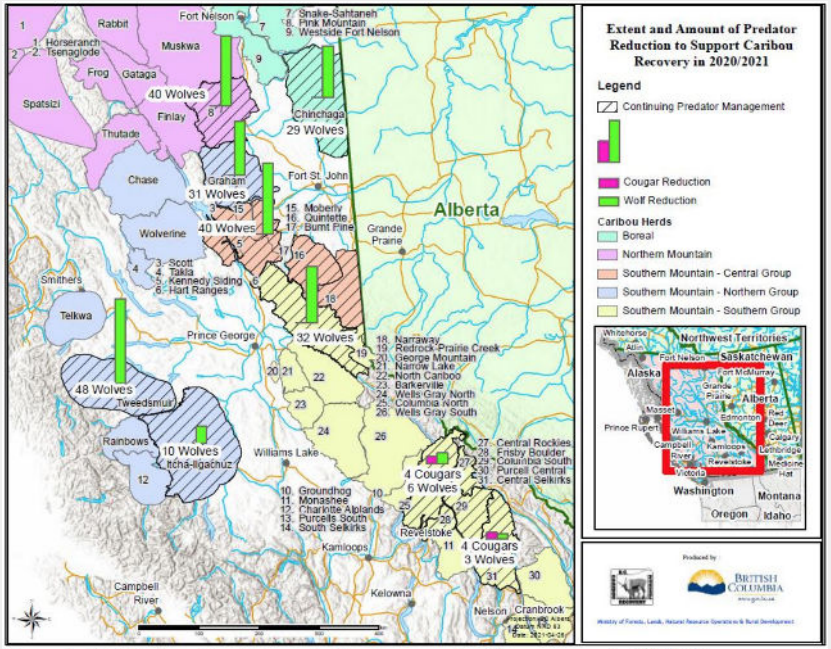

Figure 1. Distribution of predator reduction to support caribou recovery in 2020/2021.

BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. (2021). *Predator management to support caribou recovery: 2020-2021 summary*. Caribou Recovery Program. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/predator_management_to_support_caribou_recovery.pdf

See also:

Government of British Columbia. (n.d). *Caribou projects and management activities: Predator management*. Retrieved June 6. 2022, from https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/caribou/management-activities#predatormanagement

See also:

Government of British Columbia. (n.d). *Provincial caribou recovery program*. Retrieved June 6. 2022, from https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/caribou/recovery-program

See also:

Environment Canada. (2014). *Recovery strategy for the woodland caribou, southern mountain population (Rangifer tarandus caribou) in Canada*. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. viii + 103 pp.

5.1.3 Predator management to support caribou recovery: 2021–2022 summary

This report summarizes predator management over the 2021–2022 winter. Aerial shooting of wolves occurred in the ranges of 13 of British Columbia's 54 caribou populations. Ground tracking and hunting of cougars also occurred in two of the 13 caribou population ranges. In total, government contractors killed 279 wolves and seven cougars. Costs were approximately $1.7 million that year and are summarized by caribou herd within the report. Entire wolf packs are removed using GPS/VHF radio collars. The figure below depicts predator reduction areas and number of predators killed. See 3.1.2 for additional and repeated information from the previous year's summary report.

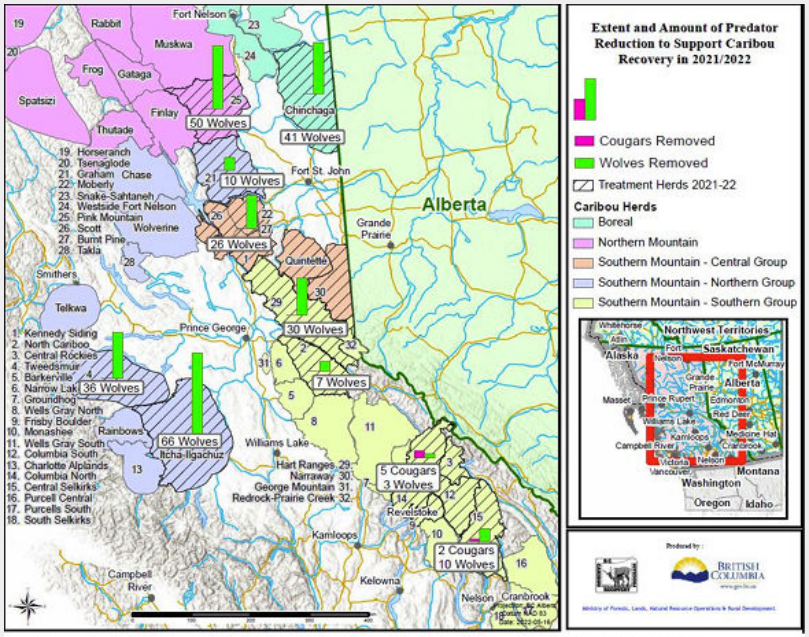

Figure 1. Distribution of predator reduction to support caribou recovery in 2021/2022.

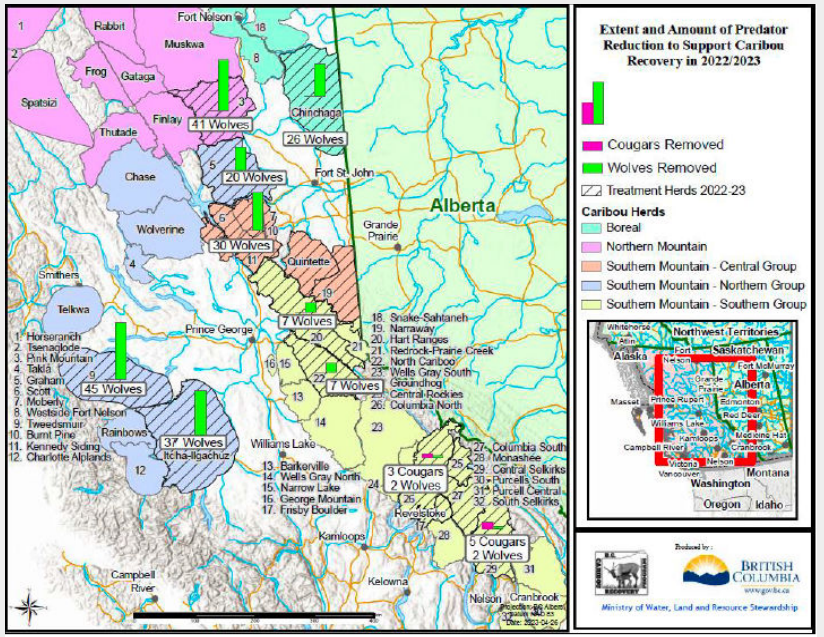

Figure 1. Distribution of predator reduction to support caribou recovery in 2022/2023.

BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. (2022). *Predator reduction to support caribou recovery: 2021–2022 summary*. Caribou Recovery Program. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/predator_reduction_to_support_caribou_recovery_2021-2022.pdf

5.1.4 Predator management to support caribou recovery: 2022–2023 summary

Between 2022 and 2023, the B.C. government conducted predator reduction across the ranges of 13 threatened caribou herds. A total of 217 wolves and eight cougars were killed. The program cost $1.65 million and was carried out using aerial shooting for wolves and ground-based methods with hounds for cougars. The predator reduction program met its goal of reducing wolf densities to below three per 1,000 km² in nearly all treated herd ranges. Calf survival rates improved in most herds, and population stabilization or growth was observed where multi-year efforts have been sustained. The figure below depicts predator reduction areas and number of predators killed.

B.C. Ministry of Water, Land and Resource Stewardship. (2023, June). *Predator reduction to support caribou recovery: 2022–2023 summary*. Caribou Recovery Program. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/predator_reduction_to_support_caribou_recovery_2022-2023.pdf

5.1.5 Predator management to support caribou recovery: 2023–2024 summary

British Columbia's Caribou Recovery Program continued predator reduction in 2023–2024, focusing primarily on wolf and, in limited cases, cougar populations. Government contractors carried out aerial wolf culls in 15 caribou herd ranges, with ground-based cougar hunting in two. A total of 248 wolves and six cougars were killed at a cost of $1.59 million. The efforts aimed to bring wolf densities below three wolves/1,000 km², stabilizing or increasing caribou populations. Despite weather-related limitations, the 2023–2024 season was largely successful and will inform future efforts. The figure below depicts predator reduction areas and number of predators killed.

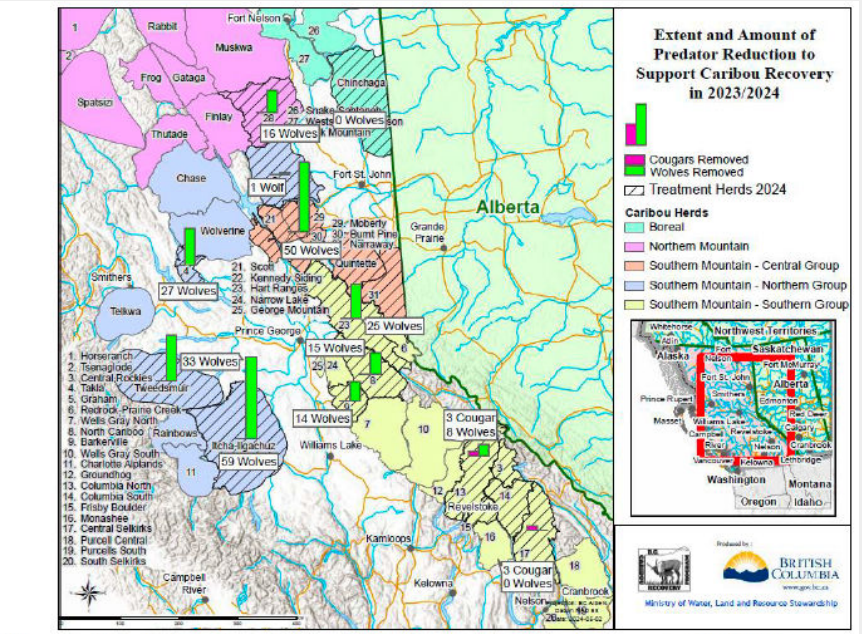

Figure 1. Distribution of predator reduction to support caribou recovery in 2023/2024.

B.C. Ministry of Water, Land and Resource Stewardship. (2024). *Predator reduction to support caribou recovery: 2023–2024 summary*. Caribou Recovery Program. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/predator_reduction_to_support_caribou_recovery_2023-2024.pdf

5.1.6 Colorado wolf restoration: 2025 translocation British Columbia

In January 2025, fifteen grey wolves were translocated from British Columbia to Colorado to support the Colorado Wolf Restoration and Management Plan. B.C.'s Ministry of Water, Land and Resource Stewardship entered into a Memorandum of Understanding with Colorado Parks and Wildlife in September 2024, followed by a $300,000 USD intergovernmental contract in October. Wolves were selected from packs targeted for predator reduction, and those not known to prey on livestock. Selected wolves were between 1–5 years old and in good physical condition. First Nations in both B.C. and Colorado were consulted, with a ceremony held on January 10, 2025, by the McLeod Lake Indian Band to support the translocation. Public consultations were limited in B.C. due to a provincial election period, though Colorado conducted extensive stakeholder engagement. Capture operations ran from January 10–15, involving net-gunning wolves from helicopters, on-site veterinary assessment, and GPS collaring. The wolves were held in custom staging pens before being flown to Colorado. One female wolf died post-sedation due to pre-existing health conditions. Upon arrival, wolves were released at two designated sites west of the Continental Divide: 12 in Eagle County and 3 in Pitkin County. GPS collars tracked their movements, revealing an average dispersal of 56.6 km in the first week, with some wolves reuniting in small groups. Despite opposition from some stakeholders, particularly Colorado's ranching community, the translocation was a scientific and operational success. The project set a precedent for future cooperation and emphasized the dual benefits of caribou recovery in Canada and wolf reintroduction in the U.S..

B.C. Ministry of Water, Land and Resource Stewardship & Colorado Parks and Wildlife. (2025). *Colorado wolf restoration: 2025 translocation British Columbia*. Government of British Columbia. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/bc_-_colorado_wolf_restoration_2025_translocation_report.pdf

6 Insufficient Protection of Caribou Critical Habitat

6.1 Insufficient Protection of Caribou Critical Habitat

6.1.1 When the protection of a threatened species depends on the economy of a foreign nation

Fortin et al. have investigated the drivers of reduced disturbance for boreal caribou habitat since 2003, when the species was listed under the federal Species at Risk Act. Boreal caribou habitat encompasses an expansive forest footprint that supplies a large proportion of Canada's timber. The study found that where logging had decreased within caribou habitat, the change was better explained by declines of the United States economy than habitat protection initiatives such as reduced annual allowable cuts or protected areas. In a given year, for every five cents US lost on the Canadian dollar, 129 square kilometers remained undisturbed by logging. The researchers were surprised by the overwhelming influence of the US economy on fluctuations in habitat disturbance and found no apparent effect of habitat protection nor endangered species legislation on land degradation. This illuminates concerns with Canada's legislation intended to protect caribou as the economy of a foreign nation governs their conservation. Economic instruments are suggested as a potential tool to conserve critical habitat, given that

economic forces have been the driver of forest degradation to date.

Fortin, D., McLoughlin, P. D., & Hebblewhite, M. (2020). When the protection of a threatened species depends on the economy of a foreign nation. *PloS One*, *15*(3), e0229555. https://doi.org/10.1371/journal.pone.0229555

6.1.2 Habitat loss accelerates for the endangered woodland caribou in western Canada

Nagy-Reis et al. highlighted considerable discrepancies between habitat recovery planning and protection actions for woodland caribou in British Columbia and Alberta. The authors quantified changes in forest cover and demonstrated that between 2000 and 2012, caribou lost twice as much habitat as they gained through protection actions over the same 12 years. Fire significantly impacted boreal and northern mountain habitat, while forest harvest was the main driver of habitat loss for the southern mountain ecotype. The researchers' findings affirm that "short-term recovery actions such as predator reductions and translocations will likely just delay caribou extinction in the absence of well-considered habitat management" (p. 1). The scientists assert that the cumulative impacts to the land must urgently be addressed in order to achieve self-sustained caribou populations. Long-term commitments for a sufficient reduction in habitat degradation combined with restoration are imperative.

Nagy-Reis, M., Dickie, M., Calvert, A. M., Hebblewhite, M., Hervieux, D., Seip, D. R., Gilbert, S.L., Venter, O., DeMars, C., Boutin, S., & Serrouya, R. (2021). Habitat loss accelerates for the endangered woodland caribou in western Canada. *Conservation Science and Practice*, *3*(7), e437. https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/csp2.437

6.1.3 The long road to protecting critical habitat for species at risk: The case of southern mountain woodland caribou

This paper demonstrated that classification as critical habitat does not guarantee protection for woodland caribou. First, Palm et al. reviewed provisions under the Species at Risk Act to protect critical habitat on non-federal lands. Second, they overlaid critical habitat maps and timber harvest maps to determine the extent to which critical habitat was protected five years after being identified in the 2014 recovery strategy. Analysis revealed that logging occurred on 909 km2 of legally-protected critical habitat under SARA. Current policy tools are clearly inadequate to protect caribou critical habitat and British Columbia has yet to implement provincial species-at-risk legislation, which could be effective. The authors recommend that the B.C. government leverage policy tools under existing provincial legislation, and employ the provincial Cumulative Effects Framework (CEF) to limit development. Furthermore, the authors recommend that both the federal and provincial governments collaborate with Indigenous peoples.

Palm, E. C., Fluker, S., Nesbitt, H. K., Jacob, A. L., & Hebblewhite, M. (2020). The long road to protecting critical habitat for species at risk: The case of southern mountain woodland caribou. *Conservation Science and Practice*, *2*(7). https://doi.org/10.1111/csp2.166

See also:

Dawe, C. (2019, March 14). B.C. approves 314 cut blocks in caribou critical habitat while negotiating conservation plans. *Wilderness Committee*. Retrieved here with map1 and map 2.

6.1.4 Conservation constrained: Protecting British Columbia's endangered caribou in a political-economy of extraction

This dissertation explores how woodland caribou herds are facing extirpation due to extraction-driven habitat destruction, primarily from oil and gas development and forest harvest. DiSilvestro argues that caribou declines are continuing despite existing legal protections (under the Species At Risk Act) because the province's economic reliance on resource extraction shapes available conservation solutions. This paper quantifies the extent to which the province subsidizes oil and gas activities in federally-designated critical caribou habitat. Active oil and gas wells are present in the critical habitat of endangered woodland caribou across B.C.. Half (54%) of these wells are run by companies receiving publicly-funded royalty credits. There are 3,114 active oil and gas wells within critical caribou habitat in B.C.. Of these, 1,678 wells are run by companies that have received publicly funded royalty assistance (subsidies) in the past three years. Public funds are being used to subsidize the extinction of caribou. This is a direct contradiction to federal and provincial commitments to protect caribou and critical habitat. DiSilvestro examines the province's dominant conservation solution to caribou endangerment—wolf culling—and unpacks its relationship to B.C.'s extractive regime. This work demonstrates that the apparent economic imperative of resource extraction in British Columbia both undercuts the potential for comprehensive solutions to caribou declines, such as habitat protection, and constrains the realm of possible interventions to those that do not inhibit further extraction.

DiSilvestro, A. M. (2022). *Conservation constrained: Protecting British Columbia's endangered caribou in a political-economy of extraction (T)*. University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0417553

6.1.5 Extirpation despite regulation? Environmental assessment and caribou

Despite federal and provincial legislation to protect caribou, both the federal and provincial governments permit industrial developments in caribou habitat. In this paper, Collard et al. examined 65 Canadian environmental assessments (EAs) with potential adverse impacts to caribou, 64 of which were approved. Findings from this review determined that project approvals were granted based on three main justifications. First, assured mitigation of adverse effects, even if proposed mitigation strategies were unsubstantiated by evidence. Second, mitigation was insufficient but benefits (i.e., jobs, tax, revenue and economic) would outweigh impacts. Third, claims that an area was already degraded and devoid of caribou. Finally, governments satisfied their constitutional duty to consult Indigenous Nations without securing their support and often ignoring Indigenous knowledge and testimony (e.g. testimony recognizing caribou presence). Considering these findings, Collard et al. (2020) contend that the EA process is failing caribou (Figure 2) because governments grant approval to major projects by falsely claiming that they will cause insignificant harm to caribou. Conservation biology should recognize this tension between economic growth and environmental protection.

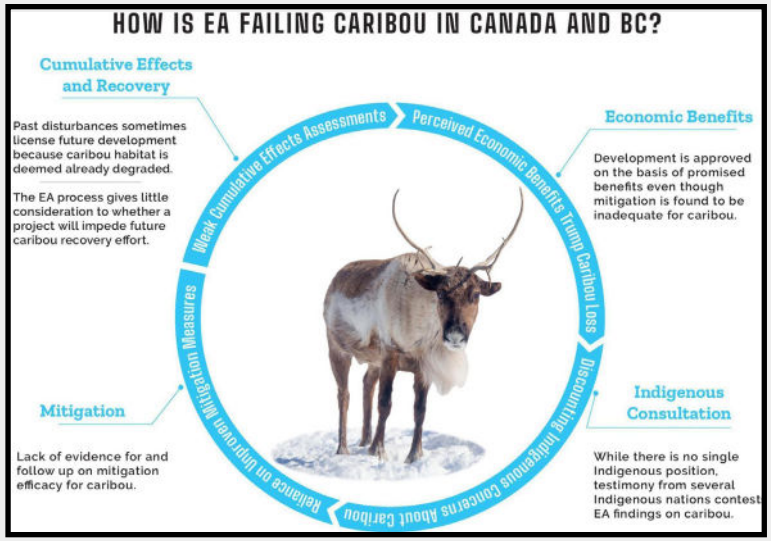

***Figure 2**. The ways in which environmental assessment fails to protect caribou. Adopted from Collard et al. (2020) (figure by Hugo Tello).*

Collard, R-C, Dempsey, J, & Holmberg, M. (2020). Extirpation despite regulation? Environmental assessment and caribou. *Conservation Science and Practice*, *2*(4); e166. https://doi.org/10.1111/csp2.166

See also:

Collard, R. C., & Dempsey, J. (2022). Future eco-perfect: Temporal fixes of liberal environmentalism. *Antipode*, *54*(5), 1545–1565. https://doi.org/10.1111/anti.12849

See also:

Collard, R., Dempsey, J., Muir, B., Allan, R., Herd, A., & Bode, P. (2023). Years late and millions short: A predictive audit of economic impacts for coal mines in British Columbia, Canada. *Environmental Impact Assessment Review*, 100, 107074. https://doi.org/10.1016/j.eiar.2023.107074

See also:

Hebblewhite, M. (2017). Billion dollar boreal woodland caribou and the biodiversity impacts of the global oil and gas industry. *Biological Conservation*, *206*(Complete), 102–111. https://doi.org/10.1016/j.biocon.2016.12.014

6.1.6 Science to inform policy: Linking population dynamics to habitat for a threatened species in Canada

Johnson et al.question the robustness of the science that informs the definition of critical habitat for the boreal caribou recovery strategy. The 2012 federal recovery strategy defines critical habitat based on a threshold of 65% undisturbed habitat that is intended to achieve the recovery goal (0.60 probability) of maintaining self-sustaining boreal caribou populations. To investigate this further, this research used modelling scenarios to compare two contrasting caribou landscapes: high anthropogenic vs. high fire disturbances. The caribou population subjected to high fire disturbance was self-sustaining under the current scenario, however under the scenario with small increases in anthropogenic disturbance (8–9%) on top of the fire-dominated landscape, the caribou population could fail in meeting the recovery goal (0.60 probability of self-sustaining herds). Therefore, the 65% threshold defining critical habitat cannot be extrapolated to all populations, as some populations are more vulnerable due to cumulative effects of pressures such as fire. Maintaining a threshold of 65% undisturbed habitat was

identified as a minimum acceptable level necessary to support recovery. However, the effectiveness of this threshold becomes diminished with considerations of climate change. Achieving higher than the minimum requirement is essential to improving caribou resilience to climate change.

Johnson, C. A., Sutherland, G. D., Neave, E., Leblond, M., Kirby, P., Superbie, C., & McLoughlin, P. D. (2020). Science to inform policy: Linking population dynamics to habitat for a threatened species in Canada. *Journal of Applied Ecology*, *57*(7), 1314–1327. https://doi.org/10.1111/1365-2664.13637

Also see: https://register.gotowebinar.com/recording/1588131705501771791

See also:

Kunegel-Lion, M., Neilson, E. W., Mansuy, N., & Goodsman, D. W. (2022). Habitat quality does not predict animal population abundance on frequently disturbed landscapes. *Ecological Modelling*, *469*(Complete). https://doi.org/10.1016/j.ecolmodel.2022.109943

See also:

Superbie, C., Stewart, K. M., Regan, C. E., Johnstone, J. F., & McLoughlin, P. D. (2022). Northern boreal caribou conservation should focus on anthropogenic disturbance, not disturbance-mediated apparent competition. *Biological Conservation*, *265*(Complete). https://doi.org/10.1016/j.biocon.2021.109426

See also:

Lisso, L., Pentney, E., & Rodrigues, S. (2020). *GIS modeling of suitable habitat for southern mountain caribou compared to priority places of conservation in British Columbia under climate prediction models.* https://geg.uoguelph.ca/sites/default/files/G9_AODA_W20.pdf

6.1.7 Southern mountain caribou critical habitat: A review of maps and data to support recovery plans

Harding identified important gaps in the 2014 recovery strategy for southern mountain woodland caribou. Specifically, the recovery strategy did not include detailed maps of critical habitat, which are mandatory to satisfy the Species at Risk Act. Harding provides the available data and mapping pertaining to critical habitat for southern mountain caribou in an effort to inform federal scientists of the missing information. The discussion section of Harding's report offers a clear summary of data insufficiencies, which have resulted in below minimal critical habitat for caribou populations. Main points include: (1) uncollared caribou or those that winter in forest where they are difficult to see in aerial surveys were likely under-sampled, thus impacting delineation of herd boundaries; (2) early winter/low elevation habitat locations were excluded as "core habitat"; (3) high suitability habitat occurs outside of mapped boundaries; (4) harmful activities (e.g., snowmobiling and timber harvest) were permitted within core critical habitats; (5) management of matrix habitat (forest surrounding caribou habitat) must be a management goal; (6) matrix habitat to provide a buffer from wolves and other activities as well as caribou corridors may need to be extended and extent required to reduce predation has not been studied or mapped; (7) herd boundaries are limited to recent distributions and exclude historical areas; (8) caribou population targets are unclear, relevant to the importance of connectivity in delineation of critical habitat due to herd isolation, low genetic diversity, and potential in-breeding depression; (9) mineral licks and associated corridors should be considered critical habitat. Recommendations are provided for the northern, central and southern groups.

Harding, L. E. (2014). *Southern mountain caribou critical habitat: A review of maps and data to support recovery plans.* SciWrite Environmental Services Ltd. Retrieved from: https://www.researchgate.net/publication/344059206_Southern_Mountain_Caribou_critical_habitat_A_review_of_maps_and_data_to_support_recovery_plans

See also:

Environment Canada. (2014). *Recovery strategy for the woodland caribou, southern mountain population (Rangifer tarandus caribou) in Canada*. Environment Canada, Ottawa, Ontario. 78 pp.

6.1.8 Regulatory barriers to mine reclamation for caribou

Singleton-Polster's research findings indicate that the reclamation commitments made for the northeast coal block mines in British Columbia are inadequate for the protection and restoration of caribou habitat. The regulations concerning mine reclamation are vague, discretionary, and often unmonitored, which makes it challenging to hold companies accountable for the level of reclamation needed at these sites. The study demonstrated that effective mine reclamation in northeastern B.C. is hindered by structural barriers such as temporal, spatial, planning, and financial mechanisms, making

restoration almost impossible. Regulatory capture is inherent in the Health, Safety and Reclamation Code for Mines in British Columbia, causing a massive-scale evasion of reclamation obligations. As a result, the reclamation regime is insufficient for healthy living conditions for many species across B.C., perpetuating slow violence against the land and Indigenous peoples. Therefore, the author argues that no new mines should be approved in caribou habitat until shifts in policies, practices, standards, and attitudes are made to ensure respect for the land. Recommendations are provided for strengthening reclamation regulations and improving accountability.

Singleton-Polster, R. (2022). *Regulatory barriers to mine reclamation for caribou* [Master's thesis, Simon Fraser University]. Summit Research Repository. https://summit.sfu.ca/item/34881

6.1.9 Fossil fuel subsidies: Big problem for B.C.'s woodland caribou

DiSilvestro et al. draw a spatial connection between B.C.'s largest oil and gas royalty credit programs and federally designated critical woodland caribou habitat.[2] Caribou declines are primarily caused by habitat destruction from extractive industries. These industries fragment caribou habitat with access roads and seismic lines which facilitates the risk of incidental predation. The authors found 3,114 active oil and gas wells in federally designated critical caribou habitat, 54% of which are run by companies that received public assistance from major subsidy programs in the past three years. B.C.'s largest oil and gas subsidy, the Deep-Well Royalty Program, is estimated to have cost the public $421 million in 2020/2021. The Infrastructure Royalty Credit Program, which encourages new capital investment in oil and gas infrastructure, can deduct up to 50% of a company's construction costs, incentivizing development beyond what would naturally occur. Despite government commitments, habitat loss continues to accelerate, threatening both caribou survival and First Nations' relations with caribou. Due to declining numbers, many First Nations (e.g. West Moberly) have stopped traditional caribou hunts, and some have sued the B.C. government (the "Province"). In Yahey v British Columbia, 2021 BCSC 1287, with plaintiff Marvin Yahey on behalf of Blueberry River First Nations ("Blueberry"), the Supreme Court found that the Province breached its obligations to Blueberry under Treaty 8. The judge held that "cumulative effects of industrial development authorized by the Province have significantly diminished the ability of Blueberry members to exercise their rights to hunt, fish and trap in their territory as part of their way of life and therefore constitute an infringement of their treaty rights" (at para 1809). The authors conclude that the Province is actively subsidizing caribou extinction through public funds.

2 Their study has been discussed in various news platforms: CBC, The Narwhal and Pique News.

DiSilvestro, A., Irvine-Broque, A., & Amron, Y. (2021). *Fossil fuel subsidies: Big problem for BC's woodland caribou*. The University of British Columbia, Department of Geography. Retrieved from: https://storymaps.arcgis.com/stories/0f0d7dd828cc4b35973e5e-188b733023?utm_source=north%2520shore%2520news&utm_campaign=north%2520shore%2520news%253A%25200utbound&utm_medium=referral&play=true&-speed=medium

6.1.10 Old growth logging in endangered caribou habitat

Brantner et al.'s analysis exposes the ongoing old-growth logging in endangered southern mountain caribou habitat in B.C. and quantifies the associated risks. The authors urgently call on the provincial government (the "Province") to halt further logging approvals, to implement immediate protection measures, and to work in true partnership with First Nations to advance caribou protection. Southern mountain caribou are at high risk of extirpation and their decline is closely intertwined with the destruction of old-growth forests. Three of the southernmost remaining mountain caribou herds, which are considered to have the best chance of recovery, are Wells Gray South, Groundhog, and Columbia North. 58% of their combined habitat is at risk of logging, with the Columbia North herd facing a 76% risk of habitat loss. Across all three herds' habitat, 5,713 hectares of forest has either been approved for logging or is pending approval, and 41% is considered disturbed. This is well above the maximum acceptable disturbance threshold of 35% set by Canada's recovery strategy. Particular logging companies are having a disproportionate impact on the destruction of old growth forests across the endangered caribou habitat of these three herds: West Fraser, Interfor, Canoe Forest Products, Stella-Jones, Integrated Fibre, and Louisiana-Pacific. Thousands of hectares of cutblocks could soon be logged, most of which are pending approval while others have been approved for logging. Hundreds of hectares overlap old-growth forests that were mapped for candidate logging deferrals as part of the Province's Old Growth Strategic Review recommendations. Brantner et al. conclude that the Province is failing to protect critically endangered southern mountain caribou by continuing to permit old-growth logging and habitat destruction. Immediate intervention is necessary to prevent their extinction.

Brantner, T., Goldberg, C., Senichenko, G., Petryshen, E., Gonzalez, L., & Hansen, T. *Old growth logging in endangered caribou habitat—forest eye*. (n.d.). Retrieved August 5, 2025, from https://stand.earth/forest-eye/2025/06/23/old-growth-logging-in-endangered-caribou-habitat/

6.1.11 Spatializing oil and gas subsidies in endangered caribou habitat: Identifying political-economic drivers of defaunation

DiSilvestro and Irvine-Broque (2023) reveal how oil and gas subsidies in British Columbia are undermining conservation efforts for endangered caribou. The authors show that over half of active oil and gas wells within critical caribou habitat are operated by companies that have received provincial royalty credits, effectively subsidizing habitat destruction. These subsidies, meant to incentivize oil and gas development, are contributing to habitat fragmentation and increased predation risk, which are key drivers of caribou decline. This subsidization occurs despite simultaneous public spending on caribou recovery and legal obligations to Indigenous Nations under Treaty 8. DiSilvestro and Irvine-Broque highlight the contradictions in B.C.'s environmental policies and argue for greater transparency and reform of harmful subsidies, emphasizing that real conservation outcomes require addressing the political-economic systems that promote industrial expansion into ecologically sensitive areas.

DiSilvestro, A. M., & Irvine-Broque, A. (2023). Spatializing oil and gas subsidies in endangered caribou habitat: Identifying political-economic drivers of defaunation. *Conservation Science and Practice*, *5*(10), e13007. https://doi.org/10.1111/csp2.13007

6.1.12 A parasite not a cannibal? How the state and capital protect accumulation amid devastation

Collard and Dempsey analyzed the relationship between capitalism and ecological degradation within British Columbia's forestry sector using Nancy Fraser's eco-Marxist theory of ecological contradiction. Rather than destroying ecosystems outright, capitalism is portrayed as parasitic—extracting value from nature while maintaining profitability, even as it undermines its own ecological foundation. Drawing on qualitative case studies, the authors track shifts in forest management, job losses, and the status of endangered species like caribou. Their review of existing literature contextualizes these findings and highlights gaps in current ecological and economic analysis. The authors found that the state plays a crucial stabilizing role, facilitating capital accumulation through subsidies and policy frameworks that prioritize industry profits over ecological sustainability, effectively shielding the forest sector from the consequences of resource depletion. Caribou population decline is framed as collateral damage in the pursuit of timber revenues, with the state prioritizing industry access to timber over species conservation. The contradiction between legislative commitments to species protection and the realities of industrial operations underscores systemic failures in reconciling ecological sustainability with economic interests.

Collard, R., & Dempsey, J. (2025). A parasite not a cannibal? How the state and capital protect accumulation amid devastation. *Antipode*, anti.70010. https://doi.org/10.1111/anti.70010

6.1.13 Canada wolf cull subsidy damages caribou habitat

Darimont and Paquet's Science letter critically examined the British Columbia provincial government's wolf cull program, focusing on its ecological, and economic shortcomings. The authors argued that wolf culling is ineffective at addressing the primary cause of caribou declines: habitat degradation. By portraying the cull as a viable long-term solution, the government diverts attention and funding away from meaningful habitat protection and restoration, while ongoing industrial activities continue to undermine caribou recovery. The authors described the program as a taxpayer-funded industrial subsidy that fails to conserve caribou or uphold ecological integrity.

Darimont, C. T., & Paquet, P. C. (2024). Canada wolf cull subsidy damages caribou habitat. *Science*, *383*(6682), 489–489. https://doi.org/10.1126/science.adn7098

6.1.14 Assessing species at risk legislation across Canadian provinces and territories

Gordon et al. conducted an extensive evaluation of species-at-risk (SAR) legislation across Canadian provinces and territories since the 2012 Ecojustice report. The authors assessed the strengths and weaknesses of existing frameworks using four criteria: species identification, protection mechanisms, habitat preservation, and recovery strategy implementation. They found significant variation across jurisdictions. While some provinces have strong legal mechanisms, others face major gaps that undermine species protection. Delays in species identification and inconsistencies in recovery plan implementation are common, and habitat protection remains uneven, particularly on private lands. In British Columbia, although progress has been made in identifying at-risk species and establishing protective legislation such as the Ecological Reserve Act and Forest and Range Practices Act, enforcement is inconsistent, recovery plans are often delayed, and habitat protections on private land remain limited. B.C. also lacks

harmonized SAR legislation and needs better integration of scientific and Indigenous knowledge. To address these issues nationally and within B.C., the study recommends seven key reforms: enacting harmonized legislation, limiting discretionary powers, integrating diverse knowledge systems, setting clear timelines for action, defining appropriate exemptions, ensuring habitat protection across all land types, and improving transparency in conservation decision-making.

Gordon, S. C. C., Duchesne, A. G., Dusevic, M. R., Galán-Acedo, C., Haddaway, L., Meister, S., Olive, A., Warren, M., Vincent, J. G., Cooke, S. J., & Bennett, J. R. (2024). Assessing species at risk legislation across Canadian provinces and territories. *FACETS*, 9, 1–18. https://doi.org/10.1139/facets-2023-0229

6.1.15 Integration of national demographic-disturbance relationships and local data can improve caribou population viability projections and inform monitoring decisions

Hughes et al. aimed to improve population viability projections for boreal caribou by integrating national demographic-disturbance relationships with local demographic data through a Bayesian population model. This approach enhances accuracy, accounts for uncertainties and biases, and supports timely conservation actions. The study assessed various local monitoring scenarios to determine their effectiveness in reducing errors in projections while identifying the need for further data collection. Hughes et al. found that caribou survival and recruitment rates significantly decreased with increasing anthropogenic disturbance, leading to unviable populations in high-disturbance areas and greater variability in demographic rates in low to moderate disturbance zones. Despite initial benefits, increased monitoring efforts yielded diminishing returns. While local data improve population viability projections under varying disturbance conditions, the utility of additional monitoring diminishes as data accumulate, especially in lower disturbance areas. In high-disturbance regions, relying on national demographic-disturbance relationships alone can yield reasonably accurate projections without needing further local monitoring. The authors identified significant variability in monitoring costs influenced by the technology used, the number of collared animals, and the landscape's operational difficulties. Hughes et al. advocates for context-specific monitoring strategies that prioritize effective conservation actions tailored to disturbance levels and population characteristics, facilitating timely interventions to protect boreal caribou.

Hughes, J., Endicott, S., Calvert, A. M., & Johnson, C. A. (2025). Integration of national demographic-disturbance relationships and local data can improve caribou population viability projections and inform monitoring decisions. *Ecological Informatics*, 87, 103095. https://doi.org/10.1016/j.ecoinf.2025.103095

7 Inadequate Scientific Evidence for Wolf Control Effectiveness

7.1 Compensatory Predation and Wolf-Prey Uncertainties

7.1.1 Cumulative effects and boreal woodland caribou: How bow-tie risk analysis addresses a critical issue in Canada's forested landscapes

Winder et al. used risk analysis tools to quantitatively evaluate cumulative effects of risks and management scenarios for boreal woodland caribou herds in northeastern British Columbia. In addition to findings pertaining to risk mitigation and risk prevention detailed in section 8.1.5, the researchers also conducted calculations of compensatory predation[3] and identified additional research gaps. Specifically, across all three herds, it was determined that a significant proportion of both adult and juvenile caribou mortality may be attributed to compensatory predation. This finding was consistent with the view of a number of other experts: that other factors may be contributing to caribou decline, hidden behind compensatory predation. The analysis by Winder et al. (2020) separated the direct effect of wolf predation and compensatory predation. High levels of compensatory predation were determined across all three herds of boreal caribou. For example, in the Chinchaga herd, compensatory predation accounted for 53.3% of adult females and 25.1% of juvenile predation events. Therefore, compensatory predation had a larger effect on adult survival than did direct wolf predation. Similarly, in the Snake-Sahtahneh herd, compensatory predation had a larger impact on juvenile survival than direct mortality by wolves. The authors point out that these very high levels of compensatory predation may be one explanation as to why the extremely high wolf reduction intensity of 80% was necessary to see any changes in caribou population trend. The compensatory predation may be attributed to other predators (bears, cougars, wolverines, immigrating meta-population wolves not targeted by the cull) or caribou health stressors and disease. Furthermore, research gaps are highlighted in terms of habitat appropriation, caribou health stressors and disease, and increasing

3 Compensatory predation, in which prey would have died even in the absence of a particular predator, due to illness, starvation, other predators, etc., versus additive predation, in which healthy prey are killed.

climate change implications, in addition to the effect of compensatory predation on mortality events. Reducing these knowledge gaps and better understanding how they relate to risk management would aid in assigning appropriate management actions. Finally, Winder et al. identify the accurateness of our understanding and sampling of caribou density and abundance as a knowledge gap due to the ever-changing monitoring methods, which may not be comparable to past methods.

Winder, R., Stewart, F. E. C., Nebel, S., McIntire, E. J. B., Dyk, A., & Omendja, K. (2020). Cumulative effects and boreal woodland caribou: How bow-tie risk analysis addresses a critical issue in Canada's forested landscapes. *Frontiers in Ecology and Evolution*, 8. https://doi.org/10.3389/fevo.2020.00001

7.1.2 The impact of wolf predation on western Canada boreal woodland caribou populations: A critical review of the evidence

Expert wildlife biologist, Dr. Gilbert Proulx, conducted a critical review of the evidence used to support wolf control in Alberta and demonstrated with supporting analytical evidence that the impact of wolf predation on boreal woodland caribou has been overstated. In the review, Proulx identifies several issues which may be paralleled with justification of wolf control programs in British Columbia. It was noted that the studies that were used to justify wolf culling programs reported that predation by wolves represented <15% of boreal caribou mortalities. Further, the studies used as the basis for wolf culling included recognition that the underlying assumptions of predator-prey models (i.e., multi-prey wolf numeric responses, wolf kill-rates of caribou, and caribou mortality by other predators) required further research. In addition, information on one ecotype was used to inform management decisions for a different one (i.e., mountain caribou differ from boreal caribou). The author reports that the wolf control program implemented in Alberta, which killed more than 800 wolves in seven years, failed to stabilize the Little Smoky boreal caribou population. Based on analysis of wolf scats and wolf tracks, Proulx (2017) concluded that woodland caribou were not an important food source for wolves, a finding supported by other noted studies. Dr. Proulx expresses concern that wolves have been wrongly assigned as the proximate cause for caribou decline. In agreement with several scientists, the paper attributes the lack of certainty in caribou declines to inherent methodological limitations and non-replicated treatments. In the Little Smokey case study, Proulx highlights that there were no studies on food habits, rates of predation and or wolf densities that informed that wolf cull. In conclusion, the author asserts that many caribou recovery programs share the same issues as the Little Smokey case, and contends that associations made between wolves and caribou trends have been qualitative, anecdotal, and prejudicial. The author cautions against wolf killing programs and appeals for the ultimate cause of caribou decline to be addressed: habitat loss and disconnection. Citing several wildlife biologist recommendations as early as 1988, Proulx recommends that a comprehensive caribou recovery program be implemented to conserve, restore, expand, and connect critical habitats across landscapes.

Proulx, G. (2017). The impact of wolf predation on western Canada boreal woodland caribou populations: a critical review of the evidence. *Canadian Wildlife Biology & Management* 6: 89–96. https://www.researchgate.net/publication/321600086_The_Impact_of_Wolf_Predation_on_Western_Canada_Boreal_Woodland_Caribou_Populations_A_Critical_Review_of_the_Evidence_Point_to_Ponder

See also:

Proulx, G., Alexander, S., Barron, H., Bekoff, M., Brook, R., Bryan, H., Darimont, C., Dubois, S., Lukasik, V., McCrory, W.P., Paquet, P., Parr, S., Powell, R., Stronen, A.V., & Wallach, A. (2017). Killing wolves and farming caribou benefit industry, not caribou: a response to Stan Boutin. *NatureAlberta*, 47 (1), 4–11. https://www.researchgate.net/publication/317592636_Killing_wolves_and_farming_caribou_benefit_industry_not_caribou_a_response_to_Stan_Boutin

7.1.3 Wolf–prey relations

This book chapter details how the wolf interacts with its prey for food, survival, and reproduction. Mech and Peterson discuss the disagreement regarding wolf effects on prey numbers. There is no scientific consensus on the significance of wolf predation in prey dynamics because ecological systems are incredibly complex and scientific interpretations differ due to the great variation in measured wolf predation rates, as well as inaccurate population data on wolf and prey densities. Wolf-prey systems are all unique and distinctively characterized by a combination of factors including: (1) prey diversity and abundance; (2) other predators; (3) human effects on predators and prey; (4) level of habitat productivity supporting prey; and (5) snow conditions. This information and the deficient scientific consensus are reiterated in the 2014 Management Plan for the Grey Wolf (*Canis lupus*) in British Columbia.

Mech, L.D. & Peterson, R.O. (2003). *Wolf–prey relations*. Pages 131–160 in L.D. Mech and L.Boitani, eds. Wolves: behavior, ecology and conservation. Univ. Chicago Press, Chicago, IL. Retrieved from: https://core.ac.uk/download/pdf/189478015.pdf

See also:

B.C. Ministry of Forests, Lands and Natural Resource Operations. (2014). *Management plan for the grey wolf (Canis lupus) in British Columbia*. B.C. Ministry of Forests, Lands and Natural Resource Operations, Victoria, BC. 48 pp. Retrieved from: https://www.env.gov.bc.ca/fw/wildlife/management-issues/docs/grey_wolf_management_plan.pdf

See also:

Prugh, L. R., Sivy, K. J., Mahoney, P. J., Ganz, T. R., Ditmer, M. A., van de Kerk, M., Gilvert, S.L., & Montgomery, R. A. (2019). Designing studies of predation risk for improved inference in carnivore-ungulate systems. *Biological Conservation*, 232, 194–207. https://doi.org/10.1016/j.biocon.2019.02.011

See also:

Theberge, J. B. (1990). Potentials for misinterpreting impacts of wolf predation through prey: Predator ratios. *Wildlife Society Bulletin* (1973-2006), *18*(2), 188–192. http://www.jstor.org/stable/3782135

See also:

Burgar, J. M., Burton, A. C., & Fisher, J. T. (2019). The importance of considering multiple interacting species for conservation of species at risk. *Conservation biology : The Journal of the Society for Conservation Biology*, *33*(3), 709–715. https://doi.org/10.1111/cobi.13233

7.1.4 Predator control may not increase ungulate populations in the future: A formal meta-analysis

Clark and Hebblewhite performed a meta-analysis to assess the effectiveness of predator removal in increasing ungulate populations by identifying ecological and experimental design factors that influence outcomes and evaluating publication bias and the experimental rigour of reviewed experiments. The meta-analysis included 52 predator removal management experiments and 10 natural experiments in which the predator population significantly decreased due to an unplanned, natural event (e.g. disease). Natural experiments almost always led to a complete removal of predators while management experiments had an average 54% reduction in predators. The target ungulates were moose, deer, elk, and caribou (in 12.9% of the experiments), and the removed predators were coyotes, mountain lions, black bears, brown bears, and grey wolves (in 37.1% of the experiments). Predator removal resulted in an average 13.1% increase in ungulate demographic responses with high uncertainty for future outcomes. Natural experiments had a stronger average increase of 41.5% compared to the average 7.8% increase of management experiments. The positive effects were stronger for young ungulates (44% increase in recruitment) than for adult survival (5.4%) and ungulate abundance (13%). Clark and Hebblewhite highlight that caribou are considered more vulnerable to predation because of their endangered status and their slower life history, with predator removal having a slightly higher average positive effect for caribou. Studies with higher experimental rigour tended to show smaller and less variable effect sizes, and studies with negative or non-significant results were less likely to be published, showing clear evidence of publication bias. The authors conclude that predator removal may lead to a slight positive increase in ungulate populations but this effect is highly uncertain for future outcomes.

Clark, T. J., & Hebblewhite, M. (2021). Predator control may not increase ungulate populations in the future: A formal meta-analysis. *Journal of Applied Ecology*, *58*(4), 812–824. https://doi.org/10.1111/1365-2664.13810

7.2 Statistics and Study Design Uncertainty

7.2.1 No statistical support for wolf control and maternal penning as conservation measures for endangered mountain caribou

Harding et al. (2020) invalidates Serrouya et al.'s 2019 paper, "Saving endangered species using adaptive management," which the B.C. government used to justify increasing the intensity of the wolf cull.

Serrouya et al. used a mathematical model to assess the effectiveness of different woodland caribou management practices, including reductions of predators such as wolves, reductions of primary prey such as moose, translocations, and maternal penning. They compared population growth between each of the different areas where intervention had occurred (treatments) and also compared each of the treatments to control areas where no management interventions had been implemented. This

comparison was based on population data across large spatial scales. They selected 18 caribou populations in British Columbia and Alberta spanning four recognized caribou ecotypes: boreal caribou, northern mountain caribou, central mountain, and southern mountain. Of the 18 caribou populations selected for the study, 12 were treatments (with interventions), and six were controls. The authors specified that they only chose six control populations to best match ecological conditions as closely as possible to the treatment populations. Serrouya et al. found that before interventions were implemented, 16 of 18 populations were in decline and that after treatments began, 6 of 12 treated populations showed stable or increasing population growth. None of the control populations had positive population growth during treatments. The authors found that the greatest population growth occurred where combinations of treatments (or multiple recovery strategies) were applied simultaneously. They also determined that the degree of ecosystem alteration (as measured by early seral forest cover) did not explain variation in changes to population growth. One of the main takeaways highlighted throughout the paper was that treatments must be applied intensively to produce a measurable effect. This means that wolf culling can't be done in low numbers: a large portion of the population must be killed (e.g., wolf cull program target 85%). Serrouya et al. found lethal wolf control and maternal caribou penning to be the most effective methods.

Harding et al. (2020) re-evaluated the same data and findings of Serrouya through a critical statistical lens by drawing on the principles of strong inference. They deemed that the work of Serrouya warranted close examination, considering the policy implications and costs of error. Their work shifts the focus toward the influence of the varying ecotypes. Throughout the paper, Harding et al. (2020) refers to the southern mountain caribou instead as "Deep-Snow" mountain caribou, as other researchers have in the past. This is because of their distinctive ecological and behavioural characteristics. Boreal, northern, and central ecotypes forage on ground-dwelling lichen that are easily accessible due to relatively shallow snow depths. In contrast, the southern mountain, or deep snow, ecotype must rely on lichen only from old growth trees due to snow depths of 3–4 metres, which they access atop the snowpack. This makes the deep snow mountain caribou distinctive. Harding et al. outline five major issues pertaining to Serrouya et al.'s study design and statistical practices.

- Serrouya et al. did not report the results of a null model, which performs equally as well as the treatments. Including a null model is standard practice in order to determine if a pattern truly exists or if it could be attributed simply to random chance/processes. So, in this case, what can we expect to see for caribou population growth without any predictors such as wolf culling. Harding ran a null model and found that there was little difference from the other models that consider management interventions or habitat alteration. The difference was so small that it was not considered statistically meaningful. This means that the wolf culling and maternal penning treatments from Serrouya explain population dynamics of caribou no better than either habitat alteration or random chance alone.
- Harding et al. went a step further to learn what could explain change in population growth. They knew that there are differences in behavior and habitat use among ecotypes, so they evaluated some additional model scenarios that considered ecotypes. They thought it is plausible that the intrinsic characteristic differences in ecotypes could explain the change in caribou population growth. Profoundly, they found that the ecotype model outperformed all others, with meaningful differences between the northern mountain and central mountain caribou as well as between the deep-snow mountain and central mountain ecotypes. This means that ecotype accounted for more variation in caribou population growth than did wolf culling or maternal penning treatments, habitat alteration, and random chance. Ecotype was the strongest indicator of caribou population growth.

- Serrouya et al.'s study design was not balanced. Wolf reduction treatments were drawn from the central mountain ecotype (n = 5) and boreal population (n = 1), whereas the six controls were drawn from deep-snow mountain (n = 3), northern mountain (n = 2) and central mountain (n = 1) ecotypes. Treatments and controls aren't distributed evenly or even represented in some ecotypes. Most of the treatments were from the central mountain ecotype. This contradicts Serrouya et al.'s claim that controls were selected based on "matching ecological conditions as closely as possible to the treatment populations" (p. 6184). Further, wolf density associated with different ecotypes or populations is another variable that cannot be accounted for since it is unknown for most areas. These study design issues make it difficult to infer causality and apply the results across ecotypes.

- More than half of the populations in the study area were omitted and not discussed. Serrouya et al. used only 18 of 42 mountain caribou populations in the study area. The 24 excluded populations included populations which had management interventions, and nine populations which became functionally extinct during the study. Population data were available for all 24 populations representing treatments and controls. Harding et al. found that strangely, several of the population trajectories of the excluded populations would contradict the

inference made in Serrouya et al.. So, for some of the excluded populations with treatments, population growth declined during or after the treatment (wolf cull, wolf sterilization, moose reduction), while areas that would be considered controls increased in population growth. These omitted populations would have allowed for a more comprehensive analysis of adaptive management approaches, but they were not even acknowledged.

- Additional adaptive management measures were neither included in analyses nor discussed. Management interventions including closures to snowmobiling and heli-skiing within large areas within the study area were not evaluated or discussed by Serrouya. Similarly, Serrouya et al. did not include the habitat protections of the 2008 provincial Mountain Caribou Recovery Implementation Plan. These may have slowed downward trajectories of some populations, thus representing potentially confounding variables.

- Habitat alteration analysis cannot be replicated. An important characteristic of good quality evidence is the ability for other scientists to be able to take the same data and reproduce the findings. In this case, Harding et al. indicated that they used the same data on forest loss, derived from Global Forest Change estimates, to estimate habitat alteration. Serrouya et al. found that the degree of habitat alteration (as measured by early seral forest cover) did not influence changes in caribou population growth. Harding et al. were unable to achieve the same habitat alteration results, deducing that an additional step was taken that was not included in their methods. Harding et al. further questioned the source of the forest loss data used. The data did not match the time period for before treatment for nine of the 18 populations and other available sources dating back to 1980s are more suitable for characterizing forest loss in the before-treatment period. Further, this type of satellite data does not fully account for roads and infrastructure, and these features can influence population growth.

Overall, the reanalysis of available data carried out by Harding et al. shows that ecotype identity is a better predictor of population trends than any adaptive management treatments considered by Serrouya et al.. The key message from Harding et al. based on their re-examination of the data is that differences among ecotypes in behavior and response to human disturbance indicate that we cannot assume that adaptive management strategies that benefit one ecotype would be beneficial to another. The success of mountain caribou recovery efforts is contingent on ecotype-specific solutions. Therefore, future research should focus on developing mitigation measures separately for each ecotype.

Harding, L. E., Bourbonnais, M., Cook, A. T., Spribille, T., Wagner, V., & Darimont, C. (2020). No statistical support for wolf control and maternal penning as conservation measures for endangered mountain caribou. *Biodiversity and Conservation*, *29*(9–10), 3051–3060. https://doi.org/10.1007/s10531-020-02008-3

See also:

Serrouya, R., Seip, D. R., Hervieux, D., McLellan, B. N., McNay, R. S., Steenweg, R., Heard, D. C., Hebblewhite, M., Gillingham, M., & Boutin, S. (2019). Saving endangered species using adaptive management. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(13), 6181–6186. https://doi.org/10.1073/pnas.1816923116

See also:

Pete, A. (Host). (2022, February 14). Lee Harding: Biologist on wolves & caribou in BC (No. 42) [Audio podcast episode]. In *Bigger Than Me*. Aaron Pete. Retrieved from:https://podcasts.apple.com/ca/podcast/42-lee-harding-biologist-on-wolves-caribou-in-bc/id1517645921?i=1000551079176

Also available from: https://www.youtube.com/watch?v=ka36Hf8EfCY&t=4051s

7.2.2 A causal modelling approach to informing woodland caribou conservation policy from observational studies

Acknowledging cause-and-effect limitations of observational studies in managing at-risk species, and weak inferences of past studies, this research explored the utility of causal modelling. Using the conservation example of woodland caribou and expanding further on Serrouya et al. (2019) and Harding et al. (2020), the authors call for a higher standard of evidence when forecasting the effects of management interventions that form the basis for policy decisions. Causal models are visual drawings showing relationships of multiple variables within a system, which are analyzed to parse out or isolate the strength of each relationship in order to understand the influence of various factors. Essentially, they are conceptual representations of the behaviour of a system and aim to improve the rigour of causal inferences. Using this approach allows researchers to be more explicit about assumptions to ensure the best available structural understanding

of a system where the gold standard of randomized controlled trials is not possible. This is particularly important to urgent issues like woodland caribou recovery where strong confidence of ecological dynamics is essential to inform conservation policy decisions. Wilson et al. make several suggestions to aid in more reliable analysis of cause and effect. In agreement with Harding et al., Wilson et al. highlight the issue of selection bias where only certain caribou populations (i.e., those declining or undergoing treatment intervention) were selected for in Serrouya et al.. Further, Wilson et al. expand on the inappropriate way in which the effect of habitat condition on caribou population trend was analyzed in relation to predator density. Specifically, predator numbers were mistakenly treated as if they acted like an outside factor, when they are part of the chain of cause-and-effect: changes to habitat affect predator density, and predator density affects caribou populations.It is therefore important to consider the steps that link habitat change to caribou decline, such as shifts in predator density, rather than removing them from analysis, since these steps reveal the actual mechanism of impact. Wilson et al. conclude with a discussion on the increasing importance of causal identification in ecology where urgent conservation decisions need to be derived from observational data. Finally, the authors point out that causal modelling has been used in a new study (Serrouya et al., 2021), however the approach has not been used for any woodland caribou recovery policy. The authors suggest that we should reconsider our current path. Forecasting management interventions by extrapolating observations is poor evidence and current models may be confounded given heterogeneous caribou range habitat and disturbance characteristics. Causal models should be an essential component of structured decision-making and conservation policy.

Wilson, S. F., Nudds, T. D., & de Vries, A. (2021). A causal modelling approach to informing woodland caribou conservation policy from observational studies. *Biological Conservation*, *264* (Complete). https://doi.org/10.1016/j.biocon.2021.109370

See also:

Serrouya, R., Dickie, M., Lamb, C., van Oort, H., Kelly, A. P., DeMars, C., McLoughlin, P. D., Larter, N. C., Hervieux, D., Ford, A. T., & Boutin, S. (2021). Trophic consequences of terrestrial eutrophication for a threatened ungulate. *Proceedings. Biological Sciences*, *288*(1943), 20202811. https://doi.org/10.1098/rspb.2020.2811

7.3 Caribou Population Assumptions and Uncertainties

7.3.1 Lines on a map: Conservation units, meta-population dynamics, and recovery of woodland caribou in Canada

This journal article describes the differing definitions of population conservation units for woodland caribou in Canada and associated challenges for recovery planning. Under the Species-at-Risk Act, caribou populations are identified broadly as Designatable Units (DUs). However, the boreal DU and the southern mountain DU were subdivided into dissimilar smaller conservation units for recovery planning (e.g., local population, subpopulation). Weckworth et al. contend that the scientific rationale for inconsistent conservation units between the two recovery strategies is unclear and lacks supportive genetic or demographic evidence. The authors argue that protecting caribou on the basis of subpopulations within DUs is inappropriate for the long-term recovery of woodland caribou. Alternatively, ensuring metapopulation dynamics, which considers genetic structure and connectivity, is crucial and highlighted as a scientifically-defensible conservation unit that is evolutionarily and ecologically relevant.

Weckworth, B. V., Hebblewhite, M., Mariani, S., & Musiani, M. (2018). Lines on a map: Conservation units, meta-population dynamics, and recovery of woodland caribou in Canada. *Ecosphere*, *9*(7). doi:https://doi.org/10.1002/ecs2.2323

7.3.2 Which caribou? Misnaming caribou population units leads to conservation errors

Harding highlights the issues that arise from contrasting definitions of British Columbian caribou populations between the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) with the federal and provincial governments. COSEWIC divides southern mountain caribou into three designatable units (DU) for conservation purposes, which are considered as separate species under the Species at Risk Act. Namely, the northern mountain (DU7), central mountain (DU8), and southern mountain (DU9) caribou populations. Contrastingly, the federal and provincial governments amalgamated southern mountain, central mountain, and nine of the 45 subpopulations of northern mountain caribou into a single artificial population. Harding notes that this can be problematic for caribou in instances like issuance of an emergency order, which is dependent on a determination of imminent threat of survival to a population. In 2018, the federal government's imminent threat analysis determined there was a risk to southern mountain caribou recovery but not survival, and thus the emergency order

was not issued. However, this decision was incorrectly based on 3,764 caribou, while there are actually only 1,240 in the southern mountain (DU9) population, effectively diluting survival risk. There were also implications for wolves. The threat analysis stated: "Wolves are the primary predator of southern mountain caribou across the range" (p. 6). While wolves are the primary predators of northern and central mountain caribou, the same is not true for southern mountain caribou. Cougars, bears, and wolverines contribute to higher mortality percentages of southern mountain caribou than wolves. Even when all wolves were culled in the South Selkirk subpopulation range, caribou declined from 11 in 2017 to zero in 2018. The author suggests that this problem can be rectified by abiding by COSEWIC population designations.

Harding, L. E. (2020). Which caribou? Misnaming caribou population units leads to conservation errors. *Journal of Ecosystems and Management*, *19*(1). Retrieved from https://subzero.lib.uoguelph.ca/login?URL=?url=https://www.proquest.com/scholarly-journals/which-caribou-misnaming-population-units-leads/docview/2450516584/se-2

See also:

Wilson, S. F. (2010). *Estimating the short-term benefit of wolf management to mountain caribou herds*. https://www.env.gov.bc.ca/wld/speciesconservation/mc/files/Estimating%20the%20short-term%20benefit%20of%20wolf%20management%20to%20mountain%20caribou%20herds.pdf

Also related:

Weaver, A. (January 16, 2015). *[Letter from MLA to Minister Thomson regarding wolf culling in the South Selkirk Mountains and in the South Peace]*. Retrieved from: http://www.andrewjweaver.ca/2015/01/19/aerial-culling-wolves-save-endangered-caribou/

7.4 Scientific Integrity of Wildlife Management Plans

7.4.1 Hallmarks of science missing from North American wildlife management

Artelle et al. defined a framework for science-based management and used it to study the status of North American natural resource management systems. Governments regularly justify wildlife conservation policy on the basis of "science-based management," which is often ambiguous and not explicitly defined. The framework identifies four fundamental hallmarks of science-based management: measurable objectives, evidence, transparency, and independent review. To facilitate assessment of the four hallmarks, they were associated with 11 indicator criteria. The presence of indicator criteria in hunt management plans were examined across 667 U.S. and Canadian management systems (62 states and provinces). Findings showed that over half of the criteria (<5 of 11) were absent from 60% of management systems. Only 10% of systems contained at least eight of 11 criteria. Supplemental material for this study was also reviewed for information specific to caribou and wolves in British Columbia. Caribou and wolf management in British Columbia met only four and six, respectively, out of the 11 criteria. Neither the caribou nor wolf management systems met the "measurable objectives" criterion, either of the two "transparency" criteria ("explain technique for setting quotas" and "respond to public inquiry"), or the two "independent review" criteria ("subject to any/internal review" and "subject to external review"). Overall, these results do not support the notion that wildlife management in North America is guided by science. This work illuminates critical issues concerning the scientific basis of hunt management in Canada and the United States. Agencies and managers can adopt this assessment framework to ensure scientific integrity upholds conservation policy decisions.

Artelle, K. A., Reynolds, J. D., Treves, A., Walsh, J. C., Paquet, P. C., & Darimont, C. T. (2018). Hallmarks of science missing from North American wildlife management. *Science Advances*, *4*(3). https://doi.org/10.1126/sciadv.aao0167

7.4.2 Predator control may not increase ungulate populations in the future: A formal meta-analysis

Clark and Hebblewhite gathered studies from the literature pertaining to predator removal and effects on ungulate populations in order to carry out a meta-analysis of predator control effectiveness. The authors quantified ungulate demographic responses (i.e., survival, recruitment, abundance, and population growth) and reviewed study designs. Most of the predator experiments included in the meta-analysis review were canids with wolves representing 37% of studies. Caribou represented 12.9% of the North American ungulate experiments. Although Clark and Hebblewhite included only two studies on predator removal for endangered woodland caribou, the discussion and conclusions of predator control provide insight on the effectiveness of predator removal programs. Overall, findings showed a slight positive effect (weak) of predator removal on ungulate populations (8% to 13%). Comparatively, effects of predator removal on endangered woodland caribou were found to be only slightly higher (14%). The authors

note that only two studies on predator removal as a recovery action for endangered woodland caribou were available, limiting their ability to directly test effects on this species.

Clark and Hebblewhite included deliberations on compensatory predation/mortality, noting the small positive increase in ungulate populations despite very high percentages of predators removed. This suggests multiple factors are likely responsible for this disparity, including predation as compensation for late-born, low weight calves that would have otherwise starved. Compensatory mortality may occur when wolves are removed, as bears, cougars, and other predators predate caribou that would have otherwise been killed by wolves. An obvious compensatory factor is habitat productivity (bottom-up pressure), which the authors of this study noted few of the experiments attempt to quantify. Clark and Hebblewhite also discuss the difficulty of effectively removing high numbers of predators due to compensatory immigration of predators from neighbouring populations.

The authors report shortfalls in experimental rigour and design, as well as publication bias (under-reporting negative effects of predator removal experiments). They make recommendations for better scientific rigour in experimental design, including appropriate evaluation of predator control practices in accordance with the National Research Council's 2007 recommendations (sociological, economic and ecological considerations). Clark and Hebblewhite also call for the establishment of a decision-making framework to determine if predator removal will be ecologically, economically, and ethically sustainable.

Clark, T. J., & Hebblewhite, M. (2021). Predator control may not increase ungulate populations in the future: A formal meta-analysis. *Journal of Applied Ecology*, *58*(4), 812–824. https://doi.org/10.1111/1365-2664.13810

7.4.3 Effectiveness of population-based recovery actions for threatened southern mountain caribou

Lamb et al. aimed to assess the effectiveness of population-based recovery actions in increasing the population of southern mountain caribou in B.C. and Alberta. The authors investigated five key population-based recovery actions: (1) maternal penning, (2) translocation, (3) supplemental feeding, (4) predator reduction, and (5) reduction of apparent competitor density. Lamb et al. compiled demographic data for 40 southern mountain caribou populations across 51 years (1973-2023). Using a statistical framework called an Integration Population Model (IPM), the authors assessed the impact of recovery actions on caribou population growth rates and overall abundance. Despite recovery efforts, the total southern mountain caribou population experienced a significant 51% decline between 1991 and 2023 with 37% of subpopulations becoming functionally extirpated. As of 2023, recovery actions have increased caribou abundance by 52% compared to a simulated scenario where no interventions were applied. Wolf reduction, applied on its own, consistently increased caribou population growth by 0.08, whereas all four other recovery actions had little effect. Combinations of wolf reduction with either maternal penning or supplemental feeding showed the strongest effect on the growth rate, with 0.16, and 0.14 increases, respectively, but these combinations were only applied to a small number of subpopulations. The authors argue that reducing predation pressure is the most effective, immediate, short-term action, but that the underlying issue is widespread industrial development that disturbs caribou habitat.

Lamb, C. T., Williams, S., Boutin, S., Bridger, M., Cichowski, D., Cornhill, K., DeMars, C., Dickie, M., Ernst, B., Ford, A., Gillingham, M. P., Greene, L., Heard, D. C., Hebblewhite, M., Hervieux, D., Klaczek, M., McLellan, B. N., McNay, R. S., Neufeld, L., … Serrouya, R. (2024). Effectiveness of population-based recovery actions for threatened southern mountain caribou. *Ecological Applications*, *34*(4), e2965. https://doi.org/10.1002/eap.2965

7.4.4 Kill wolves to save caribou? Sadly, it seems to work

Cornwall reports and contextualizes the findings of Lamb et al.'s 2024 study, "Effectiveness of population-based recovery actions for threatened southern mountain caribou." Cornwall discusses the controversies of British Columbia's wolf culling program: scientific disagreement and ethical concerns. Despite the Lamb et al.'s findings that wolf culling had the strongest positive effect on caribou population recovery, many critics argue that the true root cause of the caribou's decline—extensive logging of old-growth forests—remains largely unaddressed. Cornwall provided opinions of several wildlife biologists, beginning with Mollie Cameron, the former wildlife specialist of Pacific Wild, who emphasized that while wolf culling may show short-term benefits, it diverts attention from the need to halt habitat destruction. Cameron pointed out that the provincial government continues to approve logging in critical caribou habitat. Martin-Hugues St-Laurent, a caribou expert from the University of Québec, questioned whether it was ethical to kill one species to save another, particularly when human-caused habitat degradation is the underlying issue. According to wildlife biologist Robin Steenweg, many of Lamb et al.'s findings have been incorporated into Canada's federal recovery strategy for southern mountain caribou.

Cornwall, W. (2024). Kill wolves to save caribou? Sadly, it seems to work. *Science*, *384*(6694), 372–372. https://doi.org/10.1126/science.adq0314

7.4.5 Simulated impacts of black bear predation on neonatal loss in boreal caribou

Horne's thesis investigated how black bear movement, habitat use, and density influence predation on boreal caribou neonates, and whether caribou spatially separate from bears during calving to reduce predation risk. Using a simulation model informed by empirical data from bear and caribou populations, Horne tested predation rates by placing simulated neonates (≤2 weeks old) in both high-quality calving habitats and across the broader caribou range. Horne found that black bears were less likely to kill caribou neonates in high-quality calving habitats compared to those in areas with no specific habitat preference, supporting the spatial separation hypothesis and suggesting that caribou select calving sites to reduce bear encounters. The author also underscores the critical role of predator density estimates in understanding and managing predation pressures on vulnerable prey species like boreal caribou. Horne concluded that simply removing bears is likely not an effective strategy to mitigate predation on caribou neonates.

Horne, L. G. (2024). *Simulated impacts of black bear predation on neonatal loss in boreal caribou. ERA*. [Master's Thesis, University of Alberta]. https://doi.org/10.7939/r3-y9r6-wv96.

8 Countervailing Impacts and Unintended Consequences of Predator Removal

8.1 Pack Dissolution and Compensatory Reproduction

8.1.1 Impacts of breeder loss on social structure, reproduction, and population growth in a social canid

The population level consequence of removing reproductive individuals from a highly social species is poorly understood. Population growth could be reduced, or alternatively, not impacted due to compensatory mechanisms. This study evaluated effects of breeder loss on social stability, recruitment and population for grey wolves in Alaska using data from 1986 to 2012. Breeder loss occurred in 77% of pack dissolution cases. Loss of a female breeder or both breeders, and small size packs increased likelihood a pack dissolved. Although removal rates were low, findings showed that breeder mortality did not have any statistically meaningful effects on population dynamics (short- or long-term). This demonstrates that population growth of grey wolves can be resilient to breeder mortality disruption due to strong compensatory mechanisms. It should be noted that this is context dependent, and the resilience of some grey wolf populations could be suppressed where wolf reduction intensity is high and wolf dispersal is low. Nonetheless, this research illustrates the propensity of grey wolf populations to recover and rebound.

Borg, B. L., Brainerd, S. M., Meier, T. J., & Prugh, L. R. (2015). Impacts of breeder loss on social structure, reproduction and population growth in a social canid. *Journal of Animal Ecology*, *84*(1), 177–187.

8.1.2 The effects of breeder loss on wolves

Brainerd et al. investigated the impacts of breeder loss on wolf pup survival, reproduction, and territorial social groups by analyzing pooled data from the literature. In terms of territorial social groups, eliminating breeders from wolf packs is detrimental to pack social structure and stability, but this also has implications for overall wolf densities. Findings showed pack dissolution after breeder loss occurred in 38% of total cases. Comparing breeder loss cases where some breeders remained versus complete absence of breeders, only 26% dissolved of the cases where some breeders remained, while 85% dissolved of cases where breeders were absent. Dissolved wolf territories became re-established in 74% of cases, either by recolonizing or influx by neighbouring wolves. Budding and splitting tended to occur in larger packs. Similarly, it was noted that in Alaska, the contiguous USA, and Canada, wolf populations that were almost eliminated through intensive culling rebounded within two to four years, attributed to breeder replacement by immigration of wolves from surrounding territories. The authors discuss the disruption of packs in relation to population growth. When wolf packs subdivide existing territories, this can result in increasing overall wolf densities. Management recommendations point to the difficulties of selective removal of non-breeders.

Brainerd, S. M., Andrén, H., Bangs, E. E., Bradley, E. H., Fontaine, J. A., Hall, W., Iliopoulos, Y., Jimenez, M. D., Jozwiak, E. A., Liberg, O., Mack, C. M., Meier, T. J., Niemeyer, C. C., Pedersen, H. C., Sand, H., Schultz, R. N., Smith, D. W., Wabakken, P., & Wydeven, A. P. (2008). The Effects of Breeder Loss on Wolves. *The Journal of Wildlife Management*, *72*(1), 89–98. http://www.jstor.org/stable/25097506

Retrieved from: https://www.researchgate.net/publication/227823841_The_Effects_of_Breeder_Loss_on_Wolves

8.1.3 Kill rate by wolves on moose in the Yukon

This study analyzed the kill rate by wolves on moose prey, post-intensive wolf removal. Kill rates increased with decreasing pack size, and were related to neither prey density nor snow depth. Results supported earlier findings that the best predictor of wolf predation rates is wolf organization (number and size of wolf packs). When wolves were organized into many smaller packs, they showed higher kill rates, therefore removing a larger proportion of the prey population. The kill rates of some smaller packs were comparable to that observed in large-sized packs.

Hayes, R. D., Baer, A. M., Wotschikowsky, U., & Harestad, A. S. (2000). Kill rate by wolves on moose in the Yukon. *Canadian Journal of Zoology*, *78*(1), 49-59. Retrieved from: https://www.researchgate.net/publication/229193102_Kill_rates_by_wolves_on_moose_in_Yukon

See also:

Ballard, W. B., & R. O. Stephenson. 1982. Wolf control—take some and leave some. *Alces* 18:276–230. Retrieved from: https://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/research_pdfs/alces/6010.pdf

See also:

Sand, H., Vucetich, J. A., Zimmermann, B., Wabakken, P., Wikenros, C., Pedersen, H. C., Peterson, R. O., & Liberg, O. (2012). Assessing the influence of prey–predator ratio, prey age structure and packs size on wolf kill rates. *Oikos*, *121*(9), 1454–1463. https://doi.org/10.1111/j.1600-0706.2012.20082.x

See also:

Metz, M. C., Vucetich, J. A., Smith, D. W., Stahler, D. R., & Peterson, R. O. (2011). Effect of sociality and season on gray wolf (*Canis lupus*) foraging behavior: Implications for estimating summer kill rate. *PLoS ONE*, *6*(3). https://doi.org/10.1371/journal.pone.0017332

See also:

Wielgus, R. B., & Peebles, K. A. (2014). Effects of wolf mortality on livestock depredations. *PLOS One*, *9*(12). doi: 10.1371/journal.pone.0113505

8.1.4 Killing wolves and farming caribou benefit industry, not caribou: A response to Stan Boutin

In this paper, Proulx et al. discuss compensatory reproduction and condemn predator control in Alberta. They argue that the removal of reproductive wolves leads to a division of packs, which increases wolf densities due to compensatory reproduction. Smaller packs are required to hunt at a higher rate to feed more reproductively-compensated young than larger packs. Even with intensive wolf removal programs, the subsequent net abundance of wolves may not change and could plausibly increase. Dr. Proulx also points out that in one study, there was a 50% increase in trapped wolves in the area of culling, further highlighting the resilience of wolves from influx of other territories.

Proulx, G., Alexander, S., Barron, H., Bekoff, M., Brook, R., Bryan, H., Darimont, C., Dubois, S., Lukasik, V., McCrory, W.P., Paquet, P., Parr, S., Powell, R., Stronen, A.V., & Wallach, A. (2017). Killing wolves and farming caribou benefit industry, not caribou: A response to Stan Boutin. *NatureAlberta*, *47* (1), 4–11. https://www.researchgate.net/publication/317592636_Killing_wolves_and_farming_caribou_benefit_industry_not_caribou_a_response_to_Stan_Boutin

See also:

Proulx, G. (2017). The impact of wolf predation on western Canada boreal woodland caribou populations: a critical review of the evidence. *Canadian Wildlife Biology & Management* 6: 89–96. https://www.researchgate.net/publication/321600086_The_Impact_of_Wolf_Predation_on_Western_Canada_Boreal_Woodland_Caribou_Populations_A_Critical_Review_of_the_Evidence_Point_to_Ponder

8.1.5 Demographic responses of nearly extirpated endangered mountain caribou to recovery actions in central British Columbia.

Focusing on the Klinse-Za and Quintette caribou subpopulations, part of the endangered central group of southern mountain caribou in British Columbia, McNay et al. test the effectiveness of short-term recovery actions (maternal penning and predator

reduction). Both recovery actions were applied to the Klinse-Za subpopulation, while only predator reduction was applied within Quintette. Based on models derived from data between 1995–2021 for both populations, caribou numbers had been declining rapidly in earlier years. Results showed that wolf reductions allowed the Quintette caribou to increase, but for Klinse-Za wolf reductions alone would have only stabilized the population; the combination with maternity penning allowed them to grow. The researchers state this is the first example demonstrating success of short-term recovery actions: "To date there has been no instances of positive and persisting caribou demographic responses to management actions on such a disturbed landscape as seen here. The norm has been little to no effective and coordinated intervention and eventual subpopulation extirpation" (p. 18). For Klinse-Za, the study found that the increased wolf reduction intensity between 2016 and 2020 did not translate to an increase in caribou population growth rate, despite the program's intent of highly intensive aerial wolf reduction as critical to meeting goals. McNay et al. attribute this stagnation to other predators in the area, but also indicate evidence of splintered and remaining wolf packs. Specifically, they observed that splintered packs of approximately less than 10 animals remained per year, which were still exerting a significant impact on the Klinse-Za caribou population. McNay et al. underscore the logistic and ecological complexities in the recovery of caribou. The results suggest that short-term recovery actions can be effective while long-term commitments to habitat protection and restoration are made. The authors attribute this unique success to commitment from local First Nations (see section 4.1.3) after extirpation of neighbouring Burnt Pine caribou. The associated Partnership Agreement between local First Nations and the Provincial and Federal governments to protect ~8000 km2 of the central group caribou habitat offer hope for these caribou populations.

McNay, R. S., Lamb, C. T., Giguere, L., Williams, S. H., Martin, H., Sutherland, G. D., & Hebblewhite, M. (2022). Demographic responses of nearly extirpated endangered mountain caribou to recovery actions in central British Columbia. *Ecological Applications*, 32(5). https://doi.org/10.1002/eap.2580

See also:

Spencer B.J. (2022). *Bickford Caribou Maternity Pen Construction: Annual Report.* Wildlife Infometrics Inc. Report No. 789. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada. https://wildlifeinfometrics.com/wp-content/uploads/2022/10/Spencer_2022_WII_Report789_BickfordPenConstruction.pdf

8.1.6 Grey wolves (*Canis lupus*) shift selection of anthropogenic landscape features following predator control in the Nearctic boreal forest

Baillie-David et al. investigated the effects of wolf culling on the relative abundance, spatial distribution, and behaviour of wolves in a northwestern boreal forest landscape to understand the implications for the conservation of the threatened woodland caribou. The authors tracked independent wolf detections over three years to quantify changes in abundance and distribution before and after the cull. Associations with anthropogenic landscape features were examined to infer behavioural changes linked to hunting efficiency and mortality risks. Following cull activity, independent wolf detections decreased significantly to 24% of pre-cull numbers; however, wolves maintained approximately 75% of their spatial distribution, shifting from detection at 92% of sites pre-cull to 67% post-cull. Pre-cull, wolves were positively associated with linear features like roads for hunting efficiency, but post-cull, they avoided these areas due to increased mortality risk, developing a negative association with roads, seismic lines, and pipelines. Instead, they showed a stronger association with anthropogenic block features—such as cutblocks and well sites—indicating a behavioural adaptation to exploit habitats that provide access to alternative prey. The changing behaviours and distributions of wolves could influence their recovery post-culling and may have broader implications for the entire mammal community within the modified boreal landscape.

Baillie-David, K., Volpe, J. P., Burton, A. C., & Fisher, J. T. (2024). Grey wolves (*Canis lupus*) shift selection of anthropogenic landscape features following predator control in the Nearctic boreal forest. *Biological Conservation*, 296, 110677. https://doi.org/10.1016/j.biocon.2024.110677

8.2 Trophic Cascades

8.2.1 Predator control alters wolf interactions with prey and competitor species over the diel cycle

Frey et al. investigate the impacts of predator control (numerical and behavioural suppression) on wolves (target species) as well as prey and competitors (non-target species). Camera-trap data from before and after intensive wolf control in Alberta's boreal forest was used to assess altered patterns of activity in wolves in relation to competitors and prey. Wolves shifted their activity to nighttime in response to culling, which decreased interaction with their usual daytime prey and competitors. Frey et al. observed

unintended consequences of the wolf cull: bears, which also prey on caribou, were released from daytime overlap and competition with wolves. The resulting bear predation rates on caribou warrants more research. Additionally, reduced overlap of wolves with white-tailed deer populations would be expected to reduce predation pressure on the invasive deer. This should be investigated as abundant deer may provide ample prey for recovering wolf populations. Predator control programs have been criticized because most programs have not monitored their impacts. This study highlights the importance of understanding the indirect effects of predator control on species interactions and broader ecological community structure.

Frey, S., Tejero, D., Baillie-David, K., Burton, A. C., & Fisher, J. T. (2022). Predator control alters wolf interactions with prey and competitor species over the diel cycle. *Oikos*, 2022(8), e08821. https://onlinelibrary.wiley.com/doi/abs/10.1111/oik.088

8.2.2 Human activity mediates a trophic cascade caused by wolves

Experimental evidence in Banff National Park, Alberta, provides an example to support the wolf trophic cascade hypothesis. Researchers investigated the predation effects on elk, aspen, willow, beaver, and riparian songbirds in a low-wolf area where wolves were excluded by human activity compared to a recolonizing high-wolf area of Bow Valley. Wolf exclusion had substantial effects on elk demography, vegetation, and animal communities. In the area of predator exclusion, elk survival, recruitment, and population density were significantly greater, which in turn reduced aspen recruitment and willow production. Beaver lodge density decreased, and increased elk herbivory diminished riparian songbird community structure and abundance. Depressing habitat use by wolves demonstrated alternating patterns of cascading effects, supporting the wolf trophic cascade hypothesis. Thus, removing wolves from the landscape may have serious implications for ecosystem dynamics.

Hebblewhite, M., White, C.A., Nietvelt, C.G., McKenzie, J.A., Hurd, T.E., Fryxell, J.M., Bayley, S.E. & Paquet, P.C. (2005). Human activity mediates a trophic cascade caused by wolves. *Ecology*, 86: 2135–2144. https://doi.org/10.1890/04-1269

Also available from: https://www.researchgate.net/publication/228636301_Human_activity_mediates_a_trophic_cascade_caused_by_wolves

8.2.3 Saving large carnivores, but losing the apex predator?

Researchers argue that the persecution of large carnivores alters their behaviour and ecosystems, thereby contradicting conservation goals. Using scientific information about carnivore behaviour, ecology, trophic interactions, and the effects of human exploitation and control, the case is made that hunted carnivore species cannot fulfil their vital ecological roles at the top of food webs. Altering large terrestrial carnivore populations, such as wolves or bears, reverberate throughout ecological communities. Changes in distribution and population decline, even with sustained numbers, have caused transformations to community assemblages and loss of biodiversity. Figure 3 illustrates evidence to support ecological effects of large carnivores, without and with human intervention. Both direct (density-mediated) and indirect (trait-mediated)

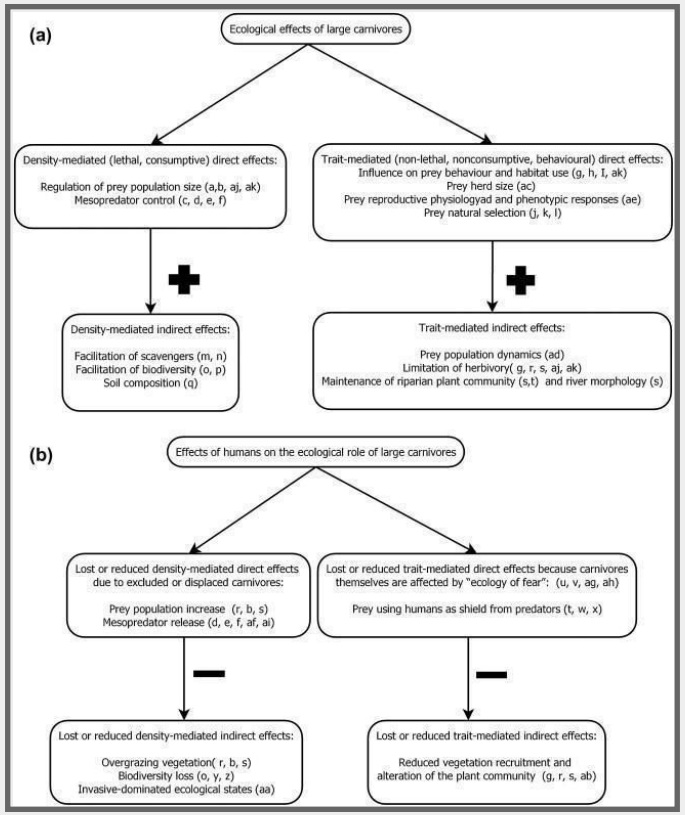

***Figure 3**. a) Pathways of large carnivores' ecological effects in ecosystems. (b) Reduced ecological effects of large carnivores under human persecution. Adopted from Ordiz at al. (2013). See journal article for effects letter citations.*

predator-prey interactions drive trophic cascades. Reduced predator numbers may not be able to control primary prey species (direct). Increased vigilance of predators due to the unnatural fear of predation risk by humans alters foraging and resting behaviour (indirect). Apex predators are effectively demoted to a lower trophic level. Humans cannot replace the ecological role of large carnivores by also attempting to control primary prey species, since indirect influences on prey behaviour and habitat use cannot be controlled. Primary prey species then elicit impacts to plant communities and so on. Management impacts to predator behaviour and particularly social structures, and thereby to ecosystems, require attention. In conclusion, long-term impacts of predator removal can reduce the quality of traits defining apex predators, with consequences for their ecological functionality, genetics, and evolution.

Ordiz, A., Bischof, R., & Swenson, J. E. (2013). Saving large carnivores, but losing the apex predator? *Biological Conservation*, 168, 128–133. doi:10.1016/j.biocon.2013.09.024

See also:

Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M. P., Schmitz, O. J., Smith, D. W., Wallach, A. D., & Wirsing, A. J. (2014). Status and ecological effects of the world's largest carnivores. *Science*, 343(6167), 1241484. https://www.science.org/doi/abs/10.1126/science.1241484

See also:

Ripple, W.J. & Beschta, R.L. (2012). Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction. *Biological*. *Conservation*. 145: 205–213.

See also:

Ripple, W. J., Beschta, R. L., Fortin, J. K., & Robbins, C. T. (2014). Trophic cascades from wolves to grizzly bears in Yellowstone. *The Journal of Animal Ecology*, *83*(1), 223–233. https://doi.org/10.1111/1365-2656.12123

See also:

Ripple, W.J., Painter, L.E., Beschta, R.L, & Gates, C.C. (2010). Wolves, elk, bison, and secondary trophic cascades in Yellowstone National Park. *Open Ecology Journal*. 3:31–37.

See also:

Berger, J., P.B. Stacey, P.B., Bellis, L., & Johnson, M. P. (2001). A mammalian predator-prey imbalance: Grizzly bear and wolf extinction affect avian neotropical migrants. *Ecological*. *Applications*. 11:947–960.

See also:

Painter, L. E., Beschta, R. L., Larsen, E. J., & Ripple, W. J. (2018). Aspen recruitment in the Yellowstone region linked to reduced herbivory after large carnivore restoration. *Ecosphere*, *9*(8), e02376. https://doi.org/10.1002/ecs2.2376

8.2.4 Recovering riparian plant communities with wolves in Northern Yellowstone, USA

Beschta et al. investigated the trophic cascade triggered by the reintroduction of grey wolves in northern Yellowstone. Authors assessed ungulate populations, recruitment levels, and the growth of riparian plant communities—vegetation found along the banks of rivers and streams—to determine whether the presence of wolves influenced plant recovery. Northern Yellowstone experienced wolf extirpation in the 1920s, leading to ungulate overbrowsing on riparian plants for seven decades. Following wolf reintroduction in 1995 and 1996, wolf numbers increased significantly. For ungulates, elk populations decreased, while Bison populations increased, altering browsing dynamics. Cottonwood trees, which had been absent for decades, began recruiting again. Plant recovery was patchy, with willows and cottonwoods showing significant height increases primarily in areas of high predation risk, while low-risk areas remained suppressed, indicating ongoing browsing by ungulates. The spatially variable plant height increases support the re-establishment of a tri-level trophic cascade driven by both behavioural and density changes in ungulates. The re-emergence of beaver colonies further indicates ecosystem restoration linked to wolves. The authors demonstrate that wolves, an apex predator, are critical in structuring terrestrial ecosystems, and suggest that policymakers consider the ecological benefits of large predators in restoring degraded ecosystems.

Beschta, R. L., & Ripple, W. J. (2008). Recovering riparian plant communities with wolves in Northern Yellowstone, U.S.A. *Restoration Ecology*, *18*(3), 380–389. https://doi.org/10.1111/j.1526-100X.2008.00450.x

8.2.5 Caribou and reindeer population cycles are driven by top-down and bottom-up mechanisms across space and time

Clark-Wolf et al. investigated how top-down mechanisms (e.g. predation), and bottom-up mechanisms (e.g. food availability) interact to influence the amplitude and period of population cycles in *Rangifer* populations. The researchers conducted a biogeographic analysis combining statistical evaluations of *Rangifer* populations with tri-trophic mechanistic models. Findings suggest that both top-down and bottom-up factors significantly impact *Rangifer* population stability across different timescales. Statistical analysis provided evidence for long-term population cycles in 19 of the 43 studied *Rangifer* herds, with an average cycle period of approximately 42 years and an amplitude of 0.91. Decreased food productivity and winter temperatures were linked to increased cycle period length and amplitude. The tri-trophic mechanistic model outcomes largely corroborated the empirical data findings, suggesting that both increased predation and reduced food availability can lead to intensified population cycling. This result reinforced the idea that the ecological mechanisms driving cycles in large mammals like *Rangifer* are consistent with those seen in smaller mammals. Anthropogenic impacts, such as climate change and habitat alteration, may exacerbate these cycles. The authors recommend that future research focus on linking climatic variables and enhancing long-term monitoring in order to refine management strategies.

Clark-Wolf, T. J., St. John, J., Rajesh, C. A., & Hebblewhite, M. (2025). Caribou and reindeer population cycles are driven by top-down and bottom-up mechanisms across space and time. *Ecology and Evolution*, *15*(5), e71348. https://doi.org/10.1002/ece3.71348

8.2.6 Restoring historical moose densities results in fewer wolves killed for woodland caribou conservation

McLellan et al. investigated how lethal removals of wolves influence moose populations, and in turn, how these dynamics affect the sustainability of woodland caribou populations. The authors examined a unique management scenario in B.C. and Alberta, where lethal wolf removals were carried out annually across specific southern mountain caribou ranges, and in some areas, moose populations were also reduced through liberalized hunting. Using moose abundance indices and wolf removal data, the authors tested whether lowering moose populations to historical targets would result in fewer wolves needing to be killed for caribou conservation. McLellan et al. found that wolf removals per km² were 3.2 times lower in areas with restored (reduced) moose density compared to those without. High-quality moose habitat was positively correlated with higher wolf abundance, indicating stronger ecological productivity supports both moose and wolves. Wolf removal efforts in adjacent areas were positively correlated with the number of wolves removed, suggesting spillover benefits from neighbouring management. Wolves also showed rapid population recovery, often rebounding within 5-6 years, highlighting the need for sustained intervention. The authors concluded that without effective moose management, continued or increased wolf removals will be necessary to prevent caribou extirpation. McLellan et al. advocated for an integrated approach that considers habitat protection, primary prey regulation, and predator dynamics to support long-term caribou conservation.

McLellan, M. L., Ford, A. T., Hervieux, D., Lamb, C. T., Hessami, M., Bridger, M. C., & Serrouya, R. (2025). Restoring historical moose densities results in fewer wolves killed for woodland caribou conservation. *The Journal of Wildlife Management*, 89(1), e22673.

8.2.7 Living in fear: How experience shapes caribou responses to predation risk

Derguy et al. investigated how boreal caribou manage their behaviour and habitat use in response to their primary predators: wolves and black bears. Utilizing telemetry data collected from 28 caribou, 31 wolves, and 12 bears, the authors analyzed whether caribou adjusted their levels of predator avoidance with increasing experience. Derguy et al. found that older female caribou demonstrated a stronger avoidance of risky areas compared to younger females, supporting the hypothesis that experience impacts risk avoidance. As caribou aged, there was a general increase in avoidance of areas with high risks of encountering both wolves and bears. Throughout their adult lives, caribou consistently avoided high-risk areas related to wolves during winter without significant behavioural changes over time. In contrast, the interaction between bear risk and monitoring years exhibited a statistically significant negative trend across all risk periods, indicating that caribou increasingly avoided high-risk areas concerning bears over the years. These findings illustrate the adaptive nature of caribou responses to predation risk and highlight the critical role of experience in shaping their antipredator strategies. Such behavioural adaptations are essential for enhancing their survival, especially during vulnerable periods like calving.

Derguy, L., Leblond, M., & St-Laurent, M. (2025). Living in fear: How experience shapes caribou responses to predation risk. *Ecosphere*, *16*(1), e70155. https://doi.org/10.1002/ecs2.70155

8.2.8 Density-dependent responses of moose to hunting and landscape change

Hessami et al. investigated the impact of resource extraction on moose populations and its subsequent effects on wolf predation and caribou decline in the Revelstoke Valley, British Columbia. The study aimed to evaluate the effectiveness of expanding moose hunting quotas as a strategy to reduce wolf predation on caribou while considering habitat conditions and human influences on moose dynamics. The authors used GPS tracking to monitor 39 adult female moose, analyzed historical harvest data, and mapped forest cutblocks by age to assess habitat preferences. Hessami et al. employed statistical models to examine the relationships among moose dynamics, habitat conditions, and wolf predation on caribou. While expanded hunting quotas initially reduced moose populations, declines continued due to hunting mortality and habitat loss linked to reduced forestry activity. Controlling moose populations moderated wolf densities, resulting in lower predation on caribou. The results also showed a persistent decline in caribou in areas of resource extraction, highlighting the importance of understanding predator-prey dynamics for effective wildlife management. Habitat changes negatively impacted moose populations, underscoring the need for habitat management strategies. Hessami et al. concluded that increasing antlerless moose hunting quotas can effectively reduce wolf densities and alleviate predation pressure on caribou without the need for targeted predator removals. While these expanded quotas provide more hunting opportunities for licensed hunters, they have raised concerns among Indigenous hunters, who oppose such measures due to cultural practices that prohibit hunting adult females or calves. The push for higher moose harvest quotas may conflict with treaty rights, as highlighted in the landmark case Yahey v. British Columbia, which linked the depletion of moose populations to violations of Indigenous land rights. These circumstances underscore the need for inclusive policymaking that acknowledges Indigenous perspectives and fosters collaboration for sustainable wildlife management and food security.

Hessami, M., Serrouya, R., Lamb, C. T., Dickie, M., & Ford, A. T. (2025). Density-dependent responses of moose to hunting and landscape change. *Ecological Solutions and Evidence*, 6(1), e70002. https://doi.org/10.1002/2688-8319.70002

8.3 Mesopredator Release

8.3.1 The rise of the mesopredator

This paper provides an overview of mesopredator release due to decline in apex predators, which can occur from human persecution, in a global context. The mesopredator release hypothesis suggests that when apex predators are removed or their population declines, mesopredators will increase in abundance. Mesopredators are defined as predators and omnivores that occupy a middle position in the food web rather than being defined by size or taxonomy. Examples include coyotes, lynx, feral cats, red foxes, raccoons, and mongooses. Their role can shift depending on the ecosystem: coyotes, for instance, function as mesopredators in Yellowstone where wolves persist, but act as apex predators in areas where larger carnivores have been extirpated. Associated prey populations decline due to the increase in mesopredators, which can have devastating impacts on community assemblage stability and lead to extinctions. The researchers show that in North America, 60% of mesopredator ranges have expanded, whereas all apex predator ranges have contracted. This trophic interaction carries ecological, economic, and social costs.

Prugh, L.R., Stoner, C.J., Epps, C.W., Bean, W.T., Ripple, W.J., Laliberte, A.S., & Brashares, J. S. (2009). The rise of the mesopredator. *BioScience* 59: 779–791. https://doi.org/10.1525/bio.2009.59.9.9

8.3.2 Effects of anthropogenic disturbance and wolf population reduction on caribou predators and competitors in west-central Alberta

This Master's thesis investigated whether top-down (wolf-driven) or bottom-up (habitat-driven) factors are more influential in shaping medium and large mammal communities in disturbed areas. Seip used remote cameras in west-central Alberta to measure the "occurrence rate" of apex predators (wolves and bears), mesopredators, and ungulates. Seip also assessed anthropogenic disturbance and wolf population reduction. The author found that wolf population reduction directly reduced wolf occurrence locally, but wolves showed rapid recolonization, indicating the need for continuous removal effort. Wolf occurrence increased with forest harvest density, and linear feature density. Ungulate occurrence rate had no effect on wolf occurrence rate. The occurrence rate for most ungulates was unaffected by wolf occurrence, except for white-tailed deer, which increased. Ungulates showed a strong positive association with both linear feature density and forest harvest density, suggesting bottom-up habitat effects are dominant.

Mesopredator occurrence increased with linear feature density, forest harvest density, and unexpectedly, with wolf and bear occurrence, contradicting the mesopredator release theory, and instead supporting the facilitation hypothesis. Both black bear and grizzly bear occurrence increased with forest harvest density, likely due to increased food availability. Black bear occurrence also increased with linear density and wolf occurrence, while grizzly bears were unaffected. Overall, bottom-up factors were more influential in shaping mammal communities than top-down control by wolves. The occurrence rate of apex predators, mesopredators, and ungulates increased in high disturbance areas, which heightened caribou predation risk. The author concluded that caribou recovery efforts should focus on reducing anthropogenic disturbance through habitat protection and restoration.

Seip, C. R. (2021). *Effects of anthropogenic disturbance and wolf population reduction on caribou predators and competitors in west-central Alberta* (Doctoral dissertation, University of British Columbia).

8.4 Wolves as Disease Regulators

8.4.1 Wolves contribute to disease control in a multi-host system

Tanner et al. examine how wolf predation contributes to disease control in multi-host systems by testing whether wolf presence reduces tuberculosis (TB) prevalence in wild boar in Asturias, Spain. Field observations and mathematical modelling explored the long-term impact of wolf predation on TB control. Tanner et al. found that wolves dramatically reduced wild boar TB prevalence with a 77% reduction in areas where they were present, while wolf-absent areas showed no significant change. Cattle TB herd prevalence remained stable in wolf-present areas but increased by 56% in wolf-absent areas. Over the 14-year study period, wolf-induced TB prevalence reduction led to a significant decrease, over 50%, in the level of TB pathogens in the environment. Because wolves engage in selective predation, they preferentially target severely infected wild boar. A key long-term finding from modelling is that wild boar populations can be regulated at similar densities either by high disease prevalence (in the absence of wolves) or by predation at low disease prevalence (in the presence of wolves). Simulations showed that removing wolves, while potentially leading to a temporary increase in wild boar, results in a significant rise in TB prevalence and environmental contamination over time. In wolf-absent areas, increased wild boar densities and environmental contamination likely explain rising cattle TB. Tanner et al. conclude that wolves reduce TB prevalence in wild boar which then lowers the risk of MTC (*M. tuberculosis complex*) transmission. The authors expect their findings to have broader implications, suggesting that wolves may similarly contribute to disease control in other regions. By regulating host densities and disrupting disease transmission pathways, wolves could play a key role in managing infections in multi-host systems beyond the study area.

Tanner, E., White, A., Acevedo, P., Balseiro, A., Marcos, J., & Gortázar, C. (2019). Wolves contribute to disease control in a multi-host system. *Scientific Reports*, *9*(1), 7940. https://doi.org/10.1038/s41598-019-44148-9

8.4.2 The role of predation in disease control: a comparison of selective and non-selective removal on prion disease dynamics in deer

Wild et al. used mathematical modelling and simulations to explore the role of wolf predation in controlling Chronic Wasting Disease (CWD) in deer populations. The authors evaluated and compared the potential influence of non-selective removal (e.g. human hunting/culling) versus selective predation by wolves on CWD infection rates. CWD's subtle, debilitating effects make infected deer more vulnerable to predation. CWD significantly reduced the deer population (from 1,000 to 736) and stabilized at a high prevalence of 29% in an affected population. Simulated selective and non-selective mortality affected CWD prevalence differently. Non-selective removal, representing a 15% annual harvest or cull, lowered both the deer population size and CWD prevalence but the disease persisted in the population. Selective (4x) mortality at the same 15% predation rate led to a more modest reduction in deer population size, but caused a rapid decline in CWD prevalence and ultimately resulted in the elimination of the disease from a closed population. The authors explain that predators likely remove infected deer earlier in the disease course, before they can shed large amounts of prions—the infectious proteins that cause CWD—and spread the disease to other deer of the same species. Wolf predation could therefore serve as a valuable natural mechanism to suppress CWD in cervids, the deer family that includes mule deer, white-tailed deer, elk, and moose.

Wild, M. A., Hobbs, N. T., Graham, M. S., & Miller, M. W. (2011). The role of predation in disease control: a comparison of selective and nonselective removal on prion disease dynamics in deer. *Journal of Wildlife Diseases*, *47*(1), 78–93.

8.4.3 The role of wolves in regulating a chronic non-communicable disease, osteoarthritis, in prey populations

Hoy et al. investigated the impact of wolf predation on moose populations in Isle Royale National Park by examining moose selection based on age and the presence of osteoarthritis. The authors aimed to assess how wolves preferentially prey on older and diseased moose and evaluate the relationship between variations in wolf kill rates and osteoarthritis incidence over a 33-year period. Using statistical models, the researchers analyzed trends in predation rates and moose health status. They found that wolves tended to avoid prime-aged moose, and showed a strong preference for senescent moose, individuals older than nine years old and past prime age of reproduction and physical condition. Prime-aged moose with severe osteoarthritis were more vulnerable to predation than those without the disease or with milder forms. Higher wolf kill rates correlated with a decline in osteoarthritis incidence, suggesting that selective predation may reduce this condition over time. The study also provided weak evidence that senescent moose with osteoarthritis were more susceptible to wolves. Furthermore, a negative correlation was observed between the incidence of osteoarthritis in dead moose and wolf kill rates, particularly when considering a lag of two to three years. Overall, the findings indicate that selective predation by wolves serves as a compensatory mechanism for moose mortality, in contrast to hunting practices that often fail to recognize and target unhealthy individuals. This underscores the critical role of wolves in shaping moose population health and highlights the ecological significance of predator-prey interactions in managing disease. Hoy et al. advocate for conservation policies that support the conservation of wolf populations as a means to enhance ungulate health management.

Hoy, S. R., Vucetich, J. A., & Peterson, R. O. (2022). The role of wolves in regulating a chronic non-communicable disease, osteoarthritis, in prey populations. *Frontiers in Ecology and Evolution*, 10. https://doi.org/10.3389/fevo.2022.819137

8.5 Genetic Impacts of Culling

8.5.1 Structural genomic variation in the inbred Scandinavian wolf population contributes to the realized genetic load but is positively affected by immigration

Smeds et al. investigated how structural genomic variation (SVs) contributes to the inbred Scandinavian wolf population's genetic load, which quantifies the fitness burden of deleterious alleles—different versions of the same gene or DNA sequence, some of which can be harmful. The authors investigated whether immigration provides a genetic rescue effect by mitigating this genetic load to determine if SVs behave similarly to other types of mutations, such as single nucleotide polymorphisms (SNPs), which are single-letter changes in DNA and the most common form of genetic variation. SVs were abundant and deleterious with over 23,000 SVs in wolves and a significant number of SVs overlapping with protein-coding genes. SVs found within these gene-coding regions were overwhelmingly rare, which is a strong sign that they are harmful and are being removed by natural selection. As hypothesized, inbreeding worsened the genetic load as shown by the amount of expressed harmful SVs, significantly increasing as wolves became more inbred. New immigrant wolves effectively reversed this trend, reducing the buildup of harmful SVs and reintroducing healthy ancestral DNA. These findings mirrored what was already known for smaller DNA changes (SNPs), confirming that both contribute to inbreeding problems and benefit from genetic rescue. While SVs are less frequent than SNPs, they can affect larger genomic regions and often have more severe fitness consequences.

Smeds, L., Huson, L. S. A., & Ellegren, H. (2024). Structural genomic variation in the inbred Scandinavian wolf population contributes to the realized genetic load but is positively affected by immigration. *Evolutionary Applications*, 17(2), e13652. https://doi.org/10.1111/eva.13652

9 Preferred Non-Lethal Methods (ranging long- to short-term)

9.1 Habitat Protection

9.1.1 Protecting boreal caribou habitat can help conserve biodiversity and safeguard large quantities of soil carbon in Canada

Johnson et al. ask: "can the protection of habitat for boreal caribou help Canada meet its commitments under the United Nations Convention on Biological Diversity and United Nations Framework Convention on Climate Change?" (p.1). Areas of high conservation value were identified as hotspots within the boreal caribou habitat based on biodiversity, climate refugia—areas expected to remain relatively stable under climate change and provide safe havens for species—and areas of high soil carbon. Across the boreal caribou distribution, approximately 80% encompasses at least one hotspot type. Hotspots are currently underrepresented in existing protected areas. Findings demon-

strated the potential co-benefits of caribou habitat protection to biodiversity, climate refugia and preservation of soil carbon. Expansion of protected areas in the boreal forest can help Canada achieve multiple conservation objectives.

Johnson, C. A., Drever, C. R., Kirby, P., Neave, E., & Martin, A. E. (2022). Protecting boreal caribou habitat can help conserve biodiversity and safeguard large quantities of soil carbon in Canada. *Scientific Reports*, *12*(1), 17067. https://doi.org/10.1038/s41598-022-21476-x

9.1.2 Lowering the rate of timber harvesting to mitigate impacts of climate change on boreal caribou habitat quality in eastern Canada

The role of climate change in explaining caribou decline has been researched less than that of habitat alteration. This study assessed the impact of climate change on caribou habitat in Quebec until 2100 using simulations that considered changes in stand dynamics, fire regime, and timber harvesting. The results indicated that logging will have a more significant effect until 2050, after which climate change will become more influential. To sustain the quality of caribou habitat in the coming years, reducing harvested volumes would be necessary. Findings strongly emphasize the urgent need for action to conserve an adequate amount and quality of caribou habitat capable of withstanding the future impacts of climate change in the boreal forests. It is crucial to shift caribou habitat recovery planning now, while considerable areas of continuous old forest remain intact.

St-Laurent, M. H., Boulanger, Y., Cyr, D., Manka, F., Drapeau, P., & Gauthier, S. (2022). Lowering the rate of timber harvesting to mitigate impacts of climate change on boreal caribou habitat quality in eastern Canada. *Science of The Total Environment*, 838, 156244. https://www.sciencedirect.com/science/article/pii/S0048969722033411

9.1.3 Proactive conservation of high-value habitat for woodland caribou and grizzly bears in the boreal zone of British Columbia, Canada

Suzuki and Parker explored conservation planning priority areas for two at-risk species in northeastern British Columbia in order to determine most effective conservation solutions. Specifically, they used a decision-support software to evaluate four scenarios to conserve high-value habitat for woodland caribou as well as grizzly bears. Scenarios were run that 1) maintained connectivity of high-value habitat without economic considerations (Maintain Connectivity); 2) conserved high-value habitat in areas with low resource potential (Minimize Conflict); 3) conserved high-value habitat in areas with high-resource potential (Reduce Development); and 4) designated areas where predation risk was potentially lower (Avoid Predation Risk). To determine the effectiveness of each scenario, they compared landscape metrics (i.e., functional habitat loss, habitat fragmentation, and edge effects). The Maintain Connectivity scenario preserved more high-value habitat than any other scenario and was characterized by a smaller total number of habitat patches. Previous research supports this finding as "maintaining connectivity among habitat patches across landscapes has been the cornerstone of conservation strategies for large mammal species with high mobility, such as caribou" (p. 98). Only slightly higher resource opportunity costs would be realized under the Maintain Connectivity scenario compared to the Minimize Conflict scenario. This research provides insight into making effective habitat conservation decisions in terms of how and where to allocate land.

Suzuki, N., & Parker, K. L. (2019). Proactive conservation of high-value habitat for woodland caribou and grizzly bears in the boreal zone of British Columbia, Canada. *Biological Conservation*, *230*(Complete), 91–103. https://doi.org/10.1016/j.biocon.2018.12.013

See also:

Lamb, C. T., Festa-Bianchet, M., & Boyce, M. S. (2018). Invest long term in Canada's wilderness. *Science*, *359*(6379), 1002. DOI: 10.1126/science.aat1104

9.2 Habitat Restoration

9.2.1 Where to begin? A flexible framework to prioritize caribou habitat restoration

Expert wildlife biologists Dickie et al. identified habitat restoration as the key to achieving self-sustaining populations of woodland caribou. Restoration is an immense challenge as disturbances extend across broad landscapes. This research aims to help managers prioritize efforts to restore linear features within the expansive network created by oil and gas development in the boreal forest. To aid in prioritization, Dickie et al. created an algorithm based on the premise of maximizing the gain in unaltered caribou habitat per unit cost while also considering other goals and weighting criteria. Landscape units were categorized into five priority ranks. Areas identified as the highest priority contributed to the greatest gains in habitat. However, the federal recovery target (maximum of 35% habitat alteration) could not be met without considering restoration within energy project boundaries even after all seismic lines were restored. The study advocates for ambitious and coordinated restoration efforts and improved

land-use planning to minimize caribou habitat alteration. This prioritization framework can be adapted to other caribou ranges.

Dickie, M., Bampfylde, C., Habib, T. J., Cody, M., Benesh, K., Kellner, M., McLellan, M., Boutin, S., & Serrouya, R. (2023). Where to begin? A flexible framework to prioritize caribou habitat restoration. *Restoration Ecology*, e13873. https://doi.org/10.1111/rec.13873

See also:

McLellan, M. L., Dickie, M., Boutin, S., Becker, M., Ernst, B., Peel, D., Zimmerman, K. L., & Serrouya, R. (2023) Prioritizing populations based on recovery potential. *Conservation Science and Practice*, 5(4). https://doi.org/10.1111/csp2.12905

9.2.2 Habitat restoration of legacy petroleum and natural gas features in the Klinse-Za caribou range: Applying an analytical framework for assessing implementation and effectiveness of restoration

The goal of this project is to restore caribou habitats in British Columbia to help sustain and recover at-risk populations. Habitat restoration, along with habitat protection and access management, is necessary for caribou populations to reach a self-sustaining state. The program focuses on functional restoration of linear disturbances to benefit caribou rather than their predators. The report outlines an analytical framework to assess restoration activities and applies it to three legacy petroleum and natural gas linear features in the Klinse-Za caribou range. The study suggests that restoration efforts are beginning to contribute to decreasing predator and human activity along legacy linear features, but more time is necessary to link restoration activities to functional effectiveness. The evolving analysis framework has the potential to integrate diverse data in order to assess restoration success.

Sutherland, G. D., McNay, R.S., Spencer, B.J., Brumovsky, V., & Woods, A. (2022). *Habitat restoration of legacy petroleum and natural gas features in the Klinse-Za caribou range: Applying an analytical framework for assessing implementation and effectiveness of restoration*. Wildlife Infometrics Inc. Report No. 818. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada. https://www.bcogris.ca/files/projects/Restoration/RMC-2022-04-Milestone-FINAL-Report-Dec-2_22-web-format.pdf

9.2.3 Cumulative effects and boreal woodland caribou: How bow-tie risk analysis addresses a critical issue in Canada's forested landscapes

Risk analysis tools are used to quantitatively evaluate cumulative effects of risks and management scenarios (risk mitigation and risk prevention measures) for three northern boreal woodland caribou herds. The provincially accepted level of a 60% chance of caribou herd self-sustainability is used as a threshold of risk (corresponding to a herd growth rate >1.025). Like studies supporting wolf control, the analysis of risk mitigation showed that a combination of mitigation strategies would provide the best outcome for caribou recovery. While the analysis found that predator control alone could achieve sustainable herds, it was also found that seismic restoration combined with maternal penning would achieve the 60% herd sustainability objective. Maternal penning alone was found to achieve this objective for the Snake-Sahtahneh herd. Moreover, in contrast to risk mitigation, findings showed that risk prevention is another viable option. The analysis showed that if two barriers preventing predation (efforts of caribou to avoid predators and management of early seral forest) were improved by 50%, there may be a chance for success. The authors suggest threat prevention could be combined with mitigation tools for enhanced outcomes and that more work is needed to understand the potential utility of threat prevention barriers.

Also see this journal article discussed in section 5.1.1 regarding compensatory predation.

Winder, R., Stewart, F. E. C., Nebel, S., McIntire, E. J. B., Dyk, A., & Omendja, K. (2020). Cumulative Effects and Boreal Woodland Caribou: How Bow-Tie Risk Analysis Addresses a Critical Issue in Canada's Forested Landscapes. *Frontiers in Ecology and Evolution*, 8. https://doi.org/10.3389/fevo.2020.00001

9.2.4 Multispecies modelling reveals potential for habitat restoration to re-establish boreal vertebrate community dynamics

Beirne et al. tested restoration effectiveness of seismic lines in disturbed oil and gas landscapes in Alberta. The researchers developed species distribution models using four years of camera trap footage to understand the response of large vertebrate habitat use to restoration of seismic lines. The research demonstrated that restored lines (i.e., decreasing line-of-sight and line density) led to shifts in species community structure and reduced use by wolves and coyotes. Such evidence indicates that restoration of linear features reduces predator-caribou encounter rates. The methods of this study (camera traps and distribution models) can be applied to other areas where caribou are

impacted by linear features in order to predict the outcomes of restoration.

Beirne, C., Sun, C., Tattersall, E. R., Burgar, J. M., Fisher, J. T., & Burton, A. C. (2021). Multispecies modelling reveals potential for habitat restoration to re-establish boreal vertebrate community dynamics. *Journal of Applied Ecology*, *58*(12), 2821–2832.

See also:

Dickie, M., McNay, R. S., Sutherland, G. D., Sherman, G. G., & Cody, M. (2021). Multiple lines of evidence for predator and prey responses to caribou habitat restoration. *Biological Conservation*, 256, 109032. https://doi.org/10.1016/j.biocon.2021.109032

Also see: https://register.gotowebinar.com/recording/546939272736055564

See also:

Wilman, E. A., & Wilman, E. N. (2017). Fast, slow, and adaptive management of habitat modification–invasion interactions: woodland caribou (*Rangifer tarandus*). *Ecosphere*, *8*(10), e01970. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecs2.1970

9.2.5 Evaluating the impact of caribou habitat restoration on predator and prey movement

In testing the response of wildlife to restoration of linear features, this 2023 study by Dickie et al. builds upon earlier research that assessed changes in wildlife use. In this work, researchers evaluated movement rates of wolves, bears, moose, and caribou to determine if restoration influenced speeds of travel. Speed was measured as animals travelled between cameras. The study found that restoration treatments reduced travel speeds along seismic lines for wolves, bears, and caribou but did not reduce moose travel speeds. Decreased movement rates of predators and caribou on restored seismic lines are likely to reduce encounters and predation events, thereby reducing caribou mortality. The outcome of this research suggests that restoration can help mitigate the impacts of seismic lines on caribou populations.

Dickie, M., Sherman, G. G., Sutherland, G. D., McNay, R. S., & Cody, M. (2023). Evaluating the impact of caribou habitat restoration on predator and prey movement. *Conservation Biology*, *37*(2), https://doi.org/10.1111/cobi.14004

See also:

Spangenberg, M. C., Serrouya, R., Dickie, M., DeMars, C. A., Michelot, T., Boutin, S., & Wittmann, M. J. (2019). Slowing down wolves to protect boreal caribou populations: A spatial simulation model of linear feature restoration. *Ecosphere*, *10*(10), e02904. https://doi.org/10.1002/ecs2.2904

See also:

Dickie, M., Serrouya, R., DeMars, C., Cranston, J., & Boutin, S. (2017). Evaluating functional recovery of habitat for threatened woodland caribou. *Ecosphere*, *8*(9), e01936. https://doi.org/10.1002/ecs2.1936

9.2.6 Prioritizing restoration of fragmented landscapes for wildlife conservation: A graph-theoretic approach

Reducing habitat fragmentation through restoration of seismic lines is imperative to recover of caribou. Yemshanov et al. applied an optimization model to the Cold Lake Area (CLA), Alberta, as a case study, in order to determine the best strategies for restoration that maximizes habitat connectivity. In the case study, Yemshanov et al. prioritized the eastern and central regions of CLA using the model. The researchers explored two strategies, one involving short-distance connections between forest patches and the other involving corridors between areas where species are known and large tracts of suitable habitat. The optimal mix of these strategies can be explored to determine the best restoration solution while considering budget. This approach can be applied in other regions to aid in prioritizing which seismic lines should be restored to improve caribou habitat connectivity.

Yemshanov, D., Haight, R. G., Koch, F. H., Parisien, M.-A., Swystun, T., Barber, Q., Burton, A. C., Choudhury, S., & Liu, N. (2019). Prioritizing restoration of fragmented landscapes for wildlife conservation: A graph-theoretic approach. *Biological Conservation*, *232*(Complete), 173–186. https://doi.org/10.1016/j.biocon.2019.02.003

9.3 Blocking Linear Features / Linear Deactivation

9.3.1 Managing animal movement conserves predator–prey dynamics

Keim et al. tested the effectiveness of reducing encounters between wolves and caribou,

thereby managing caribou predation. The study took place across the Parker Caribou Range in northeastern British Columbia, conducted as a before-after control-impact experiment over 2.5 years. Using camera traps, coincident habitat use was quantified in space and time as a measure for species encounters. Midway through the study, Keim et al. deployed mitigations designed to impede predator movement on anthropogenic linear developments (seismic lines and roads). They implemented soil mounding, tree planting, and tree felling mitigations on 61 km of 166 km of linear developments in the treatment area. The researchers monitored animal use on all linear developments. Findings showed that by deploying obstacles to disrupt ease of movement on human developments, wolf-caribou encounters were reduced by 85% and black bear-caribou encounters by 60%. Moreover, treating less than 40% of linear developments was enough to achieve the 85% reduction of wolf-caribou encounters in the treated area. This research demonstrates that by managing animal movements that regulate predator-prey encounters, risk to endangered species can be reduced without the disruptive trophic effects caused by intensive carnivore removals. Since wolf densities are typically dependent on moose and white-tailed deer populations, encounter-based management is likely to redistribute wolves with little or no impact on wolf populations. Implications of this study show that managing coincident habitat use by predators and prey provides an immediate benefit to vulnerable prey and a cost-effective alternative to predator removals or awaiting long-term habitat restoration.

Keim, DeWitt, P. D., Wilson, S. F., Fitzpatrick, J. J., Jenni, N. S., & Lele, S. R. (2021). Managing animal movement conserves predator–prey dynamics. *Frontiers in Ecology and the Environment*, *19*(7), 379–385. https://doi.org/10.1002/fee.2358

https://wolfwatcher.org/wp-content/uploads/2021/07/Keim-etal-2021.pdf

See also:

Keim, J. L., Lele, S. R., DeWitt, P. D., Fitzpatrick, J. J., & Jenni, N. S. (2019). Estimating the intensity of use by interacting predators and prey using camera traps. *Journal of Animal Ecology*, *88*(5), 690–701. https://doi.org/10.1111/1365-2656.12960

See also:

Keim, J. L., DeWitt, P. D., Wilson, S. F., Fitzpatrick, J. J., Jenni, N. S., & Lele, S. R. (2019). *Designing and monitoring the efficacy of functional restoration of linear features for boreal woodland caribou*. https://www.bcogris.ca/sites/default/files/bcip-2019-02-final-report-keim-et-al-ver-1a.pdf

See also:

Tattersall, E. R., Burgar, J. M., Fisher, J. T., & Burton, A. C. (2020). Mammal seismic line use varies with restoration: Applying habitat restoration to species at risk conservation in a working landscape. *Biological Conservation*, *241*(Complete). https://doi.org/10.1016/j.biocon.2019.108295

Tattersall, E., Pigeon, K., MacNearney, D., & Finnegan, L. (2023). Walking the line: Investigating biophysical characteristics related to wildlife use of linear features. *Ecological Solutions and Evidence*, *4*(1), e12219. https://doi.org/10.1002/2688-8319.12219

9.3.2 End of the road: Short-term responses of a large mammal community to forest road decommissioning

This study monitored the use of decommissioned forest roads by caribou, wolves, bears, and moose after reclamation with four treatments: closing the road, decompacting soil, planting trees, and adding enriched soil. Road closure, soil decompaction, and tree planting was found to be the most beneficial for caribou habitat restoration than the closed-only treatment. The study suggests that active restoration efforts should be included in caribou conservation programs, and the recommended treatment be added to road decommissioning protocols for caribou conservation, along with broad-scale habitat protection.

Lacerte, R., Leblond, M., & St-Laurent, M. H. (2022). End of the road: Short-term responses of a large mammal community to forest road decommissioning. *Journal for Nature Conservation*, *69*, 126256. https://doi.org/10.1016/j.jnc.2022.126256

9.3.3 Recovery rates of white spruce and balsam fir on seismic lines in NW Alberta, Canada

Jones et al. evaluated the natural regeneration rates of white spruce and balsam fir on seismic lines compared to adjacent mature forest areas in Alberta's boreal forest to as-

sess the potential for these trees to reach targets that reduce predator use and support woodland caribou habitat recovery. By analyzing height and density data from both locations (seismic lines and mature forests), the authors determined that both conifer species require approximately 30–50 years to reach the target conditions of three meters in height and at least 2000 stems per hectare, critical for reducing predator use in woodland caribou habitats. While the study confirmed natural regeneration on seismic lines, the authors noted that, despite meeting growth criteria, it remains challenging to evaluate the actual impact of this regeneration on woodland caribou habitat recovery. This slow regrowth raises concerns about the effectiveness of natural recovery processes, highlighting the need for further research and modeling to better understand the ecological implications for caribou conservation.

Jones, C., Kononovs, D., Trepanier, K., Harvey, J., Petty, A., & Degenhardt, D. (2025). Recovery rates of white spruce and balsam fir on seismic lines in NW Alberta, Canada. *Canadian Journal of Forest Research*, 55, 1–16. https://doi.org/10.1139/cjfr-2024-0161

9.4 Silviculture and Forest Management

9.4.1 Alternative silvicultural systems and harvesting techniques for caribou habitat

This project reviews alternative silviculture practices, harvesting methods, and regeneration techniques that have the potential to mitigate the negative effects on caribou while also enabling timber harvest. Killeen et al. carried out a literature review and expert interviews to compare impacts of alternatives to the dominant practice of clearcutting with a retention silvicultural system. Partial harvest systems or single-tree selection systems are two silviculture systems that Killeen et al. identified as having potential application in coniferous forests. Alternatives can only be applied and adapted based on local conditions. Given research gaps and unknowns, and potential for more damaging outcomes for caribou (additional access roads or spreading out partial cuts and roads) it is recommended that the provided information be used as the basis of study within specific caribou range areas.

Killeen, J., Bouchie, C., Christian, B., & Gooding, T. (2021). *Alternative silvicultural systems and harvesting techniques for caribou habitat*. Report prepared for the Alberta Regional Caribou Knowledge Partnership. https://arckp.ca/data/FORCORP%20Silv%20Review%20Full%20report%20with%20ARCKP%20Cover.pdf

9.4.2 Can partial-cut harvesting be used to manage terrestrial lichen habitat?

Where forestry does occur, best practices can be implemented to maintain lichen forage for caribou. Research studies have demonstrated that partial-cut harvesting, in contrast to clear-cut logging, is a technique that can be used to help maintain terrestrial lichen mats by modifying the successional trajectory in pine- and spruce-lichen woodlands. Trials carried out in the caribou range of the Itcha-Ilgachuz herd in British Columbia tested different types of cuts (treatments) compared to no harvest and to clear-cuts. The most successful treatment was the group selection technique, which "called for 33% removal in [canopy] openings about 15 m in diameter" (p. 16). Measurements for this treatment showed that after harvest in 1998, lichens declined to 53%, but recovered to nearly preharvest levels by 2004. Therefore, lichen cover was characteristic of an undisturbed forest. Although the study in B.C. has been the most comprehensive, similar findings have been shown in Quebec and Alberta. Certainly, a partial-cut harvest design would require a strategy to address deactivation of linear features. The authors suggested that using partial-cut logging reduces canopy closure and acts as a short- to mid-term solution for maintaining the availability of lichen to caribou.

Stevenson, S. K., & Coxson, D. S. (2015). Can partial-cut harvesting be used to manage terrestrial lichen habitat? A review of recent evidence. *Rangifer*, 11–26. DOI:10.7557/2.35.2.3461. https://www.researchgate.net/publication/291010680_Can_partial-cut_harvesting_be_used_to_manage_terrestrial_lichen_habitat_A_review_of_recent_evidence

See also:

Coxson, D. S. (2015). Using partial-cut harvesting to conserve terrestrial lichens in managed landscapes. *Canadian Wildlife Biology & Management* 4: 150–162. https://cwbm.ca/wp-content/uploads/2016/04/6-Vol-4-Issue-2-Coxson.pdf

See also (above mentioned B.C. study):

Waterhouse, M.J., Armleder, H.M. & Nemec, A.F.L. (2011). Terrestrial lichen response to partial cutting in lodgepole pine forests on caribou winter range in west-central British Columbia. — *Rangifer Special Issue* 19: 119–134. http://dx.doi.org/10.7557/2.31.2.1996

See also:

Courbin, N., Fortin, D., Dussault, C., & Courtois, R. (2009). Landscape management for woodland caribou: the protection of forest blocks influences wolf-caribou co-occurrence. *Landscape Ecology*, *24*(10), 1375–1388. https://link.springer.com/article/10.1007/s10980-009-9389-x

See also:

Stevenson, S. K., Armleder, H. M., Jull, M. J., King, D. G., McLellan, B. N., & Coxson, D. S. (2001). *Mountain Caribou in Managed Forests: Recommendations for Managers Second Edition*. Ministry of Environment, Lands and Parks, Victoria, British Columbia, Canada, Wildlife report No. R-26. https://www.for.gov.bc.ca/hfd/library/documents/bib46995.pdf

9.4.3 Terrestrial lichen caribou forage transplant success: Year 5 and 6 results

Rapai et al. investigated the survival and cover of three species of transplanted lichens from the *Cladonia* subgenus *Cladina* in a post-wildfire environment in north central British Columbia, evaluating the influence of forest litter amendments on their growth. The authors aimed to understand its potential for accelerating the restoration of winter terrestrial lichen habitat essential for southern mountain caribou. Lichens were monitored over five to six years to assess their survival rates, percent cover, and potential photosynthetic activity. The performance of transplanted lichens was compared to control groups without amendments, providing insights into the effects of litter on lichen survival. The results indicate that transplanted lichens exhibit positive outcomes in terms of survival and cover. Lichens survived for up to six years, and the treatment significantly affected lichen percent cover, with transplanted lichens showing greater coverage compared to controls. Photosynthetic activity analysis indicated that the transplanted lichens maintained a healthy stress status, unaffected by species, propagule type, or amendments. Rapai et al. concluded that transplanting *Cladonia* subgenus *Cladina* lichens into post-wildfire areas effectively enhances the recovery of critical winter habitat for the southern mountain caribou. Overall, these findings highlight the potential of lichen transplantation as a viable habitat restoration strategy in post-wildfire landscapes.

Rapai, S. B., McColl, D., Collis, B., Henry, T., & Coxson, D. (2023). Terrestrial lichen caribou forage transplant success: Year 5 and 6 results. *Restoration Ecology*, *31*(4), e13867. https://doi.org/10.1111/rec.13867

See also:

Coxson, D., & Sharples, R. (2024). Can partial-cut harvesting be used to extend the availability of terrestrial forage lichens in late-seral pine-lichen woodlands? Evidence from the Lewes Marsh (Southern yukon) silvicultural systems trial. *Canadian Journal of Forest Research*, *54*(5), 569–584. https://doi.org/10.1139/cjfr-2023-0214

9.5 Maternity Penning

9.5.1 Bickford caribou maternity pen construction: Annual report

The Klinse-Za herd in northern British Columbia, part of the endangered central group of southern mountain caribou, was predicted by the Canadian federal government to be extirpated. Reporting on the success of maternity penning, Spencer recommended continuing the maternity pen project in 2022, citing successful implementation over multiple years, higher recruitment ratio, and effective meeting of extension and reporting expectations. A new caribou maternity pen was planned by the West Moberly and Saulteau First Nations, in partnership with Wildlife Infometrics, at the original Bickford site, allowing for vegetation and lichen recovery and a change in the release point. The new pen construction is informed by the previous pens' operation to increase securement of penned caribou, reduce maintenance costs, and allocate more time to caribou husbandry. This maternity penning project exemplifies the utility of this strategy in contributing to increased caribou population growth. Although currently applied in concert with wolf removal, further study could assess overall effectiveness of the combination of continued penning with other non-lethal methods.

Spencer, B. J. (2022). *Bickford Caribou Maternity Pen Construction: Annual Report*. Wildlife Infometrics Inc. Report No. 789. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.

See also:

McNay, R. S., Lamb, C. T., Giguere, L., Williams, S. H., Martin, H., Sutherland, G. D., & Hebblewhite, M. (2022). Demographic responses of nearly extirpated endangered mountain caribou to recovery actions in Central British Columbia. *Ecological Applications*, *32*(5). https://doi.org/10.1002/eap.2580

See also:

Lamb, C. T., Willson, R., Richter, C., Owens-Beek, N., Napoleon, J., Muir, B., McNay, R. S., Lavis, E., Hebblewhite, M., Giguere, L., Dokkie, T., Boutin, S. & Ford, A. T (2022), Indigenous-led conservation: Pathways to recovery for the nearly extirpated Klinse-Za mountain caribou. *Ecological Applications*. Accepted Author Manuscript e2581. https://doi.org/10.1002/eap.2581.

See also:

Ford, A. T., Noonan, M. J., Bollefer, K., Gill, R., Legebokow, C., & Serrouya, R. (2023). The effects of maternal penning on the movement ecology of mountain caribou. *Animal Conservation*, *26*(1), 72–85. https://doi.org/10.1111/acv.12801.

See also:

Mueller, M., Johnson, C. J., & McNay, R. S. (2022). Influence of maternity penning on the success and timing of parturition by mountain caribou (*Rangifer tarandus caribou*). *Canadian Journal of Zoology*, *100*(9), 548–560. https://doi.org/10.1139/cjz-2021-0144

9.5.2 Go where you know: Range expansion and fidelity in mountain caribou following eight years of maternity penning

Hoffart et al. examined the impact of maternal penning on the distribution and habitat use of the Klinse-Za caribou herd in north-central British Columbia eight years after implementation. The authors aimed to understand how maternal penning affected caribou's range fidelity and overall space use by comparing pre- and post-penning behaviours, as well as distinctions between penned and unpenned individuals. The authors found that after maternal penning, caribou shifted their distribution closer to the maternity pens, suggesting they adapted by expanding their range use in response to the conditions provided. Despite these changes in spatial distribution, there was no alteration in habitat use concerning elevation, indicating that while caribou adjusted to their post-penning environment, their elevation preferences remained consistent. Caribou maintained fidelity to historically-used activity centers, especially in areas like the Bickford region, although this fidelity varied over time, reflecting population dynamics. Group cohesion was observed among penned and unpenned caribou, particularly during periods of larger populations. Social interactions appeared to influence spatial memory and movement patterns, with penned caribou more likely to return to previously used sites. Hoffart et al. concluded that maternal penning, while invasive and resource-intensive, had a minor long-term impact on the range and habitat use of woodland caribou, with the Klinse-Za herd adapting well to maternity pens.

Hoffart, D., Johnson, C. J., & McNay, R. S. (2025). Go where you know: Range expansion and fidelity in mountain caribou following eight years of maternity penning. *Animal Conservation*, *28*(2), 224–235. https://doi.org/10.1111/acv.12975

9.5.3 Assessing the health-fitness dynamics of endangered mountain caribou and the influence of maternal penning

Lamb et al. evaluated the health of the Klinse-Za subpopulation of southern mountain caribou, focusing on how various health metrics relate to reproductive success within the context of an Indigenous-led maternal penning initiative. Health metrics from 46 female caribou were collected from 2014 to 2021 and compared among different groups, including penned versus non-penned animals and reproductive versus non-reproductive females. The health metrics indicated that Klinse-Za caribou were generally healthy. Their levels of trace minerals (e.g. zinc, manganese, iron, and copper) were lower than those of most neighboring subpopulations. Penned caribou exhibited lower fecal cortisol levels and inflammation markers compared to free-ranging caribou. This finding supports the hypothesis that penned caribou can experience lower stress due to reduced predator vigilance and potentially greater access to quality food. The authors found correlations indicating that reproductive success in Klinse-Za caribou was linked to trace nutrient levels, while stress, pathogen exposure, and inflammation biomarkers showed no significant relationships. This highlights the critical role that trace minerals may play in reproduction. Although various pathogens were assessed, direct links between pathogen exposure and negative reproductive outcomes were not established. Lamb et al. underscore the significance of understanding caribou health in conservation efforts, emphasizing that health metrics are vital for effective wildlife management and recovery strategies.

Lamb, C. T., Dubman, E., McNay, R. S., Giguere, L., Majchrzak, Y., Thacker, C., Slater, O., Macbeth, B., Owens-Beek, N., Muir, B., & Ford, A. T. (2024). Assessing the health-fitness dynamics of endangered mountain caribou and the influence of maternal penning. *Canadian Journal of Zoology*, *102*(8), 673–690. https://doi.org/10.1139/cjz-2023-0032

9.5.4 Endangered deep-snow mountain caribou have a distinct winter diet and gut microbiome that may be altered by maternal penning

Sugden et al. investigated the dietary specialization and gut microbiome differences

between two ecotypes of southern mountain caribou: the deep-snow ecotype and the shallow-snow ecotype. The research aimed to determine how their specific diets affect gut microbiomes and the implications of dietary changes during maternal penning, an ex situ conservation practice. Using fecal DNA metabarcoding, the authors analyzed the dietary habits and gut microbiome composition of free-ranging deep-snow caribou, shallow-snow caribou, and captive deep-snow caribou from a maternity pen, along with semi-domesticated reindeer. Sugden et al. found that free-ranging deep-snow caribou primarily consumed arboreal hair lichens from the genera Bryoria and Nodobryoria, while shallow-snow caribou favoured terrestrial lichens like Cladonia and Stereocaulon. The gut microbiomes of deep-snow caribou exhibited distinct characteristics, including a higher abundance of the genus Paramuribaculum, correlated to their specialized diets. Captive deep-snow caribou showed significant changes in both forage consumption and gut microbiome composition due to penning. They consumed more foliose lichens, resulting in a microbiome markedly different from that of free-ranging deep-snow caribou. Sugden et al. argued that conservation strategies for caribou should take into account the specific dietary preferences of different populations and the effects of dietary changes on gut microbiomes, especially during captivity.

Sugden, S., Serrouya, R., Neufeld, L., Schwantje, H., St. Clair, C. C., Stein, L., & Spribille, T. (2025). Endangered deep-snow mountain caribou have a distinct winter diet and gut microbiome that may be altered by maternal penning. *Molecular Ecology*, *34*(11), e17783. https://doi.org/10.1111/mec.17783

9.6 Aversion Conditioning

9.6.1 Shock collars as a site-aversive conditioning tool for wolves

Rossler et al. tested the ability of shock collars to discourage the use of a site by wolves and lead to aversion conditioning, in order to reduce livestock losses. The researchers wanted to understand whether this behaviour was transferred to other uncollared pack members. Findings showed that collared wolves visited less and spent less time in shock zones, and stayed away for more days, than uncollared wolves. Shock collars lead to aversion conditioning which was also behaviourally transferred to other pack members. This study was validated for free-ranging wolves at the scale of livestock farms; however, it would be interesting for further research to explore if and how this technology could have application for protection of an endangered species such as woodland caribou. Perhaps this technology could protect caribou from predation in some design arrangement (e.g., fit members of a wolf pack with collars that would shock them when approaching known caribou refuge areas, or even receptor collars fitted to one or two herd members to create a travelling shock zone). In terms of suitability as a management tool, this paper cites literature confirming that nonlethal methods are generally more acceptable to the public than lethal methods.

Rossler, S. T., Gehring, T. M., Schultz, R. N., Rossler, M. T., Wydeven, A. P., & Hawley, J. E. (2012). Shock collars as a site-aversive conditioning tool for wolves. *Wildlife Society Bulletin*, *36*(1), 176–184. https://doi.org/10.1002/wsb.93

See also:

Hawley, J. E. (2005). *Experimental Assessment of Shock Collars as Non-lethal Control Method for Free-ranging Wolves in Wisconsin* (Doctoral dissertation, Central Michigan University). http://people.se.cmich.edu/gehri1tm/ms%20theses/jason%20hawley%20thesis.pdf

10 Ethics Research and Public Disapproval

10.1 Ethics Research and Public Disapproval

10.1.1 Maintaining ethical standards during conservation crises

Brook et al. deliberate ethical and animal welfare concerns in the context of experimental implementation of emergency lethal wolf culling. The researchers contend that methods of extermination (aerial shooting, strychnine, and strangling neck snares) are not in accordance with the Canadian Council of Animal Care (CCAC) guidelines because they cause long and painful deaths of wolves and the many non-target animals that are also killed. Shooting moving animals from helicopters is challenging, prone to error, and often fails to achieve deaths that are quick and painless. The American Veterinary Medical Association (AVMA) states that the objective of the shooter is a gunshot to the head causing destruction of brain tissue, and that shots to the heart or neck do not cause instant loss of consciousness. Generally, evidence to support the effectiveness of euthanasia by aerial shooting as a humane method is not adequately documented in the scientific literature. Brook et al. also discuss the adherence of wolf control studies to scientific journal ethical animal care standards. Issues of wolf control studies include insufficient data regarding animal welfare outcomes, average time to death, wounding rate, escape rate, instantaneous death rate, and location of bullet wound tracts, as well as type of helicopter, firearm, ammunition, and shooter proficiency. These shortcomings of standard animal care suggest improper consideration of humane animal deaths.

It is held that experiments of intentional inhumane killing of wildlife violate the fundamental principles of ethical science. Recommendations are that CCAC guidelines be updated to provide further clarity on field methods in wildlife studies such as shooting animals from helicopters. In addition, audits should be conducted on researchers, studies, and publishing journal institutions.

Brook, R.K., Cattet, M., Darimont, C.T., Paquet, P.C., & Proulx, G. (2015). Maintaining Ethical Standards during Conservation Crises. *Canadian Wildlife Biology and Management*, *4*(1), 72–79. https://www.raincoast.org/wp-content/uploads/2015/01/Brook-et-al-2015_wolf-caribou-CWBM.pdf

10.1.2 An environmental justice analysis of caribou recovery planning, protection of an Indigenous culture, and coal mining development in northeast British Columbia, Canada

This article discusses environmental justice theory, which states that lower socioeconomic and minority communities unfairly bear the burden of land use decisions. The case study presented is of the West Moberly First Nations, an Indigenous group in British Columbia who fought to protect a threatened herd of caribou from coal mining activities. The caribou are crucial to the First Nations' cultural integrity and the Provincial Government of British Columbia's decision to allow a mining company to destroy the critical habitat of the species disregards federal law, science, and traditional knowledge, as well as constitutional and treaty rights. The decisions place a disproportionate burden on the First Nation while prioritizing the interests of the government and the mining industry. The article concludes that the Provincial government's actions constitute intentional environmental injustice.

Muir, B. R., & Booth, A. L. (2012). An environmental justice analysis of caribou recovery planning, protection of an Indigenous culture, and coal mining development in northeast British Columbia, Canada. *Environment, Development and Sustainability*, 14, 455–476. https://doi.org/10.1007/s10668-011-9333-5

10.1.3 International consensus principles for ethical wildlife control

Dubois et al. drawn on global perspectives and experiences to develop seven principles of ethical wildlife control. Facilitated through a process of engagement and discussion, 20 international experts established the stepwise principles for ethical decision-making. Efforts to control wildlife should:

1. begin wherever possible by altering the human practices that cause human–wildlife conflict and by developing a culture of coexistence.
2. be justified by evidence that significant harms are being caused to people, property, livelihoods, ecosystems, and/or other animals.
3. have measurable outcome-based objectives that are clear, achievable, monitored, and adaptive.
4. predictably minimize animal welfare harms to the fewest number of animals.
5. be informed by community values as well as scientific, technical, and practical information.
6. be integrated into plans for systematic long-term management.
7. be based on the specifics of the situation rather than negative labels (pest, overabundant) applied to the target species.

This inclusive approach would help alleviate controversy and opposition by considering diverse perspectives grounded in science and ethics. Dubois et al. recommended that these principles guide the development of standards at all levels of government and decision-making in human-wildlife conflict management.

Dubois, S., Fenwick, N., Ryan, E. A., Baker, L., Baker, S. E., Beausoleil, N. J., Carter, S., Cartwright, B., Costa, F., Draper, C., Griffin, J., Grogan, A., Howald, G., Jones, B., Littin, K. E., Lombard, A. T., Mellor, D. J., Ramp, D., Schuppli, C. A., & Fraser, D. (2017). International consensus principles for ethical wildlife control. *Conservation Biology*, *31*(4), 753–760. https://doi.org/10.1111/cobi.12896

See also:

Proulx, G. (2018). Concerns about mammal predator killing programs: scientific evidence and due diligence. *Canadian Wildlife Biology & Management*, 7, 59. https://www.researchgate.net/publication/325010192_Concerns_About_Mammal_Predator_Killing_Programs_Scientific_Evidence_and_Due_Diligence

10.1.4 Wildlife conservation and animal welfare: Two sides of the same coin

This paper integrates ethics in wildlife conservation and animal welfare in order to establish the principle of "wildlife welfare" in conservation. Ethical foundations are deficient in wildlife conservation, even though wild animals within anthropogenically-disturbed habitats are subject to suffering. Grey wolves are used as a case study in the context of degraded wolf habitat and displacement in human-dominated landscapes,

such that their distribution, movements, survival, or fecundity may be impaired. A doctrine of wildlife welfare principles, such as that presented here, remains applicable to all species levels of all systems where suffering is endured due to degraded habitat as the root cause. Paquet and Darimont (2010) adapt the Five Freedoms of Animal Welfare to reflect human-rooted suffering borne by wildlife: freedom from thirst, hunger, and malnutrition caused by humans; freedom from discomfort due to environmental disruption caused by humans; freedom from fear and distress caused by humans; freedom from pain, injury, and disease caused by humans; freedom to express normal behaviour for the species.

Paquet, P. C., & Darimont, C. T. (2010). Wildlife conservation and animal welfare: Two sides of the same coin. *Animal Welfare*, *19*(2), 177–190. Retrieved from: https://www.researchgate.net/publication/228621252_Wildlife_conservation_and_animal_welfare_Two_sides_of_the_same_coin

See also:

Nunny, L. (2020). Animal welfare in predator control: Lessons from land and sea. How the management of terrestrial and marine mammals impacts wild animal welfare in human-wildlife conflict scenarios in Europe. *Animals*, (2), 218. https://doi.org/10.3390/ani10020218

10.1.5 Predator reduction for caribou recovery engagement survey: What we heard

In 2021, the Province of B.C. carried out a public engagement survey to seek input from British Columbians on a five-year approval for continued predator reduction to support woodland caribou recovery. The questionnaire was open from September 15th to November 15th, 2021, and focused on caribou recovery, predator reduction, and participant demographics. The Ministry of Forests, Lands, Natural Resource Operations and Rural Development published the results in a "What We Heard" report. In total, 15,196 people participated in the survey. Key findings include:

- Overall, 59% of respondents were against predator reduction for caribou recovery and 37% support predator reduction.
- The overwhelming majority of respondents (98%) feel that caribou recovery is important.
- Among stakeholder groups, those opposed to predator reduction were more likely to be concerned citizens, scientists, or those associated with environmental/ecosystem protection, the ecotourism industry, and First Nations and/or Indigenous stakeholder groups.
- Hunters and/or trappers, guide outfitters or those associated with resource extraction were more likely to support predator reduction.
- Among those who disagreed with predator reduction (59%), the most frequently mentioned reason was because they felt there were better options to achieve the same end (83% of those who disagreed with predator reduction).
- Additionally, 60% who disagree with predator reduction indicated they were opposed to the killing of wolves as a means to immediately stop caribou decline and 56% felt that predator reduction was inhumane.
- The top three caribou recovery actions selected by respondents were habitat protection (regulating land use), habitat restoration, and habitat management-beneficial management practices for recreation and industry.

Ministry of Forests, Lands, Natural Resource Operations and Rural Development. (2021). *Predator Reduction for Caribou Recovery Engagement Survey*: What We Heard. R.A. Malatest & Associates Ltd. https://engage.gov.bc.ca/app/uploads/sites/121/2022/01/WWHR-Predator-Reduction-For-Caribou-Recovery-Final-Report-JAN2022.pdf

See also:

Dubois, S., & Harshaw, H. W. (2013): Exploring "Humane" Dimensions of Wildlife, Human Dimensions of Wildlife: *An International Journal*, 18:1, 1–19. http://dx.doi.org/10.1080/10871209.2012.694014

10.1.6 Efficacy and ethics of intensive predator management to save endangered caribou

Johnson et al. critically reviewed the scientific efficacy and ethical implications of intensive predator management as a recovery strategy for endangered woodland caribou. The effectiveness of predator management is dependent on several ecological conditions:

- Mortality from predation must be the primary vital rate limiting prey population growth, not lack of food, habitat, or low birth rates.
- Predator management is more effective if predator population dynamics are decoupled from the abundance of the target prey.

- In this case, human-mediated habitat changes increase the abundance of alternative prey (moose, deer), which in turn supports higher wolf densities, creating an "apparent competition" dynamic.

The authors found that significantly reducing primary predator numbers can lead to increased caribou survival and calf recruitment short-term. This is not a long-term solution as caribou populations are expected to decline when predator control stops unless fundamental habitat issues are resolved. To be effective, predator removal must be very aggressive (65–80% wolves removed), cover large areas, and be maintained for many years. Predator management is very expensive and can have unpredictable and often unaccounted-for ecological consequences. Predator management has many ethical concerns, including the humaneness of killing methods and the moral implications of intentionally killing one sentient species to benefit another. Critics also argue that relying on predator management is a direct result of the governments' failure to protect caribou habitat through continued industrial development. The authors urge Canada to invest in comprehensive habitat restoration and protection.

Johnson, C. J., Ray, J. C., & St-Laurent, M. (2022). Efficacy and ethics of intensive predator management to save endangered caribou. *Conservation Science and Practice*, *4*(7), e12729. https://doi.org/10.1111/csp2.12729