FINAL REPORT FOR REVELSTOKE CARIBOU REARING IN THE WILD

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PREPARED BY:

Robert Serrouya, Kevin Bollefer, Rachel Cook, Sophie Gilbert, Ryan Gill, Cory Legebokow, Bryan MacBeth, Helen Schwantje, and Caeley Thacker

Final science report for RCRW

Executive Summary

A five-year pilot study was undertaken by Revelstoke Caribou Rearing in the Wild (RCRW) to determine if maternal penning could increase calf survival in the Columbia North subpopulation of southern mountain woodland caribou (*Rangifer tarandus caribou*). The stated objective was to increase calf survival by a factor of two to three times over free-range survival rates. Depending on the results of this pilot study, the longer-term goal was to increase the population growth rate of this subpopulation. From 2014 to 2018, 72 adult females were placed in the pen, including 64 that were pregnant (0.889), and 47 calves were released from the pen. Calf losses account for the difference between the number pregnant and calves released. Calf losses were caused by spontaneous abortion (n = 1), complications at parturition (stillbirth n = 1; dystocia n = 2), congenital malformation (also a stillbirth; n = 1), neonatal deaths (infections or nutrition; n = 7), long bone-fractures suspected to have been caused by trampling that resulted in euthanasia (n = 2) or transport to the Calgary Zoo (n = 2, and died at the zoo), and an orphan that was brought to the zoo (n = 1, and is alive). Calf survival from birth to the following March was 0.438 to 0.490 (depending on whether recruitment surveys or radio-collar survival estimation was used). These values correspond to an approximate doubling of the wild calf survival rate (which varied substantially before and during the penning project). Calf birth mass was the primary factor that explained calf survival both in the pen and post release. Birth mass ranged from 6.5 to 12.6 kg, and for every kg increase, the odds of surviving in the pen increased by a factor of 4.14 (95% CI 0.87 – 19.6). Similarly, the odds of surviving post release were 2.39 × higher (0.97 – 5.93) for every kg increase in birth mass.

We estimated a net of 7.2 to 9.7 10-month-old calves were added to the population during the five-year pilot. Adult female mortality in the pen (n = 4) resulted in a slightly lower annual survival than recorded for wild adults leading up to the penning project. Vital rates of penned and unpenned animals were used in a stage-based Leslie matrix to estimate the finite rate of population change (λ; λ = 1 means a stable population), and to evaluate the sensitivity of these parameters on λ. Given the baseline vital rates of wild animals ($S_{adult,}$ = 0.868 $S_{calf,}$ = 0.271, *Pregnancy* = 0.889) at a stable age distribution, λ was predicted to be 0.962. When the vital rates of the penned animals are included ($S_{adult,}$ = 0.840, $S_{calf,}$ = 0.490, *Pregnancy* = 0.889), as well as the proportion of adult females penned (*c*. 19.1 %), the predicted λ is 0.969, an undiscernible increase of 0.007. Even if all adult females were penned (*c*. 80 individuals), λ would be 0.989.

Assessments of body condition were performed in 2016 and 2018 using an ultrasonograph to measure rump fat and other metrics. Body fat was < 6% for 56% of the adult females, suggesting at least modest nutritional limitations are occurring in the Columbia North subpopulation and could be impacting population demography.

In conclusion, the RCRW project met the proximate objective of doubling calf survival, however, a combination of factors (higher than anticipated mortality of adults and calves in the pen) meant that penning a higher number of females to increase λ did not occur. Compared to other penning projects, the RCRW site location was not ideal (too low in the valley) and

probably contributed to the in-pen mortalities. If maternal penning is to proceed in this ecosystem, the site should be chosen using a number of site characteristics, including a higher elevation location. Any high-elevation site will create additional challenges given the deep snowfall that occurs in the Columbia Mountains.

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1. Introduction

Woodland caribou (*Rangifer tarandus caribou*) live across more than 3 million km^2 of the North American continent, yet many populations are declining throughout much of this broad distribution (Festa-Bianchet et al. 2011). This pattern has prompted intense research and management aimed at reversing such declines (Environment Canada 2014). In 2014, the central and southern ecotypes in British Columbia (BC) were recommended for 'Endangered' listing by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), though this status has not been ratified by the federal government. Nonetheless, a federal recovery strategy was developed (Environment Canada 2014) that outlines a variety of recovery measures including habitat protection and restoration, prey reductions to historic levels, predator reductions, and maternal penning. Habitat alteration is an ultimate cause of caribou decline, primarily because it leads to increased predation rates on woodland caribou (Apps and McLellan 2006, Wittmer et al. 2007, Apps et al. 2013). However, the legacy of habitat alteration means that population management will be needed in the interim until sufficient habitat recovery has occurred. Population management includes reducing the abundance of predators or alternative prey, as well as various 'safe haven' approaches to separate predators from caribou using fenced enclosures (Johnson et al. 2019a).

The most commonly attempted 'safe haven' approach to help increase caribou numbers is referred to as maternal penning, which can be described as the temporary protection of caribou from predators by placing pregnant adult females in a fenced enclosure where they calve. After calves are about one-month old, calves and their mothers are released back into the wild. Calf mortality rates of free-ranging non-migratory woodland caribou are usually highest during the first month of life (Adams et al. 1995, Adams et al. 2019), therefore protecting calves until they are mobile enough to evade predators, particularly bears (*Ursus spp.*) should improve their survival and lead to population growth. Although reducing predator populations can also lead to population growth, maternal penning is being considered in several jurisdictions because: 1) it can reduce the need to intensively reduce predators, which is a controversial management tool (Hervieux et al. 2015); and 2) it can garner substantial community support across a variety of stakeholders (Desrosiers 2018).

There have been four attempts at caribou maternal penning in western North America. In Yukon, maternal penning increased annual calf survival from 0.192 to 0.575 relative to wild animals, but this dramatic increase provided a limited benefit to the overall population. The proportion of adult females in the pen was too low to substantially affect population-level demographics, primarily because the total population size was much larger than initially estimated (Adams et al. 2019). In Alberta, maternal penning of the Little Smoky herd did not increase calf survival (and by extension did not benefit the population), because calves died from bear predation (*Ursus spp*.) shortly after release. More recently, maternal penning of the

Klinse-Za herd in central BC resulted in increased calf recruitment from 24 to 56 per 100 adult females (Lamb et al. *in press*). The Klinse-Za pen held a total of 73 female caribou in the high-elevation pen between 2014-2019, which collectively added 41 yearling recruits to the population. In this case, wolf (*Canis lupus*) reduction was implemented simultaneously, (Lamb et al. *in press*), and both management actions likely helped to prevent the extirpation of this critically small population.

The fourth maternal penning project was initiated in the Columbia Mountains of BC by Revelstoke Caribou Rearing in the Wild (RCRW) and is the focus of this report. RCRW is a non-profit society created to test maternal penning in the Columbia Mountains Ecosystem (CME). Our goal here is to summarize the results of the RCRW project, which was designed as a 5-year trial beginning in 2014. The specific objectives of RCRW were to:

1. Determine if maternal penning can improve the survival of calves born in a maternity pen, relative to wild-born calves, in the CME.
2. Depending upon the results of Objective 1, evaluate if captive rearing can be used as a management tool to achieve a population level effect in the Columbia North caribou subpopulation.
3. Determine whether maternal penning in the CME is logistically feasible and whether animal welfare can be maintained to ensure no cost to the population from maternal penning and enable RCRW to meet Objective 1.
4. Use data from the 5-year pilot to assess whether maternal penning is a viable tool to increase the size of the Columbia North subpopulation in the future.

Why a maternity pen in the Columbia Mountains Ecosystem?

A number of conservation actions for caribou have been implemented in the northern Columbia Mountains. In the 1990s, land-use planning was initiated, and the focus of recovery actions was on closing areas to logging and snowmobiling. During this time, the Columbia North subpopulation continued to decline at an annual growth rate of 0.95 until 2004, when it was estimated at 129 individuals (Wittmer et al. 2005). Subsequently, an experiment was initiated to reduce moose (*Alces alces*) numbers to historic levels, to indirectly reduce wolf populations without having to kill wolves. This experiment stabilized the caribou decline, and by 2013 the population was above 150 ($\lambda = 1.02$; Serrouya et al. 2017a). However, these actions did not lead to substantial population growth, so maternal penning was proposed as a means of helping to grow the population, in addition to the previous recovery measures. Furthermore, calf recruitment was consistently low compared to the early 1990s, so it was hypothesized that a boost in recruitment through penning could transition the population from stable to increasing. Previous investments in habitat protection (i.e., logging restrictions and closures to snowmobiling; Serrouya and McLellan 2016) provided the potential for the herd to recover to a self-sustaining state since habitat quality was expected to increase gradually as the early seral forest stands transitioned to closed canopies.

2. Methods

Caribou were captured in late March or early April when they were at treeline, making them relatively safe to capture because of deep, soft snow and high sightability (Wittmer et al. 2005). Caribou were transported to the pen and subsequently birthed their calves from late May to early June. The goal was to release all animals in mid-July when the youngest calves were at least one month old. After release, animals were monitored using telemetry methods. In March, a complete population census or recruitment survey was conducted, thereby completing the annual cycle. Although the biological year is bounded by June when calves are born, our cycle was bounded by the end of March because this is when population size and recruitment is estimated, and when animals were handled for collaring or transport to the pen. Some penned animals were recaptured in subsequent years and again transported to the pen. Therefore, we use the term 'wild' to mean animals that were not penned during the current annual cycle (though they may have been penned during previous years). The project ran as a 5-year pilot, beginning in 2014 (year 1), and continuing from 2015 to 2018 (years 2 through 5).

Pen construction

The RCRW maternity pen was constructed in the fall of 2013 in a sparsely restocked clearcut at 580 m elevation, next to Lake Revelstoke. The location of the pen was within occupied spring range for the Columbia North subpopulation (Fig. 1; Photograph 1). The site is located approximately 100 km north of the city of Revelstoke, within the Interior Cedar-Hemlock (ICH wk1) biogeoclimatic zone which is typified by warm, wet summers and cool winters with moderate snowfall. Climax forest stands are primarily comprised of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*), with small amounts of falsebox (*Paxistima myrsinites*) and blueberry (*Vaccinium spp.*). Hybrid white spruce (*Picea glauca x engelmannii)* is the most common seral species. The initial pen built in fall of 2013 encompassed 6.4 ha. In fall of 2015, the pen was expanded to 9.3 ha to include an adjacent stand of mature forest that provided additional shade and a cooler microclimate. The adult stocking density averaged 0.61 ha/adult (range: 0.36-0.78 ha/adult), lower than that reported for maternal penning in Yukon (0.2-0.3 ha/adult; Adams et al. 2019). Although not within typical summer calving range, the site was chosen because of a lower late-winter snowpack (approximately 1–2 m) compared to in-situ conditions (3+ m) that would make logistical aspects of the project extremely challenging. In addition, the site was adjacent to a guide-outfitters lodge with available utilities and staff accommodation. The majority of the pen site was flat to gently rolling, with occasional gullies and hummocks. The variable topography, forest age patches, and vegetation densities throughout the pen provided visual barriers and microclimate variability. To improve sight lines and overall visibility within the pen, all understory shrubs except falsebox were manually brushed. Tree branches were pruned approximately to 2 m off the ground, and plant waste was chipped or burned within the pen site.

To install fencing, the perimeter was first cleared and grubbed using a small tracked bulldozer and an excavator. Six meter-long by 10-cm diameter hollow metal fence support posts (used drilling pipe) were vibrated 2 m into the ground using a specialized attachment for a skid steer. The posts were spaced every 3 - 7 m with 1-cm diameter galvanized wire rope fed through carabiner style metal loops that were welded to the top of each post. Geotextile (non-woven ARMTEC 300, 4.57-m wide) was folded over the wire rope and sewn to itself with UV stabilized cable ties spaced 1-m apart. The geotextile was attached to the support posts using the same cable ties. The effective height of the fence was approximately 4 m with 0.5 m serving as a ground level skirt, laid toward the inside of the pen. Access to the inside of the pen was provided by two main gates on opposing sides that were large enough to allow vehicles to enter for maintenance or emergency purposes. In addition, a horizontally split gate enabled easy access for staff when the bottom half of the gate was still under snow. One of the large main gates also served as the release portal. One main observation blind and six tree stands were strategically placed around the perimeter.

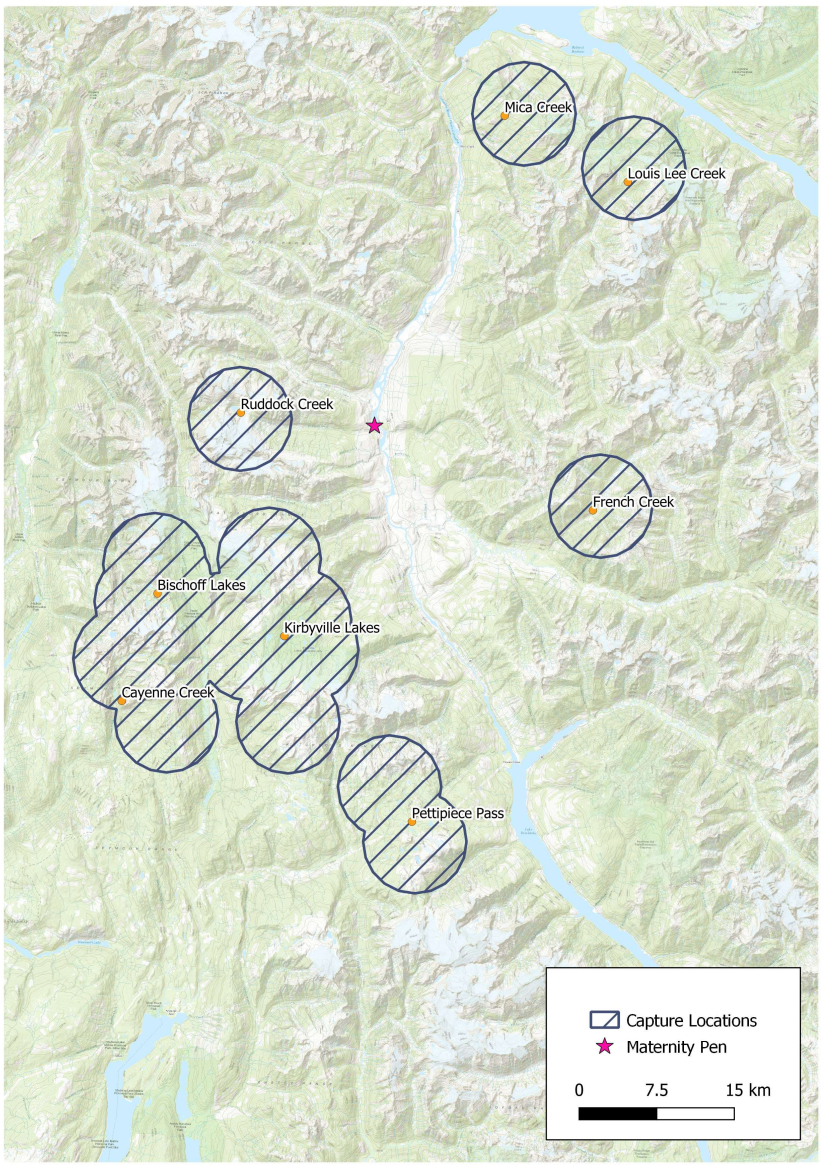
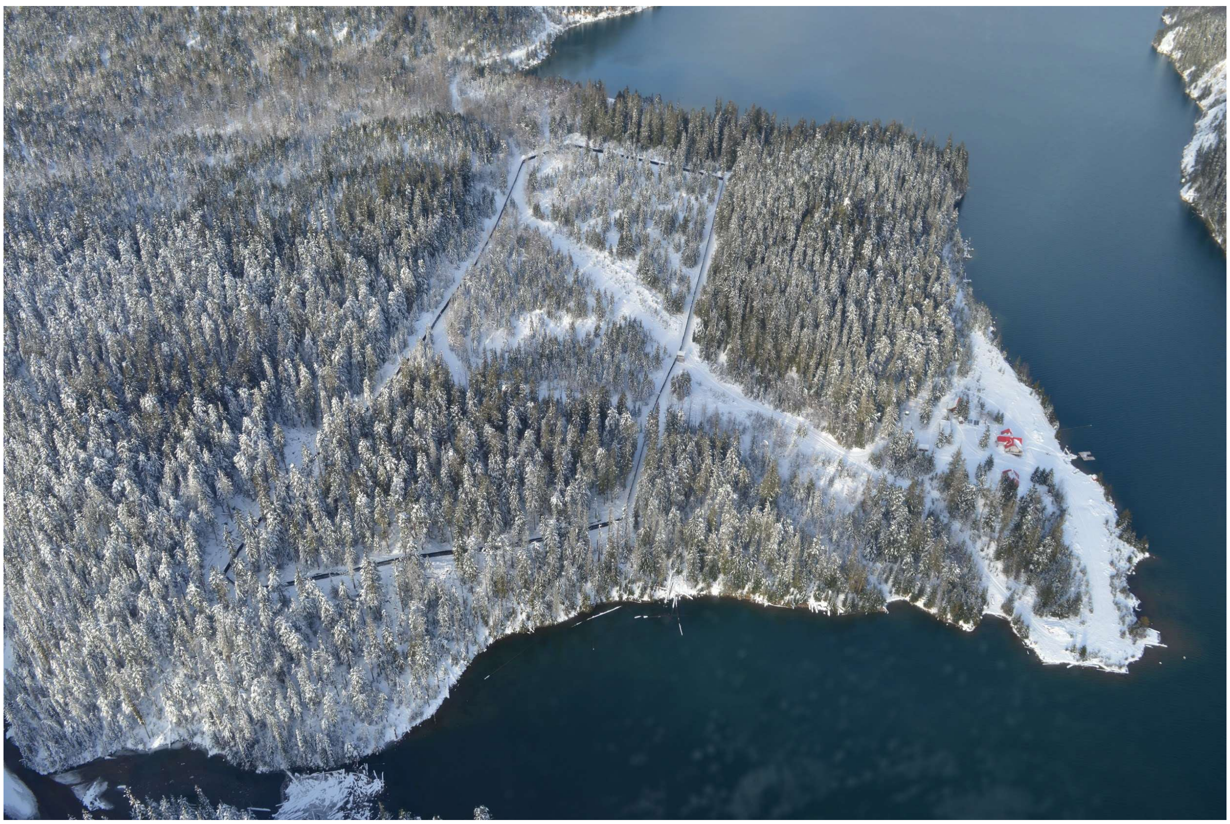


Figure 1. Mountain caribou capture locations for the RCRW maternity pen. Animals captured from Bischoff Lakes, Kirbyville Creek and Pettipiece Pass correspond to areas where caribou body fat measurements were taken in 2016 (years 3) and 2018 (year 5).

Metal outriggers on the outside of the main support posts supported a 2.4-m high electric fence that surrounded the entire pen. The fence was powered by a 110 V AC Parmak RM-1 charger with a 16,000 V output capability. The system used high tensile solid wire, rather than the more common braided poly-wire, as it provides a physical barrier and requires less maintenance. The fence system provides ground (+) wires alternating with hot (-) wires up the entire height so +/- contacts are more readily made. The fence had a total of eight hot wires interspersed by six ground wires. The electric fence was controlled from a central panel that allowed various levels or “banks” to be electrified as snow gradually melted and exposed more hot wires. Typical fence voltage was approximately 5,000 V when all eight hot wires were activated.



Photograph 1. RCRW maternity pen after completion of the expansion in year 2. The expansion added the mature forest seen in the foreground, increasing the size from 6.4 ha to 9.3 ha. Photograph by C. Legebokow.

Water was provided during years 1 and 2 by manually filling livestock watering troughs using a garden hose. Fecal accumulation and algal blooms were cause for concern by the end of year 2. In year 3 cold, clean water from Lake Revelstoke was provided on a continuous basis to two watering stations located within forest cover where algal growth would be minimized and ambient temperatures moderated (Photograph 2). The system consisted of a Grundfos 11SQF-2 solar powered submersible well pump powered by 10 solar panels mounted on a tilting support frame that could be angled to the optimal solar position. The pump was suspended off of a log that extended from the shore into Lake Revelstoke approximately 15 m. It supplied a 3.8 cm ABS potable water line that ran along the eastern flank of the pen, supplying water to individual stations. At its highest elevation point, the pump provided a total flow of approximately 45 litres/min at noon, when the sun was highest. The flow rate would subside gradually as the sun set, and ceased completely through the night. However, the troughs retained sufficient water until sunrise reactivated the pump. Each watering station had two troughs that were configured in parallel at one of the stations and in series at the second station. Each trough was made from 20 cm diameter potable water pipe with ⅓ of the circumference removed and inlet and outlet end caps added. In year 4, a third station comprised of a single trough was added with an in-series second trough completing the station for year 5. The three watering stations were spaced approximately 100 m apart. Flow entering each station was controlled by ball valves with wastewater discharging out of the pen, into the surrounding forest. This system required little maintenance and provided high quality water on a continuous basis during daylight hours.

Photograph 2. Solar powered flow-through watering troughs in use. Clean water from Lake Revelstoke entered one end while wastewater discharged from the other end to the outside of the pen. Photograph by RCRW.

Additional pen features included a remote-controlled fixed angle video camera attached to the side of the main observation blind. The camera was motion-activated with the monitor located inside staff quarters such that in-pen activities could be viewed remotely, and any incidents responded to accordingly. All video was automatically saved to a personal video recorder, allowing staff to forward clips to wildlife (project) veterinarians for assessment. In year

4, the fixed low-resolution camera was replaced with a ‘pan-tilt-zoom’ camera that provided higher resolution (1080p).

Capture and handling of adult females

All caribou in the RCRW maternal penning project were captured using a net fired by a net-gun from a helicopter. This has been the most successful and cost-effective method of caribou capture in BC, and allowed for assessment prior to sedation (e.g., sex, body condition). All helicopter pilots and field crews were experienced with and were briefed on safe winter operations in mountainous terrain, and on the safe and humane capture and transport of caribou. The primary capture team operated from a Hughes 500 and consisted of an experienced wildlife capture pilot, a net-gunner, and an animal handler. The transport team operated from an A-Star and consisted of an experienced pilot, an animal handler, and a project veterinarian. From years 1 to 3, captures were contracted to Bighorn Helicopters, and during the latter two years, Canadian Wildlife Capture performed captures.

To minimize risks to caribou, all capture efforts were limited to late winter (end of March/early April) when pregnant females were still ~ 2 months from calving and adult males had lost their antlers. Daily snow and weather conditions were assessed and capture operations were temporarily postponed if the weather was poor, the ambient temperature was > 5^{o}C or < –25 ^{o}C, or the avalanche risk was considered unacceptable based on an assessment from the Avalanche Canada daily bulletin and terrain rating. The night before capture, the team met in person and a capture briefing was conducted that included a review of protocols, human and animal safety, and avalanche safety.

Reconnaissance flights, radio-telemetry, and snow tracking were used to locate groups of free-ranging caribou in the study area prior to the capture day. On the day of capture, caribou group composition and terrain were evaluated. Capture attempts did not occur if terrain hazards (e.g., avalanche risk, rock fall, cornices, water bodies etc.) presented an unacceptable risk to animal or human safety. Groups of caribou to be targeted for capture were chosen to minimize transport times and the time between the initial chase and release into the pen. Captures were also planned so that total group size would not be reduced to less than three mature females once an animal(s) had been removed from a group (McLellan et al. 2010). Caribou expected to be pregnant and without dependent calves were the primary capture target. However, if total group size was limiting, adult females and their calves of the year were considered for capture and transported to the pen together. To reduce stress, no more than three incursions into a particular group of caribou were made in a single day. If required, hazing (distance herding of individual caribou or caribou groups) was used but kept to a minimum. The objective of helicopter hazing is controlled movement to slow moving animals into a suitable capture location in deep snow in the safest terrain available. Once a suitable caribou was located in appropriate terrain, the final close pursuit was initiated by the capture helicopter. Caribou running at high speed or showing signs of distress were not netted. Only one caribou was captured in a net at a time, however, a second or third loaded net-gun were carried and deployed if an animal was only partially restrained. The maximum time for close pursuit was 2 minutes and, if not already netted, the chase was broken off if the caribou exhibited signs of excessive stress (e.g., laboured breathing, stumbling, slowing).

Once a caribou was securely netted, the capture helicopter landed immediately and the animal was hobbled, blindfolded, and untangled by the primary capture crew. The transport helicopter landed nearby to provide additional assistance. When a caribou was safely restrained, its rectal temperature was taken by the project veterinarian or trained designate. Caribou were released immediately if their rectal temperature was > 41°C. Caribou were aged (incisor eruption pattern and wear) and received a brief physical examination. If considered appropriate, each animal was sedated for transport and allowed to respond.

During year 1, a sedative was not routinely used during helicopter transport, but in subsequent years caribou were sedated with a standard dose of 10 mg medetomidine administered intranasally (IN) using a laryngo-tracheal mucosal atomizer. If required, an additional 5 mg medetomidine was given IN or intramuscularly (IM) during transport or after arrival in the pen. Once sedated, caribou were secured in specially designed restraint bags packed with snow, loaded onto the transport helicopter, and flown to an unloading area near the maternity pen. A maximum of two sedated caribou could be transported in the helicopter. During the transport flight a project veterinarian or biologist supported the animals in sternal recumbency with the head up, and monitored the reflexes, respiration, and cardiovascular function of the caribou. Communication on the location of capture and any relevant health data such as body temperature was noted on a datasheet for transfer to the pen site. Two subadult male caribou were captured in error; one was kept in the pen while a second was returned to the wild.

Processing caribou at the pen site

Sedated and restrained caribou were unloaded from the transport helicopter at a drop-off area 200 m from the maternity pen to reduce helicopter disturbance to animals already in the pen. Each caribou was carried from the helicopter to a snowmobile skimmer with padding. A handler was positioned in each skimmer holding the caribou's head up (Photograph 3) to maintain the animal's airway and minimize the risk of regurgitation and aspiration. Once the caribou and handler were positioned, a slow-moving snowmobile dragged the skimmer into the pen to the processing site. Depending on capture logistics in the field, one or more caribou entered the pen at a time. The processing teams in the pen consisted of a data recorder, two or three animal handlers, and one project veterinarian was available for each caribou being processed.

Caribou processing occurred as quickly and quietly as possible. Upon entrance into the pen, each caribou was weighed on a portable scale while still blindfolded, hobbled, and in the transport bag. After weighing, caribou were removed from bags. The processing protocol included a complete physical examination and health assessment by a veterinarian familiar with the capture of free-ranging wildlife and *Rangifer* health. As part of this assessment, biological samples were collected from each animal for a standardized set of health measurements or archived for future research. In year 1, an ultrasound was used to determine pregnancy status of each caribou, but in following years pregnancy was assessed with serum progesterone and/or Pregnancy Specific Protein B (PSPB).

Photograph 3. Position of the animal handler and adult caribou during transfer from drop-off area to the maternity pen. Caribou were transported using a slow-moving snowmobile and skimmer. Photograph by RCRW.

Following the health assessment and sampling, each caribou was fitted with a Global Positioning System (GPS) radio-collar and ear tagged with permanent, uniquely numbered/coloured markers. All caribou received several prophylactic treatments including:

1. An anthelmintic [doramectin (Dectomax®) or ivermectin (Ivomec®) @ 1 ml/50 kg subcutaneously (SQ)] to reduce the parasite burdends of penned individuals.
2. An anti-inflammatory [ketoprofen (Anafen®) @ 3 mg/kg SQ] to reduce the chance of capture related trauma and pain (e.g., bruising, small cuts and abrasions) that can occur when caribou are captured by net-gun.
3. Vitamin E plus selenium [antioxidant (Dystosel® @ 1 ml/45 kg SQ)] to reduce issues due to low physiological levels of these compounds leading to muscle damage from capture.
4. Other medications or treatment protocols as considered necessary by attending project veterinarians.

Once the collaring and tagging were complete, hobbles and blindfolds were removed, and sedation was reversed with 50 mg atipamezole (IM) or 5-times the total medetomidine dose (IM). Sedated caribou were ambulatory within <5-10 minutes after administration of the reversal agent. Total processing time was generally under 15 minutes from a caribou's arrival in the pen to reversal and recovery.

Body condition measurements

It has long been recognized that nutrition has universal influences on animal performance that have important implications to survival, recruitment, and population dynamics. For large herbivores like caribou, nutrition is a function of forage abundance and quality available on the seasonal ranges they occupy. However, though many techniques are available to measure quality and quantity of plants across landscapes, it is challenging to measure nutritional value of habitats from the perspective of a foraging caribou. Alternatively, body condition (e.g., body fat and protein) is a product of nutrient and energy balance (i.e., acquisition versus expenditure over months or longer), and therefore has been used as an index for evaluating seasonality and severity of nutritional limitations, predicting population growth, and evaluating how nutrition may interact with predation or disease to affect survival (e.g., Bender et al. 2008, Dale et al. 2008, Couturier et al. 2009, Cook et al. 2013, Monteith et al. 2014, Johnson et al. 2019b).

Although estimates of body fat of woodland caribou have rarely been published, surveys of body condition could provide valuable information on the extent to which nutritional limitations may be operating in caribou populations. Data from populations showing animals with good to high body condition levels most of the year may indicate that nutritional limitations are of little practical concern. However, body condition estimates that indicate small and thin animals may identify populations for which additional, detailed nutritional studies are appropriate, perhaps essential, to holistically understand the full contributions of the population's environment to its persistence through time.

In late March of 2016 and 2018 (years 3 and 5), we estimated body fat and non-pregnant body mass on 32 adult female caribou captured for maternal penning. We used an Ibex ultrasonograph with a 5.0 MHz, 7.0-cm probe (E.I. Medical Imaging, Loveland, Colorado) to measure the maximum thickness of the rump fat layer and to measure thickness of the longissimus dorsi muscle (loin) between the 12th and 13th ribs (Stephenson et al. 1998, Cook et al. 2001, Cook et al. 2007, Cook et al. in press). We also recorded a body condition score that was originally presented for caribou by Gerhart et al. (1996) but modified to increase repeatability among observers (Cook et al., in press). We arithmetically combined rump fat thickness, allometrically scaled to the surface area of the caribou's body to adjust for differences in caribou size, and our body condition score to estimate ingesta-free body fat for each caribou. This new index (scaledLIVINDEX: method 3 described in detail by Cook et al. 2010) is well-correlated ($r^2 \geq 0.89$) to body fat in deer (*Odocoileus spp.*) and elk (*Cervus canadensis*; Cook et al. 2010) and caribou (Cook et al., in press). We estimated non-pregnant body mass (minus the products of conception) using girth-circumference and equations that accounted for body fat levels (Cook et al. in press; Cook et al. 2003). We considered body fat to be the primary measure of nutritional condition, but we included estimates of body mass and loin thickness to evaluate possible differences in lean mass.

Animal care and monitoring during captivity

In years 1 and 3, animal husbandry training sessions were delivered to pen shepherds and RCRW staff by project veterinarians. Training included: how to observe caribou for adequate nutrition, signs of illness or stress, and signs of parturition; how to conduct daily care and monitoring procedures; record-keeping; biosecurity and hygiene; minimizing stress; and emergency response procedures and use of basic animal First-Aid equipment. Pen shepherds were also trained in firearms handling in the event that predators became an imminent threat to animal welfare.

Detailed adult and calf husbandry protocols were developed based on expertise from other maternal penning projects and management of domestic ruminants (see section 4.1 of the overall final report). Protocols included guidelines for feeding, pen cleaning and maintenance, animal observation, predator detection and deterrence, health assessment, calving, orphaned calf care and responding to a health crisis. Husbandry protocols were adapted and refined over the course of the project.

During captivity, caribou were monitored during daylight hours from the observation blind and tree-stands. Radio-telemetry was used to monitor movement and locate individuals for daily observations. Observations were recorded twice per day and included weather conditions, predator detections, caribou activity, feeding times, pen maintenance performed, and any abnormal observations. Night-time activity recorded on the motion-triggered video camera was viewed each morning. Weekly body condition scores (5-point subjective scale) were collected to monitor nutrition. Body mass was collected using a platform scale once the snow cleared in April. The platform scale consisted of a 2 m^2 ply-wood panel overlaying a commercial scale. Lichen was used to entice individuals onto the scale and body mass was recorded by observers in the main blind and with a motion-triggered camera.

Caribou were exclusively fed lichen on pen entry and transitioned to custom feed pellets formulated for caribou over the course of 10 days at a change rate of *c*. 10%/day. In years 1 and 2, the pellet source was Hi-Pro Feeds, and in years 3 to 5 the supplier was Wetaskiwin Co-op Association Ltd. Caribou were provided 3.2 kg pellets/animal/d with adjustments based on consumption. Pellets were refreshed twice per day; pellets that became damp or were more than two days old were discarded. Commercial livestock feeding troughs were used during years 1 and 2 but were prone to feed wastage from moisture and contamination from calves climbing in the troughs. In year 3, narrower troughs were constructed out of 20-cm potable water pipe cut lengthwise and set into the larger commercial feed troughs. Feces were removed from feeding areas weekly, or as needed, to prevent build-up.

Numerous minor episodes of choking and coughing were observed during feeding of the pelleted diet. This behaviour appeared to decrease in frequency during the penning period. Choking can result in aspiration of feed and in severe cases can be fatal. Aspiration can be attributed to rapid ingestion of pellets, especially by subordinate animals, and the fine, dry texture of the pellets and pellet dust. To alleviate choking, pellets were filtered through a mesh screen to remove fine dust, and large stones were placed in the troughs to slow consumption.

The perimeter of the pen was walked daily to look for predator or tracks (lynx [*Lynx canadensis*], wolf, bear, cougar [*Puma concolor]*, wolverine [*Gulo gulo*]). During years 1–3, four Reconyx motion-triggered wildlife cameras were deployed around the perimeter and access road to the pen. Detection was only determined after downloading the content from the cards. For the last two years of the project, these cameras were supplemented by three Buckeye cameras which immediately transmitted images to the project laptop for review and possible response by pen shepherds.

In early May, pen shepherds increased monitoring of caribou for signs of impending parturition, e.g., separation from the group, pacing, visible fetal membranes, or neonate presence at heel. Time of birth was determined by previous observations and activity patterns of the adult and first sighting of the neonate. Between 24 and 48 hours after birth, calves were captured by hand for processing. This allowed sufficient time for colostrum ingestion, maternal bonding and minimized disturbance to the rest of the herd while the pair was usually still isolated. Calves were weighed, sex was determined, a permanent ear tag was applied, and a hair sample was taken. In some years, each calf was fitted with an expandable mortality-sensing radio-collar (see next section for details). Chase and handling times were recorded and kept to under 3 minutes.

Mortalities were investigated to identify cause of death to the degree possible with a full necropsy performed either by a project veterinarian or a veterinary pathologist. A standard protocol for examination and sample collection was followed. Tissues collected included lung, liver, kidney, heart, muscle, brain, skeletal muscle, spleen, long bone, blood, sections of gastrointestinal tract, brain, uterus, fetus if present, internal and external parasites if present, and any abnormalities detected. Histological and microbiological examinations were completed at the Animal Health Centre (Abbotsford, BC).

Monitoring post-release

Various models of Vectronic GPS collars were deployed on the adult females as the benefits and shortfalls of each model became apparent. Each collar model had a VHF (very high frequency) transmitter in addition to the GPS system. The VHF schedule was programmed to transmit 11-14 hours per day, and facilitated location monitoring of individuals by pen shepherds, as well as post-release collar recovery.

In years 1, 2 and 3, Vectronic GPS PLUS Iridium collars were deployed on 12, 18, and 12 animals, respectively. In years 1 and 2, collars were programmed to acquire 12 locations (or 'fixes') per day, and in year 3, the number of fixes was reduced to 6/d to extend battery life. Mortality delay for collars was set at 12 hr. In these years, Vectronic proximity collars were deployed on calves. These calf collars were dependent on proximity to the adults for location fixes and sent a 'separation' signal when the adult collar could not detect the calf collar. Each calf collar was also fitted with a VHF transmitter, and if a separation signal was detected, the collar could be located using a VHF receiver.

This collar technology resulted in multiple separation alerts and false mortality signals from the calf collars. Most calf collars were dropped in year 1 due to the elasticity and construction of the strapping material. In subsequent years, a more robust material was used that reduced the number of prematurely dropped collars. The reliability of these collars was poor because the VHF signal between the calf and adult collar was inconsistent. Often only one or two adult collars were relaying information for multiple calf collars and not just their own calf. Sensitivity of proximity sensors ranged between 200 m and > 3 km, meaning that separation alerts were unreliable. These inconsistencies prompted the use of different collar models in years 4 and 5.

In year 4, Vectronic Vertex Lite Globestar collars fitted with a timed remote release, or "blow-off," were used on 12 adults and Vertex expandable VHF fawn collars were used on calves. Adult collars were programmed to acquire 2 fixes/d, with the same 12-hr mortality delay as in previous years. One collar deployed in year 4 released prematurely, blowing off 1 mo post-release. Collars in year 4 had premature failure of their GPS transmitters, and subsequent failure of the VHF transmitter shortly after. Within twelve months post-release, 6 adult collars had gone off-air by the following July, amounting to a 54% failure rate. The calf collars were standard VHF telemetry collars that required monthly flights to determine calf survival. While this reduced the opportunity to respond immediately to calf mortality events, a survival rate could nonetheless be calculated based on monitoring these VHF collars.

In year 5, Vectronic GPS PLUS Globestar collars with a rot-off insert were used on 17 adult caribou. These collars acquired a fix every 13 hr and did not require intervention for removal. No collars deployed in year 5 have failed and the transmission of fixes has been reliable. Calf collars in year 5 were again Vertex expandable calf collars, transmitting a VHF signal 12 hr/d.

GPS collars were monitored daily, and any mortality events were investigated as quickly as possible. Investigations were conducted by experienced biologists using the standardized mortality and necropsy protocols, and detailed necropsy results are presented in Appendix 2.

Vital rates and population estimation

Compared to other ungulates in North America, mountain caribou in southern BC are easy to enumerate because they have high sightability (> 90%) in late March during years of average or greater snowfall (Wittmer et al. 2005). Their late-winter habitat is located high in the mountains at treeline where they forage almost exclusively on arboreal lichens found in the canopy of old conifer trees (Apps et al. 2001, Serrouya et al. 2007). Most mountain caribou subpopulations are censused every 2 to 3 years, but those subjected to intensive management treatments (e.g., Serrouya et al. 2019) are usually counted annually. However, not all years have adequate snowfall, therefore during years when a complete census was not possible because of low snow depth, we could still survey the core herd area and obtain recruitment rates. Recruitment is tracked as the proportion of the population that are 10-month-old calves. During March surveys we estimated the proportion of calves observed that were born in the pen since all adult females from the pen and most of their calves were marked.

Survival of penned calves after release from the pen was estimated by radio-collaring them shortly after birth. Collaring was attempted on all calves during the first two years of the study but concerns about the potential impact of handling on in-pen calf mortality led to reduced collaring during the latter years. Furthermore, calf collars frequently fell off prematurely because they were designed to rot off easily to minimize risks to rapidly growing animals. These two factors greatly reduced sample size of collared calves. Therefore, we also relied on aerial recruitment surveys in winter to infer survival, because these animals have high sightability in March and the adults were radio-collared. In summary, two methods were used to estimate recruitment into the population. The first method used March surveys (or censuses if snow conditions were deep enough), where recruitment was estimated as the proportion of calves in the population. This estimate could be partitioned into penned and unpenned animals. The second method was to estimate survival based on collared neonate calves born in the pen, though sample size was limited for this analysis.

Survival of calves while inside the pen (termed the penning period) was calculated by dividing the number of calves released from the pen by the number of pregnant females placed in the pen. This approach differs from typical neonate calf collaring studies where a calving event is estimated from daily aerial monitoring of collared adult females or vaginal implant transmitters, thus these events become the denominator or "at risk" sample. We used pregnancy rate as the denominator because this matches how wild calf survival was estimated. Furthermore, detailed monitoring of adult females in the pen provided data on abortions, stillbirths and complications at parturition that are rarely identified in studies of wild animals (see details in "Net calves produced" section). Nonetheless, the number of dystocias, abortions, and stillbirths are also reported, so readers can calculate other relevant neonatal survival rates as required.

Unlike some populations of woodland caribou (Adams et al. 2019), aerial observations of calves at heel were not possible during summer and autumn because of very dense tree cover, so recruitment from aerial surveys could only be estimated during late winter. As well, adult female vs calf ratios were usually not possible to estimate because the sex ratio of adults can be difficult to determine since both males and females have antlers. Confirming sex of adults would require extra harassment with the helicopter which increases risk to this endangered ungulate.

Adult survival was estimated from the telemetry monitoring of collared adults that were captured and penned. Survival was calculated during the penning period (April to mid-July), and during the rest of the year, with the product of the two time periods yielding the annual rate. These values, matched by the same time periods, were compared with wild adults, though comparisons were not matched by year because no wild sample existed during the penning treatment (see next section). Confidence intervals were calculated for wild animals only, by bootstrapping the distribution of individual caribou 3000 times.

Contribution of the pen to population growth

Two factors determine whether maternal penning can affect the population growth rate (λ). The first is the magnitude by which the pen changes calf and adult female survival, and the second is the proportion of adult females placed in the pen. Based on the timing of calf mortality in wild populations (Adams et al. 1995) and results from other penning studies (Adams et al. 2019), we expected that penning would increase calf survival, and may increase adult survival because the penning period corresponds to higher predation risk to adults, as well as providing a nutritional supplement (Wittmer et al. 2005). Our baseline to gauge the effect of the pen was a comparison of vital rates since the moose reduction treatment began (2004 to 2010), which amounts to a before vs after comparison. We did not have a concurrent sample of wild animals that were monitored, so a temporal control design could not be implemented. However, some animals that were caught as part of the penning project were still radio-collared from a previous penning period. These animals were considered "wild" but sample size was small and it could be argued that their survival was affected by having previously been in the pen. Therefore, for the comparison, we relied on vital rates leading up to when the penning treatment began. Prior to the moose reduction treatment, adult female survival was 0.784 (0.556 – 0.944), then increased to 0.868 (0.751 – 0.955) from 2004 to 2010 (Serrouya et al. 2017b). Given that reduced moose numbers continued when penning began, the relevant survival rate to use for baseline (pre-penning) comparison is 0.868.

We contrasted values obtained from penned and unpenned animals by using the vital rates estimated above in a post-breeding stage-based matrix model. Stages were defined as calf (0-1 years), yearling (1 – 2 yr old), juvenile (2 – 3), and adult (≥4 yr). The calf sex ratio was set at 50:50. We also assumed that yearlings and juveniles survived at the same rate as adults, although this may positively bias λ projections (Serrouya et al. 2017a). We set female reproduction at F_j = 0.57 (Adams et al. 2019) for 2-years old and F_a = 0.89 for ≥ 3-years old, using the following matrix projection:

$$\begin{pmatrix} N_{c,t+1} \\ N_{y,t+1} \\ N_{j,t+1} \\ N_{a,t+1} \end{pmatrix} = \begin{bmatrix} 0 & 0 & F_j & F_a \\ S_c & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_j & S_a \end{bmatrix} \begin{pmatrix} N_{c,t} \\ N_{y,t} \\ N_{j,t} \\ N_{a,t} \end{pmatrix}$$

where F is the fecundity (i.e., pregnancy rate), S is survival, N is abundance, and the subscripts *c, y, j* and *a* refer to calves, yearlings, juveniles, and adults, respectively.

We then estimated the proportion of the population that was penned, based on the number of adults placed in the pen, the overall population estimates during the study period, and the adult sex ratio (which was unknown, but see next section below). We then weighted the vital rates by the proportion of adult females penned to estimate the effect of the 5-year penning trial on λ for the Columbia North subpopulation. We conducted a sensitivity analysis of this matrix model to determine which vital rates had the largest influence on λ, but also to address uncertainty about parameters such as the adult sex ratio which was not directly observed (but affects the estimate of the proportion of adult females penned), and more robust parameters such as population size and pregnancy rate.

Net calves produced

The number of calves produced by the maternity pen and released alive is straightforward to report, but the more relevant metric is to estimate the net number of calves added to the population (i.e., over and above wild calves). To estimate this metric, we needed to know the number of penned calves alive the following March and the number of calves that would have been recruited in the absence of penning. The difference between these two numbers is the net contribution from the pen. The number of wild calves that would have been produced in the absence of penning (termed equivalent wild calves; EWC) was estimated by multiplying the wild calf survival rate by the number of adult females penned.

EWC = $S_{wildcalf}$ x No. Adult Females penned

In other words, this value represents what those penned adult females would have recruited, had they not been in the pen. Wild calf survival (S_{calf}) was calculated by dividing the number of calves observed during March surveys by the estimated number of pregnant females (NPF), i.e.:

S_{calf} = No. wild calves / NPF

We calculated NPF using the following equation:

NPF = (No. wild caribou – No. wild calves) x (proportion of adults that are females) x pregnancy rate

The number of wild caribou and calves was estimated during March recruitment surveys. The pregnancy rate was obtained from the captured sample of adult females (and was similar to the value reported by Wittmer et al. 2005). The proportion of adults that are females = 100 / (100 + [No. of adult males per 100 adult females]).

As mentioned, the adult sex ratio is a poorly known parameter for this local population on an annual basis. However, it was found to vary between c. 50 and 70 in southern mountain populations of woodland caribou in BC (Serrouya et al. 2017a). Given the uncertainty about the adult sex ratio, we used a central value of 60 but varied it from 50 to 70 to bound estimates of the number of net calves produced, similar to the approach of Serrouya et al. (2017a). Similarly, we did not have annual estimates of wild caribou pregnancy rates, but over a 20-yr time period, Wittmer et al. (2005) reported the pregnancy rate to be 0.92, and capture from this project provided annual pregnancy rates that varied from 0.85 to 0.92, with a mean of 0.89.

Factors affecting calf survival in the pen, and post release

A variety of abiotic and biotic factors can influence the survival of neonate ungulates (Adams et al. 2019). Based on the literature and our field observations, we developed a set of variables to explain calf survival. We considered calf birth mass, calving date, sex, number of days reared in the pen, and spring temperature as potential covariates. We expected birth mass to positively affect survival, and calves that spent more time in the pen would have higher survival post release (Adams et al. 2019). There was considerable variation in calving dates (May 19 to July 8), so we created a variable called 'days from May 30' (the median calving date), which ranged from –11 to +39, to account for the possibility that late-born calves had a lower probability of survival. There was also substantial variation in spring temperature across the 5 years of study, and preliminary observations as well as information from the literature suggested that temperature stress could negatively affect late gestation and lactation (Reinemann et al. 1992). Therefore, we considered the maximum daily temperature as an average for the month of May, while most calves were still in utero, as well as June, when most calves were born and dependent on lactating females. We also considered the number of times an adult female was brought into the pen (capture frequency), reasoning that multiple captures along with penning may negatively affect calf survival through subclinical impacts on physiology, or conversely may improve calf survival due to improved nutrition from repeated feeding in late winter.

It was challenging to consider all potentially relevant factors because some would be difficult to decouple. Any effects that are estimated as one value per year, such as pen stocking density and May temperature, would be completely correlated. Because of this design, we used a random intercept with the effect of year treated as a grouping factor, to account for annual variation. Similar to Adams et al. (2019), we ran parallel survival analyses using two sets of data: with and without birth mass. We weighed fewer calves during the latter years of study because of concerns that disturbances associated with capture and handling of calves contributed to in-pen injuries from trampling and mortalities. Including birth mass in all analyses could introduce a bias because some effects such as temperature would be less likely to be detected during the latter years given that a lower proportion of birth mass data was collected during the hottest year, which was the final year of study.

We repeated survival analyses across two time periods: mortalities that occurred in the pen, and those that occurred from survivors that were released from the pen to the following March. For both time periods, we used logistic regression to predict the probability of survival. We did not use more complex time-to-event models because data on timing of death post release was sparse. Therefore, the response metric was binary, whether or not the calf survived to the end of the penning period, or whether it was present during March surveys (though in reality this metric was supported by repeated flights during the winter to monitor the collared adult females, so that multiple viewings of cows without a calf at heel was used to estimate the absence of a calf). Logistic regression models were run using the lme4 package in r (Bates et al. 2015), and candidate models were ranked using AICc (Burnham and Anderson 2002) using MuMIn (Barton 2020). To guard against the inference of models that contain uninformative variables, we considered relative importance of individual variables, in addition to the weights of individual variables (Arnold 2010), R^2 were calculated using the r.squaredGLMM function in MuMIn. This function calculates a marginal R^2 for the fixed effects, and a conditional R^2 for the entire model, so that the additional variance of the random effect (year) could be quantified.

3. Results

A total of 72 adult female caribou were transported to the pen, ranging from 10 to 20 in a given year (Table 1). Two 10-month-old female calves were also transported to the pen during the first year because they were part of the larger groups that were captured (these calves were ear tagged but not collared, and released at the same time as the other caribou). In year 3, two subadult male caribou were transported to the pen in error and were released at the same time as the other animals.

Vital rates

Of the 72 adult females captured and transported to the pen, 64 were pregnant (0.889; Table 1). Adult survival in the pen was 0.944 (68/72), with one mortality in year 2 and three in year 5. Causes of mortality included dystocia (n = 2), internal infection, and poor nutrition (Table 2, Appendix 2). Survival post-release until March 31 the following year was 0.889 (56/63 functioning collars). Annual survival of adult females subjected to the penning treatment was 0.840, compared to 0.868 (0.750 – 0.948) from 2004 to 2010 for the wild animals prior to penning. Causes of death post-release included predation by wolves (n = 3) and cougars (n = 2; note that 2 adults and 2 calves were killed in one predation event by a single cougar), an avalanche (n = 1), and a severe infection and invasive tumor of the head that was first detected at capture (n = 1). One uncollared adult male was also killed in the same avalanche as the female.

Table 1. Summary of the number of adult females captured, calves born, and different life stages during penning (e.g., number of pregnant adults, number of adult females and calves released, number of adults and calves that died) by year.

Year	Adult females captured	Pregn -ant	Calves born[c]	Calves collared and released	Calves released	Calf mortality in pen[D]	Adults released	Adult mortality in pen	Adults at risk[a]	Adults that died[a]	Calves at risk[a]	Calves that died
2014	10	9	9	9	9	0	10	0	10	0	5	4
2015	18	16	15	11	11	4	17	1	15	2	8	2
2016	12	11	11	6	7	4	12	0	9	1	3[b]	1[b]
2017	12	11	10	5	9	2	12	0	12	1	4	1
2018	20	17	14	6	11	2	17	3	17	3	5	1
Total	72	64	59	37	47	12	68	4	63	7	25[b]	9[b]

[a]At risk means having functioning radio collars, and numbers reported apply from pen release to the following March.
[b]One calf died due to ice buildup on the collar, so it could be removed from survival estimation, thus the post-release survival rate is = 1 - (8/24) = 0.667, as opposed to 1 - (9/25) = 0.640.
[c]A birth was considered live, and thus excluded a spontaneous abortion (n = 1; 2015), dystocia (n = 2; 2018), and stillbirth (n = 2; 2017 and 2018)
[D]Includes 3 calves that died at the Calgary Zoo (2015: n = 2; a fracture and an infection; 2016 fracture), but the "mortality process" began in the pen. This column excludes the dystocias, stillbirths, and the spontaneous abortion, since they were not "live born" in the pen.

From the 64 pregnant females, 59 calves were born and 47 were released. The median calving date was May 30 (Fig. 2) The known sex of calves was 32 female (53%) and 29 male (47%). Sex was determined while radio-collaring, or if the calf was not handled for collaring, sex was determined at the time of death. One sex was not known because it was not handled, and pen shepherds were unable to determine sex while calves were urinating. Twelve calves died in the pen and one was orphaned and sent to the Calgary Zoo (and was alive at time of writing). In 2015, one pregnant female did not calve so it was suspected that a spontaneous abortion occurred following capture. Two dystocias occurred that resulted in the death of adults and calves, and although the calves were not born live, they were still considered as dead relative to the denominator which was the pregnancy rate.

Survival in the pen to release was 0.734 (47/64; note that 47 does not include the orphaned calf sent to the Calgary Zoo; its mother died shortly after birth so this calf would have likely died regardless). Of the 47 calves released, 25 had functioning radio-collars to estimate survival for the remainder of the year, however one of these animals died because a large ball of ice accumulated on the collar and caused suffocation, so it was excluded from analyses. Therefore 24 calves were considered "at risk" and 8 died during the remainder of the annual cycle, for a post-release survival rate of 0.667. However, if the collaring process is considered part of the maternity pen “management action,” then that mortality should be considered part of the survival estimation (unlike traditional collaring studies), in which case the post-release survival rate is lower: 0.640. Combining in-pen and post-release rates produces an annual calf survival of 0.490 (or 0.470 if the ice-collar calf is included). Known causes of calf death post release were predation by wolves (n = 2), cougars (n = 2), and black bear (n = 1). Cause of death was not known for two collared calves because we were unable to get to the carcasses in time. The alternate method of estimating calf survival, i.e., using March recruitment surveys, provided a survival rate of 0.438 (28 observed/64 pregnant females in the pen).

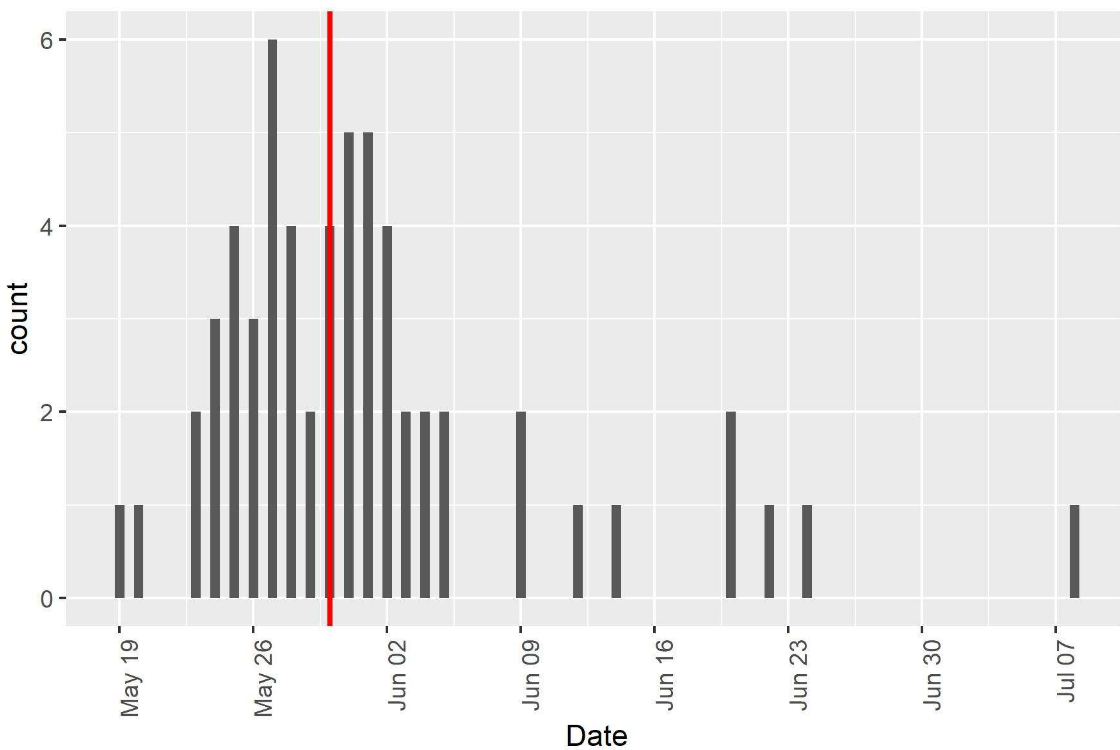


Figure 2. Frequency distribution of birthing dates (n = 59) for calves born in the RCRW maternity pen. The median calving date (red line) was May 30.

Net addition of calves

Across the 5-year study, we estimated that the total of 435 caribou counted during March surveys included 224 pregnant females. Given that 57 10-month-old calves were observed during those surveys, survival of wild calves = 0.271 (0.255–0.288 depending on adult sex ratio [50-70 males per 100 females]). Thus, the 72 adult females included in penning would have produced 19.5 calves if left to calve in the wild. We observed 28 penned calves that survived to mid-March, so the additional calves resulting from penning equaled 7.9 (6.7–9.2 depending on adult sex ratio). Detailed calculations are:

$$NPF = (435 – 57) \times (0.625) \times (0.889) = 210$$

Values in [ ] represent the range when the adult sex ratio was varied from a low of 50 to a high of 70 males per 100 females.

$$S_{wildcalf} = 57 / 210 = 0.271 \ [0.254 – 0.288]$$

Then, EWC = $S_{wildcalf}$ x No. Adult Females penned = 0.271 x 72 = 19.5, which is the number of calves that would have been produced to March 31 in the absence of penning. Given that 28 calves were observed during March surveys, the difference between 28 and EWC = 8.5 [7.2 - 9.7], which is the number of calves estimated to have been added to the population over the five years of maternal penning. Figure 3 shows the change in $S_{wildcalf}$ and recruitment over the course of the project.

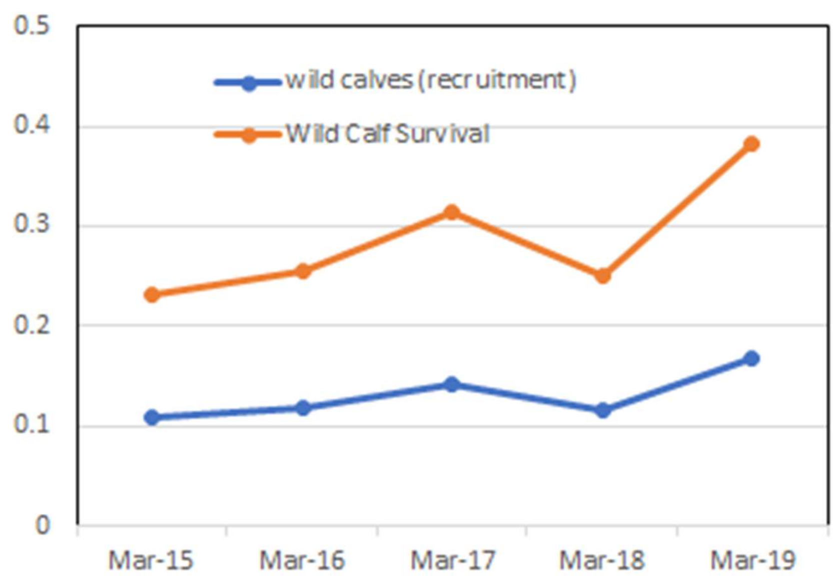


Figure 3. Recruitment (proportion of calves in the populations) of wild calves in March following each year of maternal penning, obtained from aerial surveys. Also shown is an estimate of wild calf survival, based on the assumptions and equations presented in the Methods (e.g., adult sex ratio of 60 males per 100 females, pregnancy rate of 0.889).

Table 2. Summary of calf and adult female (AF) mortalities and injuries during penning. WLH ID refers to the Wildlife Health ID.

Caribou ID	WLH ID	Calf /AF	Associated Calf /AF ID	Date of Death /Incident	Description of Findings	Cause of Death/Final Diagnosis
2015-19	15-6411	AF	2015-20	28 May 2015	Found dead. Had appeared sick prior to death. The carcass was emaciated, and post-mortem showed nutritional stress.	Nutrition
2015-20	15-6592	calf	2015-19	28 May 2015	Found dead at 4 days old. The carcass was emaciated and the stomachs empty. Likely neonatal and in-utero malnutrition.	Neonatal death – nutrition
2015-22	15-6593	calf	2015-05	29 May 2015	Found dead at less than 1 day old. Post-mortem showed Inflammation of the lungs, brain, and peritoneum. Gastrointestinal protozoal infection.	Neonatal death – infection
2015-32	none	calf	2015-01	26 June 2015	Fracture of front leg possibly due to a herd stampede on 26 June 2015. Captured and transported to Calgary Zoo for treatment. Died on 5 July 2015. Post-mortem showed rib fractures, front leg fracture, and respiratory infection.	Injury – fracture – zoo
2015-34	none	calf	2015-09	6 July 2015	Calf lethargic. Captured and transported to Calgary Zoo for treatment. Died 12 July 2015. Post-mortem showed infection of the lungs, liver, and abdomen associated with umbilical infection.	Neonatal death – infection – zoo
2015-09	14-4968	AF	2015-34	15 May 2018	Draining wound on top of shoulders. Immobilized and treated on 2 July 2018. Released with group.	**Recovered** – wound infection
2016-15	16-8377	calf	2016-03	28 May 2017	Found dead at 3 days of age. The carcass and a piece of placenta were submitted. The placenta had signs of infection; no other cause of death was determined but likely placentitis.	Neonatal death – infection

Caribou ID	WLH ID	Calf /AF	Associated Calf /AF ID	Date of Death /Incident	Description of Findings	Cause of Death/Final Diagnosis
2016-19	16-8389	calf	2016-08	25 May 2016	Calf found recumbent, unresponsive, and breathing slowly at 2-3 days of age. Treatment initiated, but died. On post-mortem, gastrointestinal infection was present.	Neonatal death – Infection
2016-20	none	calf	2016-09	26 June 2016	Fractured right hind leg. Captured and transported to Calgary Zoo for treatment. X-rays showed severe fracture of the right femur. Died on 2 July 2016.	Injury – fracture – zoo
2016-21	none	calf	2016-10		Severe right hind lameness. Captured and hip dislocation treated on site. Recovered and released.	**Recovered** – dislocated hip
2016-23	none	calf	2016-12	20 May 2016	Found dead at 2 days of age and scavenged. No injuries or wounds were found. Necropsy showed infection of the brain due to an unknown cause.	Neonatal death – Infection
2017-20	17-9973	calf	2017-08	23 May 2017	Stillborn, likely on 22 May 2017. The fetus was scavenged, but skeletal abnormalities were found, including contracted limbs and an abnormal head shape.	Stillborn – Congenital malformation
2017-18	17-9983	calf	2017-05	26 June 2017	Found dead at 2 days of age. Diagnosed as septicemia due to umbilical infection.	Neonatal death – Infection
2018-05	17-10638	AF		30 May 2018	Found dead 2 days after calving. On post-mortem there was fluid in the abdomen and inflammation of the uterus and placenta.	Infection – Neutrophilic placentitis
(Kirby)	18-12195	calf	2018-05		Cow found dead during neonate collaring. Calf treated on site for dehydration and hyperthermia. Calf transported to Calgary Zoo where it recovered and is currently kept.	**Recovered** Zoo – Orphaned

Caribou ID	WLH ID	Calf /AF	Associated Calf /AF ID	Date of Death /Incident	Description of Findings	Cause of Death/Final Diagnosis
2018-06	16-8285 (2016), 17-10639 (2018)	AF	Calf stillborn, no calf ID assigned	9 May 2018 25 May 2018 31 May 2018 June 2018	Severely infected ear wound at capture treated. Immobilized twice in May for treatment, then to calve a stillbirth. Immobilized in June for treatment. Released from the pen early and alone in June. Found dead in November 2018, emaciated with a severe infection and an aggressive squamous carcinoma involving her jaw and invading her spine.	**Recovered** Neoplasia infection
-	none	calf	2018-06	31 May 2018	AF had been sedated and treated multiple times for an infection of the face/ear. Calf delivered dead.	Stillbirth
2018-11	17-10644	AF		28 May 2018	Found dead after seen in labour 20 minutes prior. On post-mortem the calf was breech. Post-mortem revealed poor body condition and inflammation of the placenta.	Dystocia – malnutrition placentitis
-	-	calf	2018-11	May 28 2018	Found dead with AF during parturition. Calf presented backwards with hock protruding from vulva. Calf's metatarsals were fractured from the cow struggling.	Dystocia
2018-17	17-10650	AF		27 May 2018	Observed in prolonged labour. Immobilized but died. On post-mortem a laceration of the uterus and blood in the abdomen were found. Metritis diagnosed.	Dystocia
-	-	calf	2018-17	27 May 2018	Calf presented normally but pulled from cow dead.	Dystocia
2018-19	17-10652	AF	2018-32	17 May 2018	Severe right hind lameness on 15 May 2018. Immobilized on 17 May 2018 and no abnormalities detected; however, a 'pop' heard during positioning. Likely hip dislocation treated successfully. Released.	**Recovered** – hip dislocation
2018-26	18-12197	calf	2018-08	9 June 2018	Front left leg fracture at over a week of age. No other abnormal findings. Euthanized.	Injury – fracture – euthanasia

Caribou ID	WLH ID	Calf /AF	Associated Calf /AF ID	Date of Death /Incident	Description of Findings	Cause of Death/Final Diagnosis
2018-30	18-12200	calf	2018-16	9 June 2018	Front left leg fracture at over a week of age. No other abnormal findings. Euthanized.	Injury – fracture – euthanasia

Factors affecting calf survival in the pen, and post release

Survival in the pen

Our analyses of in-pen survival included 63 potential calving events and 15 calf deaths (12 live born calves that died plus the 2 dystocias and stillbirth from 2018). We excluded the apparent abortion from 2015 because most variables would have no data associated with this event (e.g., birth mass, birthing date, sex). However, when the data were restricted to samples with known birth mass, there were 45 births and 10 deaths.

The mean maximum daily temperature in May ranged from 19.2°C in 2014 to 24.6°C in 2018 (Fig. 4). Compared to June temperature, May temperature explained > 2 orders of magnitude more variation in pen mortality, but neither relationship was significant. Nonetheless, because this analysis revealed that May temperature was more predictive, we retained this variable for subsequent multivariate logistic regression analyses.

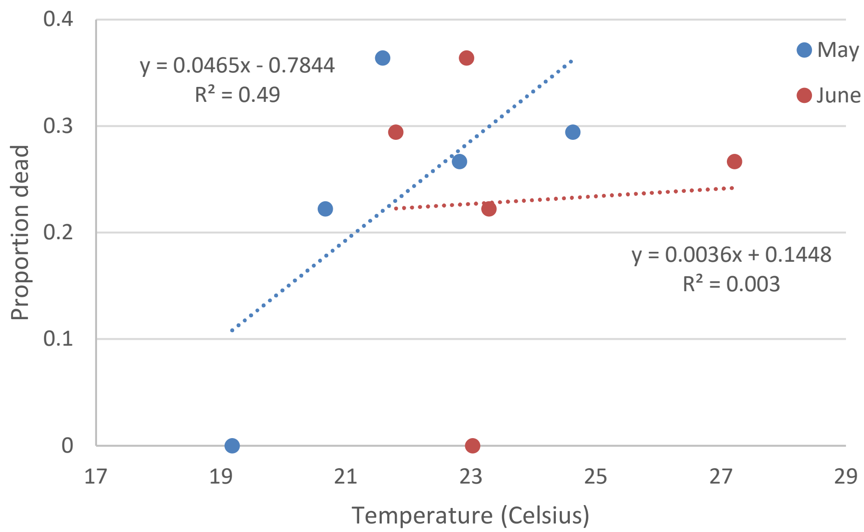


Figure 4. The relationship between mean maximum daily temperatures for May (blue) and June (orange), and the proportion of calves that died in the pen. Neither relationship was significant based on a linear model ($p > 0.14$).

To predict survival in the pen, fixed effects included in the full logistic regression model were calf sex, birth mass, birthdate from May 30, and May temperature. Birth mass was positively and significantly associated with survival and was present in all models within 4 AICc of the top model (Table 3), with the exception of the intercept-only model (ΔAICc = 3.58). R^2 for the top ranked models ranged from 0.21 to 0.36 for the fixed effects components of the model (marginal R^2), but R^2 for the full model (conditional R^2) were consistently and substantially higher, meaning that the effect of year accounted for considerable variation (Table 3).

Table 3. Model selection with coefficients for fixed effects predicting calf survival while in the maternity pen. Results within 4 AICc units of the top model are included. Marginal R^2 refers to the fixed effects, whereas conditional R^2 applies to the fixed & random effect. Year was the random intercept.

Intercept	Sex: Female	Birth mass	Capture freq.	Days from May 30	May temp	df	logLik	AICc	ΔAICc	Weight	R^2 marginal	R^2 conditional
-10.320		1.578	-1.831			4	-19.6	48.2	0	0.218	0.32	0.70
-8.035		1.023				3	-21.3	49.2	1.07	0.127	0.21	0.51
-0.665		1.624	-1.676		-0.471	5	-19.3	50.1	1.94	0.083	0.36	0.70
2.020		1.108			-0.495	4	-20.7	50.4	2.19	0.073	0.28	0.52
-10.360	0.550	1.555	-1.900			5	-19.4	50.4	2.23	0.071	0.33	0.69
-10.280		1.586	-1.839	-0.024		5	-19.5	50.5	2.31	0.068	0.32	0.71
-8.102		1.041		-0.021		4	-21.2	51.4	3.28	0.042	0.22	0.54
-8.080	0.239	1.013				4	-21.3	51.6	3.41	0.040	0.21	0.51
1.336						2	-23.7	51.8	3.58	0.036	0	0.07

Table 4. Model averaged fixed effects predicting calf survival in the pen. Year was a random intercept.

Parameter	Estimate	Adjusted SE	z value	Pr(>|z|)
Intercept	-7.77	8.88	0.88	0.38
Birth mass	1.42	0.79	1.79	0.07
Capture freq.	-1.79	1.17	1.52	0.13
May temp	-0.47	0.66	0.72	0.47

Table 5. Model selection table with coefficients for fixed effects predicting calf survival after release from the maternity pen to the following March. Results within 4 AICc units of the top model are included. Marginal R^2 refers to the fixed effects, whereas conditional R^2 applies to the fixed & random effect. Year was the random intercept.

Intercept	Sex: Female	Birth mass	Days from May 30	Days in pen	Capture freq.	df	logLik	AICc	ΔAICc	Weight	R^2 marginal	R^2 conditional
-7.55		0.86				3	-18.64	44.1	0	0.19	0.25	0.29
-5.51		0.79		-0.04		4	-17.78	44.9	0.87	0.12	0.31	0.33
-5.08		0.97		-0.05	-1.10	5	-16.91	46.0	1.90	0.07	0.39	0.39
-7.73		0.96			-0.60	4	-18.34	46.1	1.98	0.07	0.27	0.32
0.76						2	-20.87	46.1	2.05	0.07	0	0.19
-8.07		0.90	0.03			4	-18.46	46.3	2.23	0.06	0.25	0.30
-7.46	-0.13	0.85				4	-18.62	46.6	2.56	0.05	0.24	0.28
2.22				-0.04		3	-20.06	46.9	2.85	0.05	0.10	0.20
-5.43	-0.14	0.79		-0.04		5	-17.77	47.7	3.61	0.03	0.31	0.33
-5.15		0.77	-0.01	-0.04		5	-17.77	47.7	3.62	0.03	0.31	0.33

Birth mass and capture frequency were the two fixed effects in the top model (Table 3; $p_{birth\ mass}$ = 0.044, $p_{capt\ freq}$ = 0.11, random intercept var = 4.06), with an odds ratio of 4.85 for birth mass (95% CI 1.4 – 37.9). The model averaged coefficient for birth mass was 1.42 (Table 4), providing an odds ratio of 4.14 (0.89 – 19.6).

The larger data set that contained calves with and without known birth mass included May temperature, capture frequency and days from May 30 as covariates (Table A1). This analysis resulted in the intercept-only model with the lowest AICc value, and the R^2 of the top model with covariates was < 0.06. The top model that included a covariate was ΔAICc = 0.04 and included a negative relationship between May temperature and survival (p = 0.15). We repeated this analysis to exclude calves that died as a result of other physical factors (traumatic fractures followed by euthanasia) to only include calves that died in utero or from infections shortly after birth, reasoning that these latter factors may be more susceptible to temperature effects. Results were unaffected, with the intercept-only model again as the top-ranked model (Table A2).

Survival post release

We obtained birth mass data for 34 calves that were released from the pen and 12 of these calves died by the time March aerial surveys occurred. For all calves (with and without birth mass), 47 calves were released and 21 died by the following March. We included the number of days in the pen as an additional covariate in this analysis. Birth mass was again the most consistent predictor of calf survival and was present in 8 of 10 models within 4 AICc units of the top model (Table 5). The top model contained only birth mass (Table 5; β = 0.856, SE = 0.43, P = 0.048, odds ratio 2.35 [1.06 – 6.20]), and model averaged coefficients for 0 – 2 ΔAICc are shown in Table 6. The model averaged coefficient for birth mass was 0.87 (Table 6), with an odds ratio of 2.39 (0.97 – 5.93). In contrast to the in-pen mortalities, the year effect was not nearly as strong to predict post release survival, with R^2 for the conditional effect (fixed & random) being only slightly better than R^2 for the marginal effects (Table 5). Models that included all released calves (including those with no birth mass, i.e., birth mass was not included as a covariate) had little support – the intercept-only model was the top model and none of the fixed effects approached significance.

Table 6. Model averaged fixed effects predicting calf survival until March after they were released from the maternity pen. Year was a random intercept.

Parameter	Estimate	Adjusted SE	z value	Pr(>|z|)
Intercept	-6.63	4.59	1.45	0.148
Birth mass	0.87	0.46	1.89	0.059
Days Penned	-0.04	0.03	1.28	0.201
Capture freq.	-0.85	0.87	0.98	0.326

Contribution of the pen to population growth rate

Over the course of 5 years, 72 adult females were penned, representing an annual average of 16.9 to 19.1% of the population of adult females, depending on whether the adult sex ratio is assumed to be 70 or 50 males to 100 females, respectively. Using a total population of 150, the number of adult females during the study ranges from 73 to 89, based on March recruitment values and varying the adult sex ratio from 50 to 70. Given the baseline vital rates of wild animals (S_{adult}, = 0.868 S_{calf}, = 0.271, Pr = 0.889) at a stable age distribution, λ is predicted to be 0.962. When the vital rates of the penned animals are included (S_{adult}, = 0.840 S_{calf}, = 0.490, Pr = 0.889), as well as the proportion penned (we used 19.1% to be optimistic), the predicted λ is 0.969, a difference of 0.007 which is undetectable and trivial. Even if all adult females were penned, the expected λ is 0.989; an increase of 0.02.

These fixed values do not account for the uncertainty related to the proportion of total population that was placed in the pen, which is partly influenced by the uncertainty of the adult sex ratio (which also influences calf survival that is estimated by aerial surveys). Therefore, we present a sensitivity analysis that varies the proportion penned in relation to the three focal vital rates (S_{adult}, S_{calf}, Pregnancy) and how varying these parameters affect λ (Fig. 5). This sensitivity analysis jointly addresses multiple sources of uncertainty, as well as clarifies scenarios regarding the penning effort needed to achieve population growth. For example, all else being equal, annual calf survival would have to reach > 0.90 with 30% of the adult female population penned to achieve $\lambda \geq 1$, or survival of 0.60 with 80% penned to achieve the same threshold (Fig. 5). Similarly, stability could be achieved if S_{adult} was > 0.9 and > 35% of the adult females were penned (all else being equal). The pregnancy rate had comparatively little bearing on λ (Fig. 5).

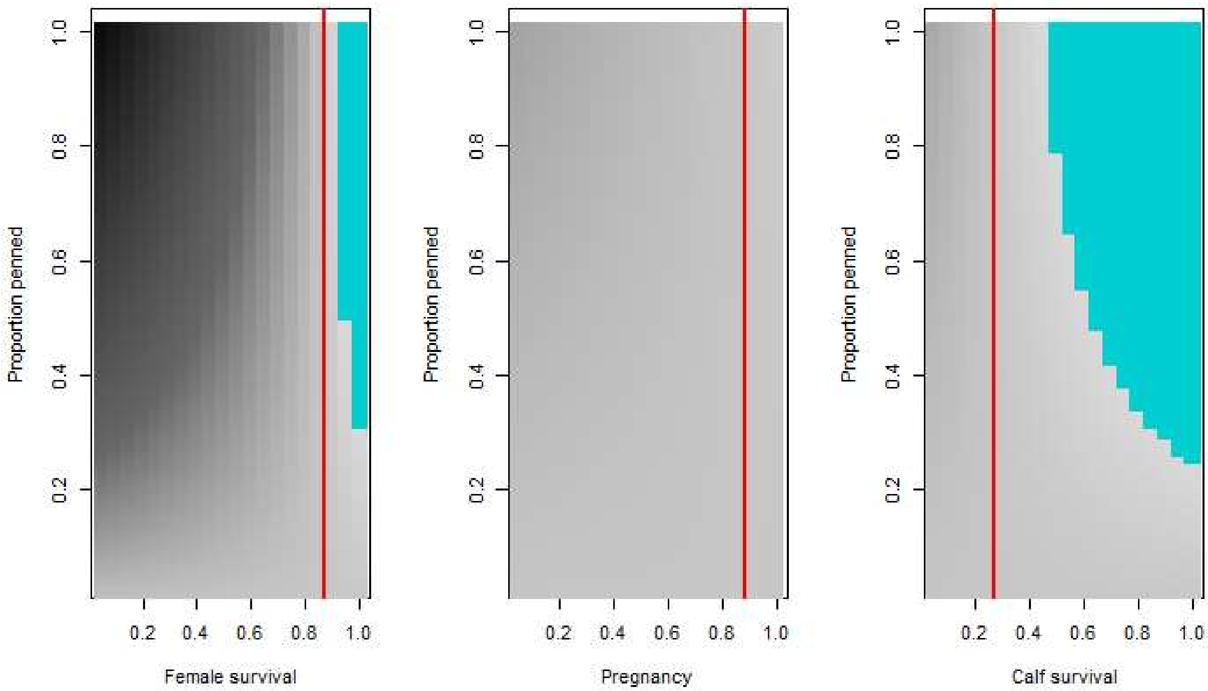


Figure 5. Sensitivity analysis of parameters affecting λ. Lighter grey shading shows higher λ values and blue shading shows λ values ≥ 1. Red line shows the baseline (wild) vital rates used in the matrix model.

Body condition estimates

Across all adult females and both sampling years (3 and 5), body fat, non-pregnant body mass, and loin depth averaged 6.1 ± 0.4% (2.6-9.2%), 117 ± 1.1 kg (range = 106-132 kg), and 3.9 ± 0.06 cm (3.1-4.3 cm; Fig. 6). We found little difference in mean values of the condition indices across the two years of data collection. Eighteen (56%) females had body fat less than 6%, a threshold of concern depending on when winter conditions cease. Separating all caribou by broad sub-categories reflecting capture/wintering locations (Fig. 1), we found some notable differences in estimates of body fat and non-pregnant body mass (Fig. 6). Of those females with <6% body fat, 7 were Bischoff caribou and 11 were Kirbyville caribou. Kirbyville caribou also had the lowest average body mass and body fat (115 kg, 5.2%). Pettipiece caribou had almost double the amount of body fat (9.1%) as those from Bischoff (5.9%) and Kirbyville (5.2%).

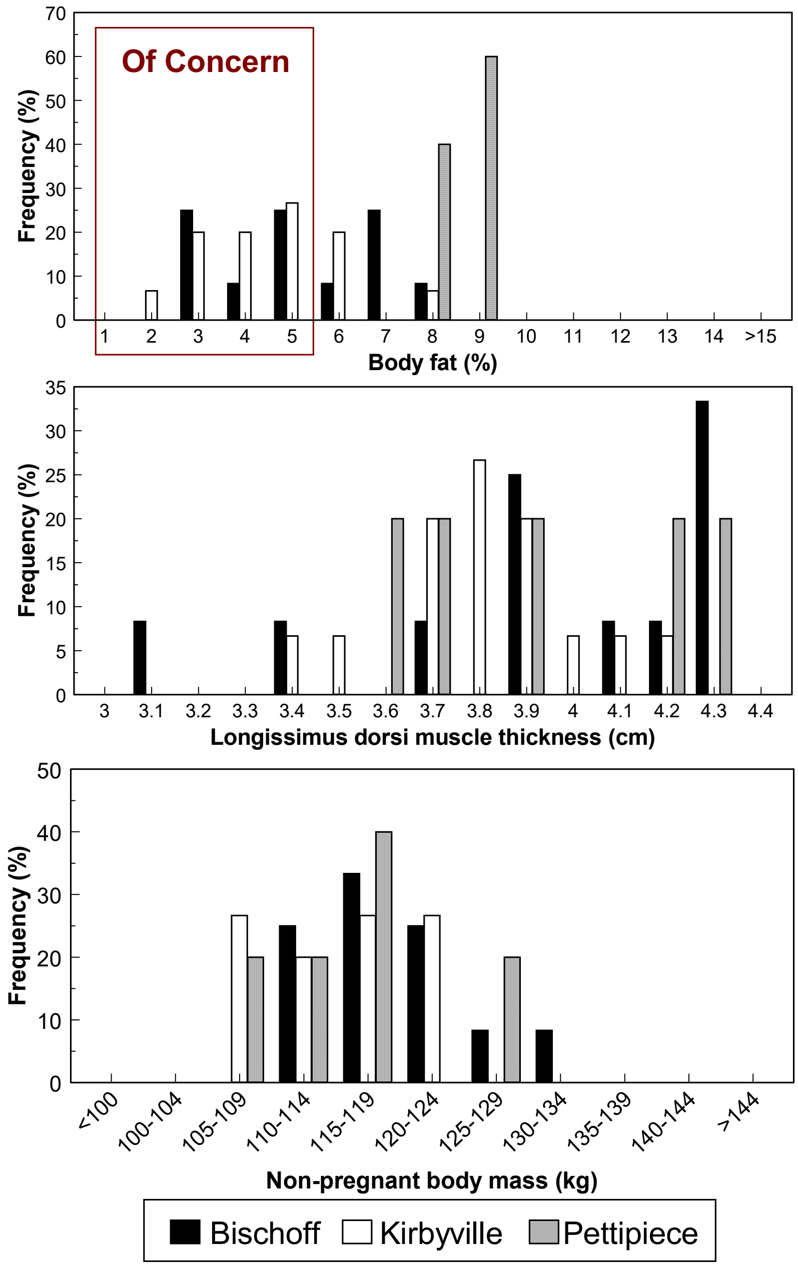


Figure 6. Frequency distribution of ingesta-free body fat (%), longissimus loin depth (cm), and body mass (kg) for 32 adult female caribou captured in late March for RCRW. Caribou have been grouped into three broad regional categories depending on their capture location. For body fat, caribou having less than 6% body fat in late winter are considered to be at higher risk of mortality depending on winter weather and vegetation regrowth.

4. Discussion

Conservation efforts can be evaluated using a broad variety of social, economic and ecological criteria. Even within ecological criteria, distinctions must be made among limiting factors that can be influenced by humans, such as rates of habitat disturbance and recovery, or population vital rates such as adult survival, recruitment, and disease. All these factors may affect the ultimate metric of population change, to varying degrees. Many conservation efforts fall under the same umbrella as the RCRW project that include a diverse range of captive breeding or rearing methods are used to boost a demographic rate. Such projects include the "headstart" program for juvenile sea turtles (Heppell et al. 1996), a myriad of fish hatcheries (Brown and Day 2002), and even other ungulate recovery projects that utilize short or long-term captivity (e.g., desert bighorn sheep (*Ovis canadensis*; Goldstein et al. 2008), addax antelope (*Addax nasomaculatus*), and scimitar horned oryx (*Oryx dammah*; SCF 2019)). Metrics of success for these programs must be carefully defined, because proximate metrics such as juvenile survival or number of released fry may not necessarily translate into population growth, which is the ultimate metric for recovery. This apparent dichotomy has been demonstrated with organisms as varied as sea turtles (Heppell et al. 1996) to woodland caribou (Adams et al. 2019).

It is important to distinguish among proximate and ultimate metrics of success, and this highlights why RCRW developed a phased approach to this pilot study. RCRW initially focused on proximate metrics such as calf survival, with the option of potentially evaluating the ultimate goal of increasing population growth by gradually increasing the proportion of adult females penned. Prior to this study, population modelling for the CME suggested that approximately 30 – 40% of the adult females had to be penned (Furk unpublished report) to achieve stability. However, RCRW penned a smaller proportion (14%) during the initial years to test logistical and biological feasibility within the CME. Indeed, across all 5 years of study, calf survival was roughly doubled as a result of RCRW maternal penning, compared to wild rates. Unfortunately, the ultimate goal of increasing population growth was not realized due to a variety of factors, primarily because mortality of calves and adults within the pen was higher than anticipated, and higher than what was reported elsewhere in other maternal penning studies (see "Vital Rates" section below). These incidents substantially hindered the ability of the RCRW team to increase the stocking density in the pen. Summarizing each year will provide context for how some of the proximate metrics objectives were achieved, and some of the challenges that were encountered.

In year 1, there were no in-pen mortalities so confidence in animal care and husbandry protocols was high. Unfortunately, post-release survival of calves was low, with only 2 of 11 calves accounted for in March surveys (7 of 9 calf collars fell off prematurely), with one collared calf consumed by wolves. Based on these results, there was no net addition of calves to the population during this first year. The winter of 2014/15 was unusual because there were prolonged periods of warm weather and lack of snowfall, creating ice crusting for much of the winter. During caribou recruitment surveys, wolf tracks were often noted high in the alpine, whereas previous years of collared wolf data showed that they were almost completely restricted to valley bottom during winter (Stotyn 2008). Nonetheless, there was agreement to pen more adults because pen survival of calves and adults was 100%, and adult survival was 100% post release to the following March.

In year 2, 18 adults were captured, but 4 calves and 1 adult female died in the pen. Post-release survival of calves was high, with 9 of 11 (0.818) released calves surviving until March 2016. It is estimated that a net of 4.7 calves were added to the population. Multiple and interacting factors affecting health included the following: poor nutritional condition of adults (on entry into the pen, prior to calving, and in the early lactation period), a difference in female behaviour and social stress, deficiencies in biosecurity with wet and muddy pen conditions, and a potential accumulation of pathogens in the pen. For example, adult females entering the pen in poor condition (a factor that could not be controlled) are challenged to produce high quality colostrum or milk during lactation. Moreover, calves born to animals in poor condition are more likely to be of smaller birth weight and weak from *in utero* nutritional stress negatively impacting their growth and development. Poor quality and quantity colostrum and milk post-partum would have further compromised their immunity, growth, and resilience. Physiological stress related to pen stocking density, intra-specific aggression, disturbances, and possibly pen design (e.g., lack of refugia or competition for preferred calving and resting areas) may also have negatively impacted colostrum or milk production and adult female-calf bonding. Poorly mothered, weak, and immunocompromised neonates are at high risk of death from exposure, disturbance and/or infections from environmental pathogens. Likewise, intraspecific aggression caused by suboptimal pen conditions or stocking density may have contributed to calves being injured. These factors are a common cause of neonatal injury, illness, and mortality in domestic livestock production systems (Mench et al. 1990).

An animal health and husbandry review was conducted by one of the project veterinarians following year 2. Deficiencies in biosecurity, pen conditions, monitoring protocols, and pen infrastructure (feed and watering strategies) were identified, and recommendations were made. The RCRW team immediately took action to improve biosecurity, pen hygiene, health monitoring, visitation and pen work protocols were implemented, feed and watering strategies were revised, and low-lying areas of the pen were drained. The results from year 2 also prompted the decision to reduce pen density by capturing fewer adult females in year 3 (n = 12), and to expand the pen from 6.4 to 9.3 ha. The goals were to reduce social stress on adults and female-calf pairs, and to reduce pen contamination. Nonetheless, it should be noted that the pen density in year 2 was still far below that employed in other captive reindeer or caribou maternal penning programs. For example, at Chisana, there was 0.2 – 0.3 ha/adult female, whereas RCRW in year 2 had about double that area available per adult. Other pen factors such as sighting and ambient temperatures during penning periods could not be controlled.

During year 3, 12 females were captured and penned. Despite the aforementioned mitigation, four calves died. Causes included a fractured femur, inflammation of the brain (encephalitis), an E. coli infection, and an unknown cause. Seven calves were released, with four known to be alive the following March. It is estimated that 0.24 calves were added to the population in year 3. There was a higher incidence of retained fetal membranes after parturition in year 3, relative to the previous years. In some cases, the membranes persisted for several days to a week; expulsion of membranes usually occurs within 8 hours in cattle (Beagley et al. 2010). No specific cause was determined, but this is usually a pathological condition and can be attributed to a variety of causes, such as disease, trace mineral deficiencies, metabolic status, metritis or endometritis, dystocia, toxic plant or compound ingestion, or other abnormalities with the calf or process of parturition. No cause could be determined for the caribou, however, ongoing health analyses on archived materials may still show some association with an etiology.

In year 4, the same stocking density was maintained, with 12 adult females placed in the pen. Fewer calves were captured for collaring (5 of 11 born), out of concern that handling was contributing to in-pen mortalities. Two calves died in the pen and the cause was a congenital malformation (stillborn) and an umbilical infection. Nine calves were released with four calves known alive in March (either via telemetry or aerial surveys). It was estimated that 1.2 calves were added to the population.

Given that the 5th year was the final pilot trial, more animals were placed in the pen ($n = 20$) to determine if a higher stocking density was suitable to begin to affect λ. However, three adults died in the pen within a few days of each other, and only 12 calves survived to release out of 17 pregnant females (breech births and other post-birth complications). One calf was also orphaned and brought to the Calgary Zoo, and another lost its mother shortly after release when she was killed by wolves. Although causes of adult and calf deaths were varied, the consensus was that the management action of capturing and placing these animals in the pen contributed to these events. Post-release calf survival was high, with 9 of 12 (0.75) calves surviving to March. It was estimated that 1.8 calves were added to the population. However, the addition of these calves does not take into account the adults that probably died because of this recovery action (see next section). The underlying cause of the adult deaths caused by dystocias are unknown, yet in livestock there are numerous causes and contributing factors to dystocia including infection and inflammation of the placenta or uterus, stress, nutritional deficiencies, toxicities, abnormal birth presentation, adult female or calf size, and potential genetic factors.

Birth mass strongly predicted survival in the pen and post release. This finding is consistent with the Chisana penning results (Adams et al. 2019), although they point out that numerous other studies found no relationship between birth mass and subsequent survival (Mahoney et al. 1990; Whitten et al. 1992; Adams et al. 1995; Jenkins and Barten 2005). The magnitude of our results is even stronger than Adams' et al. (2019), where the odds ratio of in pen survival was 4.14 (and up to 4.85 for the top model). The implication is that if a calf weighed 11 kg vs 8 kg, it had 71 × the chance of surviving in the pen: this is a strong biological effect. Similarly, the odds ratio of a released calf surviving until March was 2.39, meaning that a 3 kg difference in birth mass would result in 13.7 × the chance of survival until March.

That birth mass remained a factor post-release is an important result, because the assumption for maternal penning is that mortality risk from predation is greatest during the first month of life. If a young caribou is encountered by a predator, its chance of dying is very high (Haber 1977), regardless of physical variation. To quote Adams "For calves < 2 weeks old, high vulnerability of all individuals to predation (Adams et al. 1995; Jenkins and Barten 2005) may overwhelm any effects of comparatively subtle physical differences." However, our in-pen analysis may contradict this finding somewhat, because larger calves were less vulnerable to a broad variety of (non-predation) mortality factors, including trampling, and neonatal infections.

Calf predation from bears is greatest during the first few weeks of life (Adams et al. 1995). Once a young caribou can evade a bear, that source of mortality is expected to decrease substantially, and this appears to be the case for calves reared in a pen that are at least a month old after release. Subsequently, wolf predation risk increases for caribou that survive the bear-predation phase. Our results, and those of Adams et al. (2019), suggest that birth mass has an effect that lasts beyond the initial “gauntlet” of bear mortality risk, and any size advantage from birth may shorten the time span that neonate calves are vulnerable to any source of predation. The Chisana study had the advantage of weighing released calves during the following October. In 2005 and 2006 the mass of female calves was similar for penned and wild-born calves. However, in 2004, pen-reared calves were 7 kg (11%) heavier than their wild counterparts in autumn. Adams et al. (2019) explained this difference due to a very warm and dry summer, relative to 100-year climate records. Taken together, these results suggest that although predation is still the proximate limiting factor, nutritional factors mediated by climate and perhaps maternal condition will interact with predation risk to affect survival to recruitment age.

That the effect of year was important for in-pen survival but not post-release survival is also noteworthy, because it suggests that neonate calves are vulnerable to certain extrinsic factors such as warmer spring temperature or multiple handling of females, both of which were weakly associated with mortality. It is difficult to gauge the relative influence of these two factors since they are correlated (r = 0.33; Figure A1), yet year effects were not pronounced once calves were released from the pen. This contrast suggests that once calves survive the first few weeks of life, extrinsic factors may be less important, though birth mass remained influential until recruitment age.

Vital rates and population growth rates

The adult female survival rate during the penning period was 0.944 for the RCRW pen, compared to 0.993 at Chisana, where one of 149 adults died (Adams et al. 2019). Also at Chisana, 146 pregnant adults were penned and 136 calves were released (S = 0.932), which compares to 47 of 64 (S = 0.734) at RCRW. At the Klinse-Za pen, adult female survival was 0.974 (2 of 76 adult females died) and 54 calves were released out of 64 pregnant adults (S = 0.844). Taken together, the results suggest that the RCRW site was less suitable for maternal penning compared to Chisana and Klinse-Za. Suspected factors include high summer temperatures at the valley bottom, which produced a variety of stressors including insect harassment, accumulation of pathogens and potential distress during the hottest days with bouts of laboured breathing observed. However, the logistical challenge of locating a pen at high elevation in the CME is formidable because of the deep snowpack in this region.

The annual survival of penned adult females from RCRW was 0.840, which is lower than the wild adult survival rate in the decade prior to penning. This lower survival rate was caused primarily by the four adult deaths in the pen. It is possible that repeated captures and penning on the same animals caused chronic health challenges, however this has not been observed with Klinse-Za animals, where almost all of the females captured have been in the pen before. Our prediction was that the annual rate of penned females would be higher than the wild rate, because penned females would be free from predators for three months of the year during a season of high mortality risk (Wittmer et al. 2005).

Despite these results, the objective of increasing calf survival was realized, which is an important result for RCRW. However, this increase was not enough to offset the adult mortalities in the pen, or the fact that not enough pregnant adults could be placed in the pen for the increased recruitment to sufficiently affect λ. Notably, even if all adult females from the Columbia North herd were placed in the pen (at least 3 pens would be required to house 70 to 90 adult females), λ would change from 0.958 to 0.978, an increase of ~0.02, which is not enough to obtain a stable population, and likely not enough of a difference to be detectable. This result is in contrast to our preliminary modelling, which suggested a greater benefit to λ with only 30 to 40% of the adult females. The discrepancy between the initial modelling vs empirical results was because the increased annual recruitment we measured was less than what was forecasted (i.e., values were assumed to be closer to the Chisana experiment), and more importantly, the in-pen mortalities of adults reduced the vital rate that has the greatest influence on λ (Gaillard et al. 1998). Another factor contributing to the limited effect on λ was the increased survival rate of wild calves, which was at 0.231 in 2014, but peaked at 0.381 in 2018, possibly because of the wolf reductions that began in 2017. Paradoxically, any increase of wild calf survival would dampen the benefit of maternal penning, because the difference in calf survival rates between penned and unpenned animals would be less pronounced.

For context, we can compare the hypothetical increase of 0.02 λ units (obtained if all Columbia North adult females are penned) to other recovery actions for woodland caribou in BC. The moose reduction increased Columbia North herd by 0.07 λ units, from 0.95 to 1.02, and wolf reductions in the Peace Region of BC increased λ by > 0.25 units, to > 1.13 (Bridger 2019, Serrouya et al. 2019). Assuming a population is decreasing at 5% per year, and 14% per year for the Peace River herds, these λ values can be shown as a time series population projection (Fig. 7):

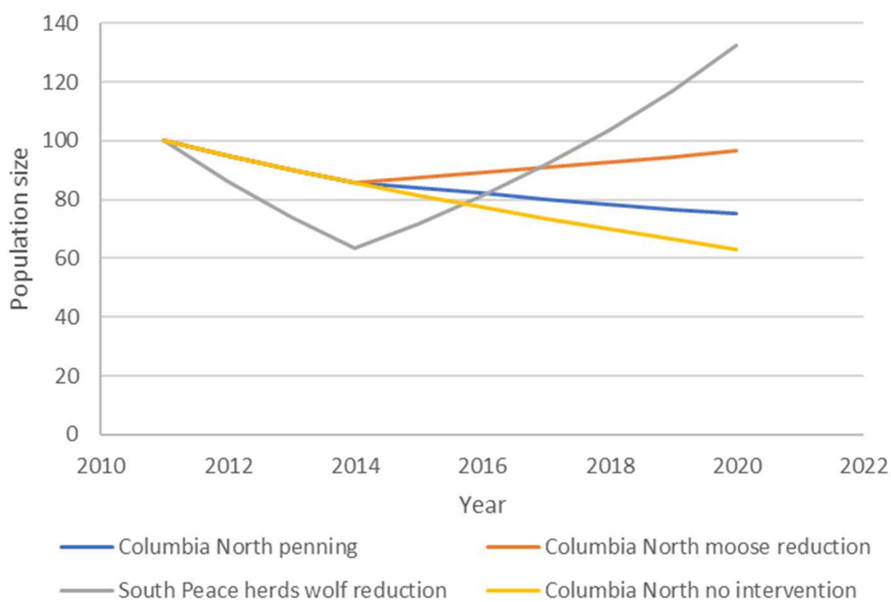


Figure 7. Projections for caribou populations starting at 100 individuals, with treatments beginning in 2014. Assumptions are that Columbia North pre-treatment λ was 0.95, and Peace River herds λ are 0.86. Post-treatment λ are based on empirical data for Columbia North and Peace River herds, but for penning, the post-treatment λ is based on the assumption that all adult females are penned, using the vital rates recorded during the RCRW pilot.

Body condition from fat analyses

Interpretation of spring body condition, particularly with small sample sizes, can be challenging for three reasons:

1. It can be unclear the extent to which body fat in late winter/early spring is a function of winter severity over the previous several months or a function of body condition in late autumn, the latter representing a 'carry-over' effect from autumn through winter. A carry-over effect is when body condition of the animal in one season strongly influences condition of the animal in the subsequent season(s). Autumn-to-spring carry-over effects on body fat and body mass have been reported for elk (Cook et al. 2013), mule deer (*Odocoileus hemionus*; Monteith et al. 2014), and caribou (Cook et al. *in prep*). In all three citations, autumn body fat accounted for most of the variation in spring body fat regardless of differences in winter weather across years or regions. Unique to caribou, Cook et al. (*in press*) found that while spring body fat was correlated to autumn body fat in the same way as reported for elk and deer, the amount of condition (fat and mass) lost over winter was modest; thus, levels of body fat in March were highly correlated to and quite similar to those in late autumn.

2. Fatter animals lose more condition over winter than skinnier animals due to a variety of compensatory processes (Cook et al. 2013, Cook et al. *in press*). For comparisons among populations, then, the magnitude of difference in body condition levels between relatively fat versus thin populations declines over winter, thereby potentially underestimating the full difference in body fat that existed among these populations in late summer at least through early winter.

3. Without knowing each adult female's history of raising a calf the previous summer and autumn, interpreting her body condition levels in late winter/early spring is difficult. Body condition in autumn is strongly dependent not only on the habitat the animal used that summer and early autumn, but whether (and how long) she successfully raised a calf, because lactation imposes huge nutritional costs. Thus, if nutrition is limited, lactating females will be thinner in autumn than their non-lactating counterparts (but if nutrition is not limited, lactating and non-lactating females will have similar body fat levels in autumn [Cook et al. 2004]). In late winter/early spring, adult females will have weaned their calves making it difficult to distinguish between females that did raise a calf the previous summer/autumn and those that did not.

These concerns have implications for interpreting body condition data from caribou captured in Revelstoke. The differences in body fat between Pettipiece, Bischoff and Kirbyville animals, for example, may be a reflection of where they foraged in the previous summer, where they wintered, or may simply be a reflection of whether they had a calf-at-heel through the growing season the previous year.

However, grouping Revelstoke data into a larger data set collected from other montane populations in BC and from boreal populations in BC and the Northwest Territories (NWT; Fig. 8) shows some interesting trends (Cook et al. unpublished data). Generally, montane and boreal caribou in BC are thinner and smaller than boreal caribou in NWT; ~40% of caribou in the montane sample and in the BC boreal sample had late February/March body fat less than 6%, a level of concern depending on how long winter weather persists into spring, as compared to ~20% of the NWT boreal sample. In addition, the proportion of montane caribou with 3-4% body fat was greater than for BC boreal caribou. Caribou occupying montane ranges were smaller; 74% of the BC montane animals measured were estimated to be less than 120 kg as compared to 32 and 23% of BC boreal and NWT boreal animals. Size differences could be related to sub-species adaptations, but they may also reflect long-term nutritional deficiencies (less than optimal growth when animals were sub-adults).

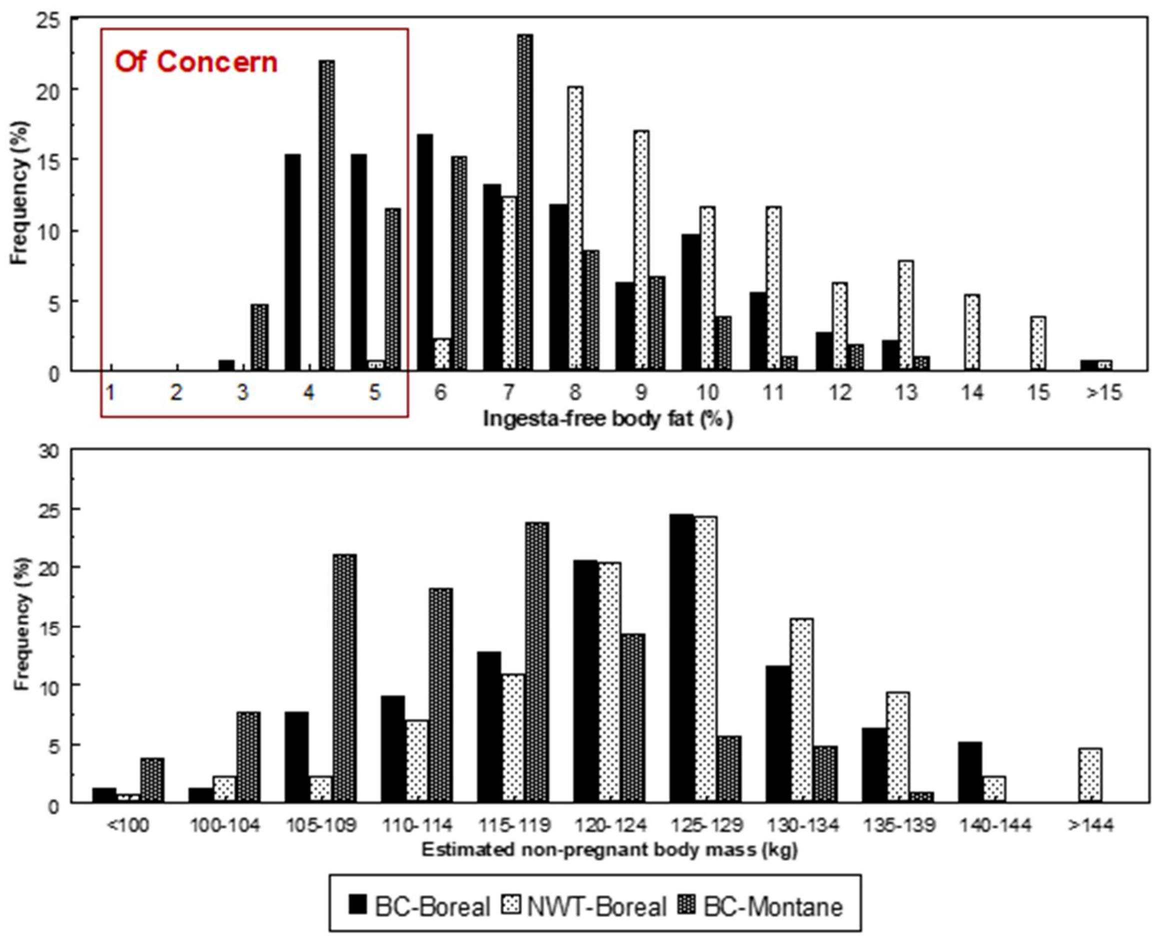


Figure 8. Frequency distribution of ingesta-free body fat (%) and body mass (kg) for adult, female caribou captured in mid-February through late March (2012 – 2018) from montane (*n* = 95 capture events including Revelstoke caribou) and boreal habitats (*n* = 144 capture events) in BC and from boreal habitats in the Northwest Territories (*n* = 91 capture events; *Cook et al. unpublished data)*. For body fat, caribou having less than 6% body fat in late winter are considered to be at higher risk of mortality depending on winter weather and vegetation regrowth.

Overall, the body condition data from the Revelstoke caribou, in combination with additional data collected on montane caribou in BC, suggest at least modest nutritional limitations occurring in these populations which could be impacting performance directly (e.g., pregnancy rates, calf viability and growth) or indirectly (susceptibility to predation or disease). Collecting body condition data in autumn and/or in a repeated sampling approach (capturing the same individuals across time) from autumn to spring would allow more insight into the severity of the limitations, whether they are a result of summer/autumn limitation, winter limitations, or a combination of both, and may explain some of spatial variation seen in these data. Worldwide literature increasingly identifies nutrition in summer as being inadequate to support these life processes at high levels in many ecosystems and illustrates that nutrition in summer functions as a vital link between productivity of large ungulates and the habitat on which they depend (Hjeljord and Histol 1999, Cook et al. 2013, Hurley et al. 2014, Rolandsen et al. 2017, Cook et al. 2018). Such findings also are emerging for barren-ground caribou (e.g., Dale et al. [2008], Cameron et al. [2005], and Post and Klein [1999] in Alaska; Crête and Huot [1993] and Pachkowski et al. [2013] in Quebec; Schaefer and Mahoney [2013] in Newfoundland; and Post and Forchhammer [2008] in Greenland).

It is possible that our selective capture for barren females may have biased the results of body fat and also calf survival. Females without a calf would be in better condition compared to those that reared a calf until March. However, our sample also may include females that are less likely to successfully rear a calf. The degree to which these factors may have influenced results is not known.

It should be noted that even though nutritionally stressed populations are susceptible to a variety of pressures, they can still increase in number under certain conditions. In fact, some montane herds with low levels of body fat are increasing at $\lambda > 1.11$ (see Fig. 7, Peace River herds) after wolf reductions were implemented in 2015/16 (Bridger 2019, Serrouya et al. 2019). However, as calf survival increases, a greater proportion of the female population must endure the high nutritional demands of raising a calf, and thus the degree to which nutritional limitations will factor in to λ may increase over time, particularly if populations continue to grow. For example, acceptable forage may be reduced with higher population numbers, diminishing summer range quality over time, which could lead to reduced pregnancy rates, increased chance of mortality over severe winters, susceptibility to disease, and/or reduced calf performance (growth, survival).

Conclusions

The implementation of recovery actions comes with risks, yet the alternative approach of not pursuing population management has one likely outcome: continued population decline. The RCRW project was created with well-prepared population forecasting and logistical planning, using available demographic data, and by consulting experts from other maternal penning projects. For example, the lead biologist from the Chisana pen (Rick Farnell) took part in the first year of animal handling and processing at RCRW, and RCRW staff consulted with and visited the Chisana pen in 2005. All penning projects were in continual contact. Nonetheless, the RCRW in-pen survival rates were lower than anticipated (and lower compared to other penning projects), with indications that the pen site was at least partly the cause. Our recommendation is that the current RCRW site should no longer be used for maternal penning. However, it can potentially be used as a temporary holding facility for caribou transported from other herds, as was done with animals from the Purcells and Selkirks in 2019. If additional penning is to be considered in the CME, careful planning should be undertaken using knowledge gained from the experiences here and elsewhere. These perspectives should include, at a minimum:

- Selection of site terrain using criteria including drainage, slope and ruggedness
- Snow depth, avalanche hazard, and site-level wind effects on snow movement
- Accessibility for construction of the pen and housing for shepherds
- Access for capture and on-site shepherd crews
- Suitable elevation and habitat for calving

Additional aspects of maternal penning, beyond the scope of this report, should also be considered in future work. For example, it is possible that maternal penning can affect the home range placement of individual animals, if animals become influenced by being housed in a maternity pen that is always in the same location. This aspect is currently being examined by Adam Ford at the University of British Columbia, and will be reported on within the next 12 months.

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Project Partners

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- North Columbia Environmental Society,
- Parks Canada,
- Province of BC,
- Revelstoke Community Forest Corporation,
- Revelstoke Snowmobile Club, and
- Splatsin.

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- Columbia Basin Trust,
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- Mustang Helicopters,
- Mustang Powder,
- Parks Canada,
- Private cash donators,
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- Selkirk Tangiers Heli Skiing,
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6. References

Adams, L. G., R. Farnell, M. P. Oakley, T. S. Jung, L. L. Larocque, G. M. Lortie, J. Mclelland, M. E. Reid, G. H. Roffler, and D. E. Russell. 2019. Evaluation of Maternal Penning to Improve Calf Survival in the Chisana Caribou Herd. Wildlife Monographs **204**:5-46.

Adams, L. G., F. J. Singer, and B. W. Dale. 1995. Caribou calf mortality in Denali National Park, Alaska. Journal of Wildlife Management **59**:584-594.

Apps, C. D., and B. N. McLellan. 2006. Factors influencing the dispersion and fragmentation of endangered mountain caribou populations. Biological Conservation **130**:84-97.

Apps, C. D., B. N. McLellan, T. A. Kinley, and J. P. Flaa. 2001. Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia. Journal of Wildlife Management **65**:65-77.

Apps, C. D., B. N. Mclellan, T. A. Kinley, R. Serrouya, D. R. Seip, and H. U. Wittmer. 2013. Spatial factors related to mortality and population decline of endangered mountain caribou. Journal of Wildlife Management **77**:1409-1419.

Arnold T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management **74**:1175–1178

Barton, K. 2020. MuMIn: Multi-Model Inference. R package version 1.43.17.

Beagley J. C., K. J. Whitman, K. E. Baptiste, and J. Scherzer. 2010. Physiology and treatment of retained fetal membranes in cattle. Journal of Veterinary Internal Medicine **24**:261-8.

Bender, L. C., J. G. Cook, R. C. Cook, and P. B. Hall. 2008. Relations between nutritional condition and survival of North American elk Cervus elaphus. Wildlife Biology **14**:70-80.

Bridger, M. 2019. South Peace Caribou Recovery following Five Years of Experimental Wolf Reduction. BC Ministry of Forest, Lands, and NRO.

Brown, C., and R. L. Day. 2002. The future of stock enhancements: lessons for hatchery practice from conservation biology. Fish and Fisheries **3**:79-94.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edn. Springer, New York

Cameron, R. D., W. T. Smith, R. G. White, and B. Griffith. 2005. Central Arctic caribou and petroleum development: distributional, nutritional, and reproductive implications. Arctic **58**:1-9.

Cook, R. C., Cook, J. G., and Irwin, L. L. 2003. Estimating elk body mass using chest girth circumference. Wildlife Society Bulletin. **31**:536-543.

Cook, J. G., B. K. Johnson, R. C. Cook, R. A. Riggs, T. Delcurto, L. D. Bryant, and L. L. Irwin. 2004. Effects of summer–autumn nutrition and parturition date on reproduction and survival of elk. Wildlife Monographs **155**:1-61.

Cook, J. G., R. C. Cook, R. W. Davis, M. M. Rowland, R. M. Nielson, M. J. Wisdom, J. M. Hafer, and L. L. Irwin. 2018. Development and evaluation of a landscape nutrition model for elk in western Oregon and Washington. Pages 13-30 in Rowland, M. M., M. J. Wisdom, R. M. Nielson, J. G. Cook, R. C. Cook, B. K. Johnson, P. K. Coe, J. M. Hafer, B. J Naylor, D. J. Vales, E. K. Cole, C. D. Danilson, R. W. Davis, F. Geyer, S. Harris, L. L. Irwin, R. McCoy, M. D. Pope, K. Sager-Fradkin, and M. Vavra. 2018. Modeling elk nutrition and habitat use in western Oregon and Washington. Wildlife Monographs **199**:1-102.

Cook, R. C., J. G. Cook, D. L. Murray, P. Zager, B. K. Johnson, and M. W. Gratson. 2001. Development of predictive models of nutritional condition for Rocky Mountain elk. Journal of Wildlife Management **65**:973-987.

Cook, R. C., T. R. Stephenson, W. L. Myers, J. G. Cook, and L. A. Shipley. 2007. Validating predictive models of nutritional condition for mule deer. Journal of Wildlife Management **71**:1934-1943.

Cook, R. C., J. G. Cook, T. R. Stephenson, W. L. Myers, S. M. McCorquodale, D. J. Vales, L. L. Irwin, P. B. Hall, R. D. Spencer, S. L. Murphie, K. A. Schoenecker, and P. J. Miller. 2010. Revisions of rump fat and body scoring indices for deer, elk, and moose. Journal of Wildlife Management **74**:880-896.

Cook, R. C., J. G. Cook, D. J. Vales, B. K. Johnson, S. M. McCorquodale, L. A. Shipley, R. A. Riggs, L. L. Irwin, S. L. Murphie, B. L. Murphie, K. A. Schoenecker, F. Geyer, P. B. Hall, R. D. Spencer, D. A. Immell, D. H. Jackson, B. L. Tiller, P. J. Miller, and L. Schmitz. 2013. Regional and seasonal patterns of nutritional condition and reproduction in elk. Wildlife Monographs **184**:1–45.

Cook, R.C., J.A. Crouse, J.C. Cook, and T.R. Stephenson. In press. Evaluating indices of nutritional condition for caribou (*Rangifer tarandus*): which are the most valuable and why? Canadian Journal of Zoology.

Couturier, S., S.D. Côté, J.Huot, and R.D. Otto. 2009. Body-condition dynamics of a northern ungulate gaining body condition in winter. Canadian Journal of Zoology **87**:367-378.

Crête, M., and J. Huot. 1993. Regulation of a large herd of migratory caribou: summer nutrition affects calf growth and body reserves of dams. Canadian Journal of Zoology **71**: 2291-2296.

Dale, B. W., L. G. Adams, W. B. Collins, K. Joly, P. Valkenburg, and R. Tobey. 2008. Stochastic and compensatory effects limit persistence of variation in body mass of young caribou. Journal of Mammalogy **89**:1130–1135.

Desrosier, F. 2018. It takes a village. FD Productions, Revelstoke, BC. https://www.youtube.com/watch?v=1eEgj3fQIyY&t=140s

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

Festa-Bianchet, M., J. C. Ray, S. Boutin, S. Cote, and A. Gunn. 2011. Conservation of caribou (Rangifer tarandus) in Canada: an uncertain future. Canadian Journal of Zoology **89**:419-434.

Gaillard, J. M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. Trends in Ecology & Evolution **13**:58-63.

Gerhart, K. L., R. G. White, R. D. Cameron, and D. E. Russell. 1996. Estimating fat content of caribou from body condition scores. Journal of Wildlife Management **60**:713–718.

Goldstein, E. J., E. M. Rominger, and B. C. Bartlett. 2008. Science and Hard Work, A Story About Saving Desert Bighorn Sheep in New Mexico. https://mountainlion.org/wp-content/uploads/2021/01/NM-A-NMDGF-2008-Science-and-Hard-Work-A-Story-About-Saving-Desert-Bighorn-Sheep-in-New-Mexico.pdf

Haber G.C. 1977. Socio-ecological dynamics of wolves and prey in a subarctic ecosystem. University of British Columbia. PhD Thesis.

Hervieux D., M. Hebblewhite, D. Stepnisky, M. Bacon, and S. Boutin. 2015. Addendum to “Managing wolves (*Canis lupus*) to recover threatened woodland caribou (Rangifer tarandus caribou) in Alberta” Canadian Journal of Zoology **93**:245–247.

Hjelford, O., and T. Histol. 1999. Range-body mass interactions of a northern ungulate—a test of hypothesis. Oecologia **119**:326-339.

Hurley, M. A., M. Hebblewhite, J-M Gaillard, S. Dray, K. A. Taylor, W. K. Smith, P. Aaber, and C. Bonenfant. 2014. Functional analysis of normalized difference vegetation index curves reveals overwinter mule deer survival is driven by both spring and autumn phenology. Philosophical Transactions of the Royal Society B **369**:1-15.

Heppell, S. S., L. B. Crowder, and D. T. Crouse. 1996. Models to evaluate headstarting as a management tool for long - lived turtles. Ecological Applications **6**:556-565.

Jenkins, K. J., and N. L. Barten. 2005. Demography and decline of the Mentasta Caribou Herd in Alaska. Canadian Journal of Zoology **83**:1174–1188.

Johnson, C. J., M. A. Mumma, and M. H. St-Laurent. 2019a. Modeling multispecies predator–prey dynamics: predicting the outcomes of conservation actions for woodland caribou. Ecosphere 10:e02622.

Johnson, B. K., D. H. Jackson, R. C. Cook, D. A. Clark, P. K. Coe, J. G. Cook, S. N. Rearden, S. L. Findholt, and J. H. Noyes. 2019b. Roles of maternal condition and predation in survival of juvenile elk in Oregon. Wildlife Monographs **201**:1-60.

Lamb, C. T., R. Willson, C. Richter, N. Owens-Beek, J. Napoleon, B. Muir, S. McNay, E. Lavis, M. Hebblewhite, L. Giguere, T. Dokkie, S. Boutin, and A. Ford. In Press. Indigenous-led conservation: pathways to recovery for the nearly extirpated Klinse-Za mountain caribou. Ecological Applications.

McLellan, B. N., R. Serrouya, H. U. Wittmer, and S. Boutin. 2010. Predator-mediated Allee effects in multi-prey systems. Ecology **91**:286–292.

Mahoney, S. P., H. Abbott, L. H. Russell, and B. R. Porter. 1990. Woodland caribou calf mortality in insular Newfoundland. Transactions of the International Union of Game Biologists **19**:592–599.

Mench, J. A., J. C. Swanson, and W. R. Stricklin. 1990. Social stress and dominance among group members after mixing beef cows. Canadian Journal of Animal Science **70**: 345-354.

Monteith, K. L., V. C. Bleich, T. R. Stephenson, B. M. Pierce, M. M. Conner, J. G. Kie, and R. T. Bowyer. 2014. Life - history characteristics of mule deer: effects of nutrition in a variable environment. Wildlife Monographs **186**:1–56.

Pachkowski, M., S. D. Côté, and M. Festa-Bianchet. 2013. Spring-loaded reproduction: effects of body condition and population size on fertility in migratory caribou (*Rangifer tarandus*). Canadian Journal of Zoology **91**:473-479.

Post, E., and M. C. Forchhammer. 2008. Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. Philosophical Transactions of the Royal Society B **363**:2369-2375.

Post, E., and D. R. Klein. 1999. Caribou calf production and seasonal range quality during a population decline. Journal of Wildlife Management **63**:335-345.

Reinemann D. J., T. R. Smith, M. B. Timmons, and A. P. Meyers. 1992. Cumulative effects of heat stress on milk production in Holstein herds. Paper-American Society of Agricultural Engineers (USA) no 924027

Rolandsen, C. M., E. J. Solberg, B-E Sæther, B. V. Moortor, I. Herfindal, and K. Jørnerass. 2017. On fitness and partial migration in a large herbivore – migratory moose have higher reproductive performance than residents. Oikos **126**:547-555.

SCF 2019. Sahara Conservation Fund. Sandscript: an eye on conservation of the wildlife of the Sahara and the Sahel. Issue 25, Spring 2019.

Schaefer, J. A., and S. P. Mahoney. 2013. Spatial dynamics of the rise and fall of caribou (Rangifer tarandus) in Newfoundland. Canadian Journal of Zoology **91**:767-774.

Serrouya, R., S. Gilbert, R. S. McNay, B. N. McLellan, D. C. Heard, D. R. Seip, and S. Boutin. 2017a. Comparing population growth rates between census and recruitment-mortality models. Journal of Wildlife Management **81**:297-305.

Serrouya, R., B. N. McLellan, and J. P. Flaa. 2007. Scale-dependent microhabitat selection by threatened mountain caribou (*Rangifer tarandus caribou*) in cedar-hemlock forests during winter. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere **37**:1082-1092.

Serrouya, R., and B. N. McLellan. 2016. Next steps for Southern Mountain Caribou recovery in planning unit 3A, the Revelstoke Shuswap Region. Columbia Mountains Caribou Research Project and BCMF, Revelstoke, Canada.

Serrouya, R., B. N. McLellan, H. van Oort, G. Mowat, and S. Boutin. 2017b. Experimental moose reduction lowers wolf density and stops decline of endangered caribou. PeerJ **5**:e3736.

Serrouya, R., D. R. Seip, D. Hervieux, B. N. McLellan, R. S. McNay, R. Steenweg, D. C. Heard, M. Hebblewhite, M. Gillingham, and S. Boutin. 2019. Saving endangered species using adaptive management. Proceedings of the National Academy of Sciences **116**:6181-6186.

Stephenson, T. R., K. J. Hundertmark, C. C. Schwartz, and V. Van Ballenberghe. 1998. Predicting body fat and body mass in moose with ultrasonography. Canadian Journal of Zoology **76**:717–722.

Stotyn, S. 2008. Ecological interactions of mountain caribou, wolves and moose in the north Columbia Mountains, British Columbia. M.Sc. Thesis. University of Alberta, Edmonton.

Whitten, K. R., G. W. Garner, F. J. Mauer, and R. B. Harris. 1992. Productivity and early calf survival in the Porcupine Caribou Herd. Journal of Wildlife Management **56**:201–212.

Wittmer, H. U., B. N. McLellan, D. R. Seip, J. A. Young, T. A. Kinley, G. S. Watts, and D. Hamilton. 2005. Population dynamics of the endangered mountain ecotype of woodland caribou (Rangifer tarandus caribou) in British Columbia, Canada. Canadian Journal of Zoology **83**:407-418.

Wittmer, H. U., B. N. McLellan, R. Serrouya, and C. D. Apps. 2007. Changes in landscape composition influence the decline of a threatened woodland caribou population. Journal of Animal Ecology **76**:568-579.

Appendix 1. Supplemental Figures and Tables

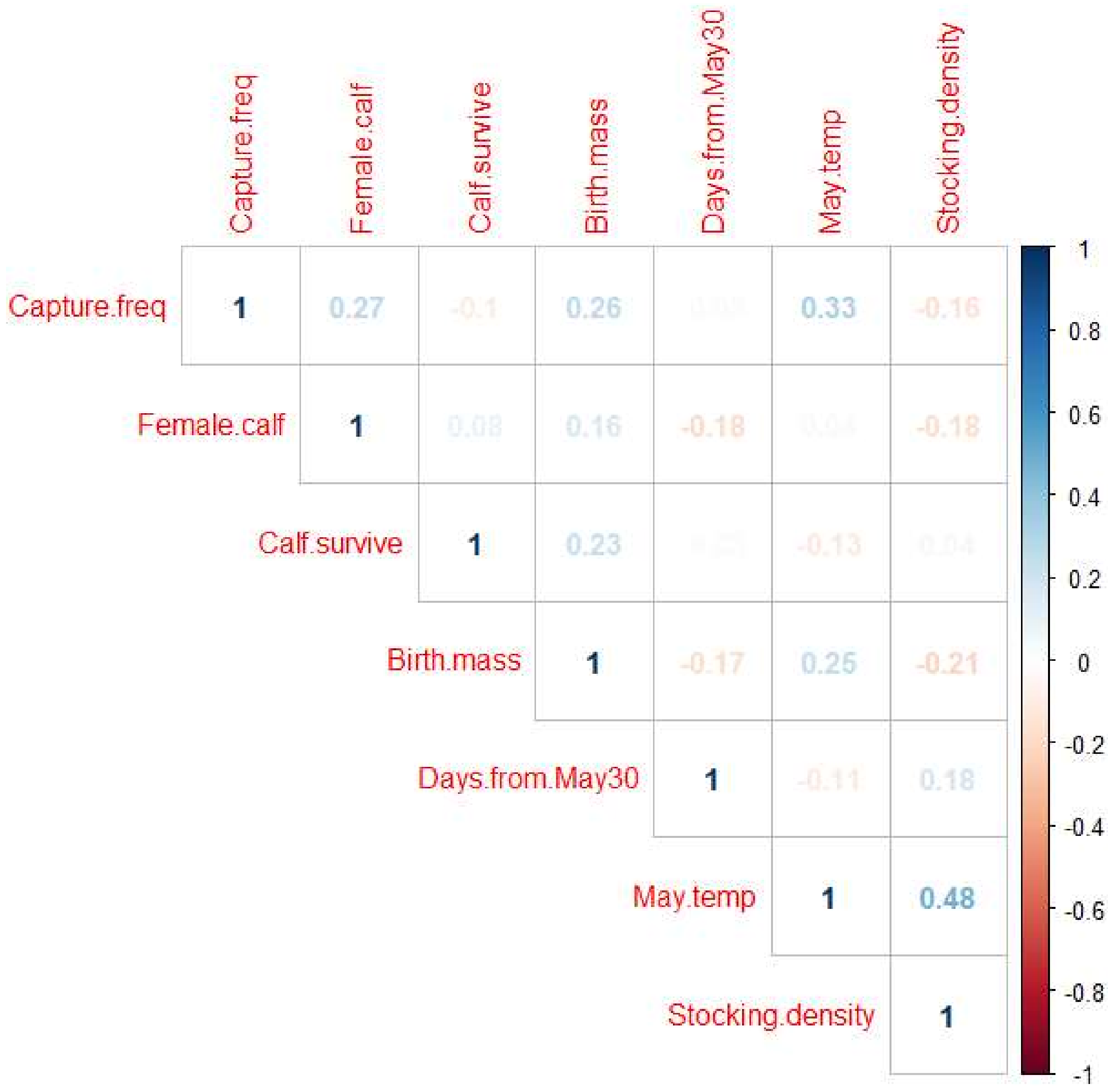

Figure A1. The correlation among all variables examined for the in-pen survival analysis, using data from calves with known birth mass (kg). The relatively high correlation between the capture frequency and May temperature (°C) is spurious, simply because as the years progressed there would be more adult females recaptured and 2014 was the coolest year while 2018 was the warmest. Similarly, stocking density (ha) and May temperature has no biological relevance. Later born calves tended to be lighter and were less likely to be female.

Table A1. Model selection table with coefficients for fixed effects predicting calf survival while in the RCRW maternity pen, including data without calf weights. Results within 4 AICc units of the top model are included. All models were flagged for singularity.

Intercept	Days from May 30	May temp	Capture freq.	df	logLik	AICc	Delta	Weight
1.163				2	-34.579	73.4	0	0.247
6.581		-0.242		3	-33.494	73.4	0.04	0.243
1.958			-0.562	3	-33.853	74.1	0.75	0.170
5.955		-0.192	-0.339	4	-33.277	75.2	1.89	0.096
1.163	-5.35E-05			3	-34.579	75.6	2.21	0.082
6.640	-5.13E-03	-0.244		4	-33.484	75.7	2.30	0.078
1.964	-1.93E-03		-0.563	4	-33.851	76.4	3.03	0.054

Table A2. Model selection table with coefficients for fixed effects predicting calf survival while in the RCRW maternity pen, including data with ought calf weights, and excluding calves with long bone fractures. Results within 4 AICc units of the top model are included. All models were flagged for singularity.

Intercept	Days from May 30	May temp	Capture freq.	df	logLik	AICc	Delta	Weight
1.473				2	-28.380	61.0	0	0.363
5.274		-0.170		3	-27.943	62.3	1.35	0.185
1.454	0.0171			3	-28.293	63.0	2.05	0.131
1.282			0.148	3	-28.354	63.1	2.17	0.123
5.710		-0.214	0.421	4	-27.765	64.3	3.30	0.070
5.163	0.0154	-0.166		4	-27.881	64.5	3.53	0.062

Appendix 2. Details of in-pen mortalities and injuries

Calves

Calf of 2015-14 (No WLHID) – Spontaneous abortion

Adult female (2015-14), determined to be pregnant following capture, did not produce a calf. Calf was considered to be spontaneously aborted during the penning period.

Calf 2015-20 (WLH ID 15-6592) – Neonatal death – nutrition

Female caribou calf 2015-20 (calf of adult female 2015-19) was found dead on May 28, 2015, four days after birth. The cow was found dead on the same day. The calf was collected and transported to the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) office in Revelstoke where it was frozen intact until delivery to BC Ministry of Agriculture's Animal Health Lab (AHC) on June 1, 2015. The necropsy revealed that the calf was emaciated with empty forestomachs, presumably due to lack of nursing. A lack of protective immunoglobulin G (IgG) was noted, resulting in a failure of passive transfer of immunity from a lack of colostrum intake. No evidence of infectious disease was identified and trace nutrient levels were within normal limits. Based on these results, the proximate cause of death was most likely hypoglycemia and/or hypothermia. Based on the calf's age, the profound state of emaciation may have been associated with both in-utero and post-partum malnutrition. This finding of malnutrition and lack of colostrum intake was consistent with poor milk production due to the poor condition of the calf's mother (adult female 2015-19).

Calf 2015-22 (WLH ID 15-6593) - Neonatal death - infection

Male caribou calf 2015-22 (calf of adult female 2015-05) was found dead in the maternity pen on May 29, 2015, less than one day after birth. The carcass was collected by staff and transported to the FLNRORD office in Revelstoke where it was frozen intact until delivery to AHC on June 1, 2015. The necropsy revealed that the calf was in good body condition but had moderate bacterial (*E. coli*) bronchopneumonia, mild encephalitis, peritonitis, and a gastrointestinal Cryptosporidium (protozoal) infection. Trace nutrient levels were within normal limits but a lack of protective IgG was also noted (failure of passive transfer of immunity). The cause of death in this case was related to bacterial/parasitic infection associated with failure of passive transfer of immunity, environmental contamination, and neonatal stress and most likely a combination of these factors.

Calf 2015-32 (no WLH ID) - Injury - facture - zoo

Female caribou calf 2015-32 (calf of adult female 2015-01) was observed with a limp on June 26, 2015 at 6 days of age. An injury to the right front leg was suspected and confirmed with a video to project veterinarians on June 28, 2015. The injury was suspected to have resulted from a herd stampede on June 25, 2015, in response to a staff member walking outside the pen. Pen shepherds also noted that the 2015 penned animals were "exceptionally flighty" compared to animals held in the pen in 2014. They tended to run or stampede in response to weather (e.g., thunder) and movement inside or outside the pen. To minimize disturbance and the risk of injury to other adult female-calf pairs, the affected animal was monitored by staff until

June 30, 2015, when its condition declined. On July 2, 2015, the calf was captured and assessed by project veterinarians (Macbeth and Caulkett). A fracture to the right ulna was suspected but the calf was otherwise stable (not febrile, good suck reflex, good lung sounds, mild dehydration). The calf was tranquilized (with azaperone) and transported to the Calgary Zoo for treatment.

On arrival at the zoo the calf was assessed by a Calgary Zoo veterinarian (Sandie Black). It was hyperthermic and dehydrated but alert. Radiographs confirmed damage to the right ulna with no displacement. An umbilical hernia with mild, superficial infection was also noted. Supportive care was administered including intravenous (IV) fluids, vitamins, antibiotics, and anti-inflammatories. The leg was stabilized and the calf began to improve and bottle feed. The calf progressively declined after the initial treatments and died on July 5, 2015. A necropsy at the Calgary Zoo (Whiteside) confirmed a non-displaced fracture to the right olecranon process, identified three nondisplaced rib fractures, and lung changes consistent with a severe acute respiratory syndrome. No infectious agents were identified.

Calf 2015-34 (no WLH ID) - Neonatal death - infection - zoo

Male caribou calf 2015-34 (calf of injured adult female 2015-09), was observed by staff to be increasingly depressed between July 5 and 6, 2015, at approximately 2 weeks of age. Project veterinarian (Macbeth) captured and assessed the calf on July 6, 2015. The calf was subdued (could be easily approached and was captured by hand) but body temperature was normal. It had a moderate suck reflex, slightly elevated lung sounds, and moderate flystrike. The calf was given 300 ml of oral fluids (dextrose + Lactated Ringer's Solution [LRS] and 0.75 L of subcutaneous [SQ] fluids [LRS]). Mentation improved rapidly and markedly on administration of oral fluids. The calf was tranquilized (acepromazine and alfaxalone) and transported to the Calgary Zoo for in-treatment.

On arrival, the calf was assessed by a Calgary Zoo veterinarian (Doug Whiteside). It was hyperthermic, moderately depressed, and dehydrated with severe flystrike infesting the ventral surface of the body, rectum, and umbilicus. Supportive care was administered, including IV fluids, vitamins, antibiotics, anti-inflammatories, and anthelmintics. In the days following, the flystrike was resolved, treatment of secondary bacterial infection was initiated, and the calf began to improve. Bottle feeding was unsuccessful and the calf received milk via nasogastric tube. However, the calf began to feed on pellets and browse on July 10, 2015. Despite initial improvements, the calf's condition declined suddenly, and it died on July 12, 2015. Necropsy revealed a low-grade bronchopneumonia and chronic peritonitis with adhesions secondary to extensive liver abscesses. The origin of this infection was most likely an umbilical infection with bacteria entering the umbilicus after birth.

Calf 2016-20 (no WLH ID) - Injury - facture - zoo

Male calf 2016-20 was born on May 30, 2016, but at almost a month of age (June 26) he was observed with a severe limp of the right hind leg. The calf was monitored by staff, assessed by a local veterinarian, and was reported to be improving until approximately July 1, 2016. The calf was then assessed by project veterinarian (Macbeth) on July 1, 2016. The calf was very mobile but not weight bearing on the affected leg. Based on clinical signs, a femur fracture was suspected. The calf was subsequently immobilized in the pen. The right hind leg was swollen and firm and a femur fracture was considered likely. The calf was otherwise bright, alert and stable (normal temperature, normal mentation, normal lung sounds, excellent suck reflex) and it was transported to the Calgary Zoo for treatment. The calf was tranquilized (azaperone) prior to and during transport.

On arrival at the Calgary Zoo it was assessed by a veterinarian (Whiteside). The calf was hyperthermic and distressed. It was stabilized and then sedated. Radiographs confirmed a severe midshaft oblique femur fracture. Although the calf recovered well from anesthesia it died suddenly on July 2, 2016. Necropsy revealed that the damage to the bone was chronic and severe and euthanasia would likely have been the most humane outcome.

Calf 2016-21 (no WLH ID) – Recovered – dislocated hip

Male caribou calf 2016-21 (calf of adult female 2016-10) was noticed to have severe right hind limb lameness at one day of age. The calf was captured by hand and assessed by a project veterinarian. Examination revealed ventral dislocation of the right hip, which was reduced. The lameness came and went over the time the calf was in the pen, likely due to a pelvic or tendon injury or ongoing pain. However, the calf continued to eat and keep up with the herd, generally improved in condition over the duration of its time in the pen and was successfully released.

Calf 2016-23 (WLH ID 16-18376) - Neonatal death - infection

Female calf 2016-23 (calf of adult female 2016-12) was first observed the evening of May 20, 2016, presumed to be the date of birth. On May 22, the adult was seen feeding without her calf. She returned to the area where the calf was suspected to be and moved around the area grunting. Later that evening she was observed in the herd without her calf. The calf was subsequently found dead. The ground under the calf was dry and it had been raining most of the day. A necropsy was done at the pen and revealed moderate fly strike in the inguinal and axillary regions and around the mouth and eyes, with the front half of the tongue, the perineal region and rectum scavenged. The carcass was not in rigor mortis and no obvious wounds, injuries or causes of death were present. Tissues were submitted to AHC for further analysis. A mild non-suppurative encephalitis of unknown etiology was found.

Calf 2016-19 (WLH ID 16-8380) - Neonatal death - infection

Male calf 2016-19 (calf of adult female 2016-19) was first observed the evening of May 23, 2016; it was dry, mobile, and suckling and likely born earlier in the day. The calf was captured for collaring the evening of May 24. On the morning of May 25, the adult and calf were initially located together, but later the adult was observed coming to feed alone. That afternoon the calf's collar transmitted a mortality signal, and the calf was found lying in left lateral recumbency. The calf was unresponsive but breathing slowly and had milk around its mouth. It was carried back to the cabin, where respiration ceased but there was still a pulse. Doxapram hydrochlorate was administered and staff attempted to warm the calf with a towel and rubbing. The calf died, and necropsy revealed flystrike in the inguinal region, milk in the esophagus, and good perirenal fat. The intestines were uniformly gas-dilated, the caecum was markedly gas-distended. Samples were submitted to the AHC, and an acute septicemia (systemic infection) caused by the bacteria *E.coli* was diagnosed as the cause of death.

Calf 2016-15 (WLH ID 16-8377) - Neonatal death – infection - suspected

Male calf 2016-15 (calf of adult female 2016-03) was observed alive and healthy (nursing, mobile) at approximately 9:00pm on May 27, 2016. On the morning of May 28, at an estimated 3 days of age, it was found dead with no visible abnormalities. The placenta was assumed to be associated with this calf, and both were transported to AHC. The calf was well-hydrated and in fair nutritional condition with adequate fat stores. The thymus was smaller than expected. The most significant lesion in this case was a severe bacterial placentitis, with *Aerococcus urinae* isolated as a significant and pure culture. There were no obvious gross or microscopic lesions in the calf.

Calf 2017-20 (WLH ID 17-9973) – Stillborn – Congenital malformation

Male calf 2017-20 (calf of adult female 2017-08). This young (3-yr old) adult was observed to be absent from the rest of the herd briefly on the morning of May 22, 2017. She rejoined the herd in the afternoon, but had fetal membranes hanging from her vulva. Membranes remained for over 3 days, though she appeared healthy. A piece of placenta was recovered on May 23, and a scavenged fetus was found on May 25. The fetus and placenta were submitted to AHC. The calf had contracted fore and hindlimbs that could not be straightened (tendon contraction or arthrogryposis) and multiple skeletal anomalies of the skull, including maxillary brachygnathia (overbite or shortened lower jaw), and a markedly domed head. These types of congenital anomalies can be seen together and are generally fatal, typically developing early in the gestation period and often causing dystocia. Potential causes in caribou are unknown, but similar anomalies in domestic livestock are reported to be associated with genetic defects or toxic plant ingestion.

Calf 2017-18 (WLH ID 17-9983) - Neonatal death - infection

Female calf 2017-18 (calf of adult female 2017-05; older adult, estimated at 5+ years) was born on June 24, 2017. This was the last calf born in year 3, as the rest were born between May 23 and 30. The calf was seen alive and following its mother on June 25 but was found dead at 9:20 am on June 26. The cause of death was attributed to an umbilical infection.

Calf of 2018-06 (no WLH ID) - Stillbirth

This was the stillborn male calf of adult female 2018-06 (see case report below). The adult had a significant infection and flystrike of her right ear and side of the head and underwent multiple sedations with a combination of butorphanol-azaperone-medetomidine (BAM), and treatment with florfenicol, oxytetracycline, ivermectin, and moxidectin. She was observed to be calving with difficulty on the morning of May 31, 2018 and was again sedated with BAM. The calf was dead in the pelvis and manually extracted by two project veterinarians (Macbeth and Thacker). The death of the calf was undoubtedly associated with the stress of the multiple immobilizations of the female.

Calf 2018-26 (WLH ID 18-12197) - Injury - facture - euthanasia

Female calf 2018-26 (calf of adult female 2018-08) was observed with an obvious and significant left front leg fracture and euthanized on June 9, 2018 at over one week of age. It was immobilized with BAM and euthanized with intravenous pentobarbital. No other abnormal macro- or microscopic changes were detected. The cause of the leg fracture was undetermined but was most likely related to inadvertent trampling or aggressive behaviour by another caribou.

Calf 2018-30 (WLH ID 18-12200) - Injury - facture - euthanasia

Male calf 2018-30 (calf of adult female 2018-16) was observed with an obvious and significant left front leg fracture and euthanized on June 9, 2018 at over one week of age. It was immobilized with BAM and euthanized with intravenous pentobarbital. No other abnormal macro- or microscopic changes were detected. The cause of the leg fracture was undetermined but was most likely related to inadvertent trampling or aggressive behaviour by another caribou.

Calf of 2018-05 (WLH ID 18-12195) – Recovered – Zoo – Orphaned

In 2018, an adult female (2018-05) was found dead during an attempt to collar a neonate male calf (WLH ID 18-12195). The calf was captured and examined. The calf was dehydrated and hyperthermic. Antibiotics and anti-inflammatories were administered, and alternate feedings of milk and electrolytes were given. He was initially housed in an outside enclosure in order to minimize human contact and habituation; however, due to the risk of exposure and time until he could be moved to an appropriate facility for rearing, he was moved indoors. At a week of age, he was transported to the BC Wildlife Park, a zoo and wildlife rehabilitation facility in Kamloops, BC and at two months of age, he was moved to the Calgary Zoo, where he joined other caribou and has become part of the permanent collection and continues to thrive. On necropsy, the adult female of this calf had a placentitis with vasculitis from an unknown etiology.

Calf of 2018-11 (NO WLH ID) – Dystocia – malnutrition placentitis

Female calf was found dead when the adult female (2018-11) died during parturition. The calf was presented backwards with a hock protruding from the vulva (breech presentation), and the calf’s metatarsals were fractured due to the adult’s struggling. It weighed 5.6 kg. A necropsy was performed on the adult and samples submitted to AHC including the intact calf carcass. A final diagnosis of neutrophilic placentitis with necrosuppurative vasculitis was made.

Calf of 2018-17 (WLHID?) – Dystocia

Male calf presented normally, with two feet protruding from the vulva during the cow’s protracted labour. On immobilization, the calf was pulled from the cow with ease, but was dead. Samples were collected from both cow and calf and submitted to the AHC.

Adult Females

16 AF 2015-19 (WLH ID 15-6411) - Nutrition

Adult female 2015-19 calved a female calf (2015-20) on May 24, 2015, with no abnormalities noted. Both the adult and calf died suddenly on May 28, 2015. Prior to death the adult was observed looking “off” with a small amount of probable bloody discharge observed (from a distance) draining from her vulva (or possibly rectum). The calf was heard calling and later found dead in a curled-up position. Both carcasses were moved to the freezer at the FLNRORD office in Revelstoke. A necropsy was conducted on the adult by a project veterinarian (Macbeth) on May 29, 2015. Biological samples and tissues were collected and submitted to AHC along with the intact calf carcass.

Gross necropsy findings on the adult included: a reduced amount of ingesta in the rumen, a lack of formed feces in the rectum, markedly poor body condition (emaciation), moderate, multifocal haemorrhages in muscle and SQ tissues of the flank, neck and hindlimbs (likely due to peri-mortem, agonal thrashing), serosanguinous discharge from the mouth, nose and vagina (artefact due to carcass bloat) as well as locally extensive congestion and consolidation of the cranioventral lung with associated thoracic and pericardial effusion. Owing to the time passed since death and necropsy, tissues were moderately autolysed and no clear evidence of infectious disease could be identified on microscopic examination. However, microscopic changes observed in the oropharynx and esophagus (hyperkeratosis) were consistent with inappetance or anorexia and degenerative changes were observed in skeletal muscle, liver, and spleen that were consistent with nutritional stress. Trace nutrient levels were within acceptable limits. It appeared she had not been eating well for some time which may have led to the calf not feeding properly.

17 AF 2015-09 (WLH ID 14-4968) – Recovered – wound – infection

On June 28, 2015, adult female 2015-09 was observed by staff with a swollen and draining wound on the top of her shoulders. Though the adult appeared subordinate and was observed licking her wound, she was behaving normally and was eating and drinking. The adult was immobilized by project veterinarians (Macbeth and Caulkett) on July 2, 2015. A large, fistulous, draining wound was identified. The origin of the wound could not be determined; however, similar injuries have been reported when animals have been accidentally struck by net-gun weights or other trauma. While immobilized, she was placed on supplementary oxygen and IV fluids. The wound was debrided and flushed repeatedly with saline and dilute betadine (iodine) and long-acting antibiotics were administered. She remained stable throughout the approximately 30-min procedure, recovered without incident and was observed reuniting with her calf after recovery. The adult female fully recovered from her wounds and was released with the rest of the adults and calves. This animal was still alive as of December 2018.

18 AF 2018-19 (WLH ID 17-10652) - Alive

On May 15, 2018, adult female 2018-19 was observed by staff with a pronounced right hind leg limp, which worsened over time. A project veterinarian (Macbeth) assessed her on May 17, 2019. The limp was severe, and a decision was made to immobilize the animal to evaluate her injury. Once immobilized, she was placed on supplementary oxygen. No obvious fractures, wounds, swelling, heat etc. were noted on physical examination of the legs, joints, tendons, and hooves. The range of motion of the leg was normal. However, a distinct “pop” was noted when she was being blindfolded and positioned immediately after induction and a hip dislocation was suspected but self-resolved. She was treated with an anti-inflammatory, reversed, and released to the pen. Lameness improved rapidly after handling and was nearly non-discernable by May 19, 2018. She gave birth to a healthy female calf (2018-32) on June 26, 2018 and was released from the pen with other adult female-calf pairs.

19 AF 2018-06 (WLH ID 16-8285 [2016], 17-10639 [2018]) – Infection neoplasia - alive

Adult female 2018-06 was captured in March of 2018. The capture was uneventful but at the time of processing, her right ear had a semicircular deficit that had removed a third of the ear. The remaining tissue was malodorous and necrotic with a suppurative discharge. The external ear was clipped of hair and the necrotic tissue removed to normal ear skin and cartilage and sutured. She was treated with long-acting antibiotics and an anti-inflammatory. The injured ear appeared to be the result of a failed predation attempt and a wolverine attack seemed likely. The wound appeared to heal but with warmer weather, a discharge and a maggot infestation were noted. She was immobilized in the pen several times for treatment consisting of extensive debridement, flushing of significant draining tracts around the right ear, right orbit and into the mandibular joint area, administration of antibiotics, anti-inflammatories and anthelminthics. It appeared to be a chronic bacterial wound infection with recurrent flystrike. During an immobilization for treatment, a veterinarian assisted with calving, removing a stillborn calf (see above). At her last immobilization and treatment, she was released alone in July, with hopes that she would leave the lower elevation and seek less fly infested habitat.

She was found dead and unscavenged in November 2019. Investigators reported that the wound appeared to have progressed and she was in an emaciated body condition. Her head was removed and provided for necropsy. There was a severe, necrotizing cellulitis of the entire area and, on dissection, draining tracts extended into and involved her anterior cervical vertebrae. Swabs and tissue were removed for culture and histopathology. An aggressive malignant tumour (squamous cell carcinoma) was present in addition to the infection. Infection accompanied by neoplasia (cancer) is unusual but is reported. A similar finding of partial ear removal accompanied by bacterial infection was found in another collared caribou mortality in a different herd in BC, however it is believed such incidents are extremely rare in wildlife. Subsequently there have been more cases of squamous cell carcinoma in other BC caribou and this health challenge will be further explored.

20 AF 2018-17 (WLH ID 17-10650) - Dystocia (infection)

Adult female 2018-17 was first observed at approximately 7:00 am on May 27, 2018 with two feet protruding from her vulva. She repeatedly laid down and stood, and there was no progression of calving. She also had fetal membranes hanging from her vulva and was attracting flies. She was immobilized at the same location that she was first observed. The male calf was dead but in normal presentation with front legs and head in the birth canal, and it did not take much effort to pull it out. The adult was treated with antibiotics and oxytocin and the immobilization drugs were reversed. Her breathing was initially shallow during anaesthesia, respiration ceased, and she did not recover. Chest compressions were attempted but were unsuccessful.

A necropsy was performed at the FLNRORD office in Revelstoke. The abdomen was full of clotted and fresh blood. The dorsal aspect of one horn of the uterus had an out-pouching, potentially a partial uterine tear, approximately 15cm diameter, with a full thickness tear at the apex. There was little subcutaneous fat, and a moderate amount of perirenal and omental fat (estimated body condition score of 2.5 out of 5). She had good udder development with milk/colostrum. Samples were collected from the female and calf carcasses and submitted to AHC. The final diagnosis was eosinophilic endometritis.

AF 2018-05 (WLH ID 17-10638) – Infection – Neutrophilic placentitis

Adult female 2018-05, estimated to be 8+ years of age at capture, was found dead the morning of May 30, 2018, after calving calf 2018-05. There was no sign of struggle or movement around the carcass. She had calved during the night of May 28 and was discovered dead in lateral recumbency after the calf was born. Her collar was not in 'mortality' mode, indicating that she had moved within the past 3 hours. On necropsy, there were no abnormal external signs. The intestines were gas-distended, but the intestinal walls appeared normal. Her uterus was intact, the wall was opaque and there was an opaque pink creamy layer lining the lumen. There was a small amount of clear red fluid in the abdomen. There was gas distension of the abdomen. The rumen was full of green plant material. All abdominal organs and the thorax appeared normal. Samples were collected and submitted to AHC. A final diagnosis of neutrophilic placentitis with necrosuppurative vasculitis was made. The orphaned calf was later observed approaching another cow-calf pair. Project veterinarians captured and treated the calf for a week then transferred it to the BC Wildlife Park and then the Calgary Zoo where it remains in permanent captivity as part of the zoo's existing mountain caribou herd.

22 AF 2018-11 (WLH ID 17-10644) - Dystocia (Infection)

At 6:15 am on May 28, 2018, grunting was heard from the southwest tree stand and presumed to be from adult female 2018-11 due to her last known radiotelemetry location. She was first observed at approximately 8:30 am from the south road inside the pen with part of a calf visible at the vulva, still covered in fetal membranes. She was observed again at approximately 9:30 am; no progression of the calf had occurred, but the membranes were no longer covering the calf, and decision to intervene was made. She was observed standing up and lying down repeatedly on a snow patch and, then down on her front knees while standing on her hind legs. During an attempt to dart her at approximately 10:00 am, she was found dead.

On necropsy, the female calf (2018-11) was presented backwards with a hock protruding from the vulva (breech presentation), and the calf's metatarsals were fractured. The calf was dead and its abdomen was distended. There was minimal opaque pink uterine fluid. There were petechial hemorrhages on the spleen and intestines and abdominal surface of the uterus. She had no subcutaneous fat and minimal abdominal fat (estimated body condition was 2 out of 5). Samples were collected from the adult carcass and submitted to AHC along with the intact calf carcass. A final diagnosis of neutrophilic placentitis with necrosuppurative vasculitis was made.