DETERMINING FACTORS AFFECTING MOOSE POPULATION CHANGE IN BRITISH COLUMBIA: TESTING THE LANDSCAPE CHANGE HYPOTHESIS

2017 Progress Report: February 2012–April 2017

by

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Cover Photo: Collared cow Moose with twin calves observed in the Entiako study area (Photo: Joey Chisholm)

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EXECUTIVE SUMMARY

This technical report is preceded by Kuzyk and Heard (2014), Kuzyk et al. (2015), and Kuzyk et al. (2016). In response to declining Moose numbers in central British Columbia (BC) since the early 2000s, the BC Ministry of Forests, Lands and Natural Resource Operations (FLNRO) (as of 2017, the Ministry name changed to Ministry of Forests, Lands, Natural Resource Operations and Rural Development) initiated a 5-year (December 2013–March 2018) provincially-coordinated Moose research project. A Moose study with similar objectives that began in February 2012 on the Bonaparte Plateau was integrated with this project. The primary research objective of this project is to evaluate a landscape change hypothesis, that is, Moose survival will increase when: a) forestry cutblocks regenerate to the point where vegetation obstructs the view of predators and hunters; b) resource roads created for logging are rendered impassable due to deactivation or forest ingrowth; and c) Moose become more uniformly dispersed on the landscape. We are evaluating that hypothesis by identifying the causes and rates of cow Moose mortality, and examining factors that contributed to their vulnerability. In January 2017, Moose calves were collared to assess the causes and rates of calf mortality; an important research gap previously identified in this project. This progress report provides data and a preliminary interpretation of the results from 28 February 2012 to 30 April 2017 from five study areas in central BC: Bonaparte; Big Creek; Entiako; Prince George South; and the John Prince Research Forest.

Since this project was initiated in 2012, we fitted 388 cow Moose with GPS-radio-collars across five study areas during annual December to March captures. Twenty calf Moose (12 female, 8 male) were fitted with GPS-radio-collars in the Bonaparte study area during January/February 2017. There were 255 cow Moose captured by chemical immobilization using aerial darting and 133 by physical restraint using aerial net gunning. Three configurations of GPS-radio-collars were used: those programmed for one fix/day (n = 147), 2 fixes/day (n = 107), and >2 fixes/day (n = 134). As of 30 April 2017, of the 388 radio-collars deployed on cow Moose, 215 were active, 101 censored (i.e., dropped at end of battery life, stopped collecting data or slipped from Moose), and 72 were associated with Moose that died. We identified the probable proximate cause of death for the 72 cow mortalities as 36 predation (31 Wolf, 3 Cougar, 2 bear), 12 hunting (1 licensed, 11 unlicensed), 16 health-related (8 apparent starvation, 3 septicemia, 1 peritonitis, 4 unknown health-related - two of which have health tests pending), 3 natural accidents, and 5 unknown. Of the 20 calf Moose radio-collared in 2017, there were 11 mortalities with the proximate cause of mortality being 5 due to predation (4 Wolf, 1 bear), 5 health-related (4 apparent starvation, 1 unknown health-related with health tests pending) and 1 vehicle collision.

The majority of cow and calf Moose were in good body condition at the time of capture; however, some cows captured in 2017 were assessed as in very poor or emaciated body condition. A standard set of biological samples that included age estimates and body condition estimation by live animal assessment or through marrow fat was collected at capture and during mortality site investigations, as available. Bone-marrow-fat analysis conducted on cow Moose mortalities (n = 43) found that 21% had acute malnutrition (<20% marrow fat) and 19% were in poor body condition (20–70% marrow fat). Serological screening and ancillary testing did not demonstrate substantial exposure to pathogens (i.e., pathogens that would likely have increased a Moose's likelihood of death); however, some cows were emaciated at death with no apparent additional cause(s) of death determined to date. Future testing of biological samples may provide insight on pre-existing health conditions or other health-related factors that could have contributed to poor body condition and death. The average annual survival rate of cow Moose (±

95% Confidence Interval) from all study areas combined was 92 ± 8% in 2013/14, 92 ± 5% in 2014/15, 86 ± 5% in 2015/16 and 89 ± 7% in 2016/17.

Analyses on habitat selection patterns of radio-collared Moose are currently underway at the University of Northern British Columbia (UNBC) and University of Victoria. A comprehensive survival analysis to provide inferences on factors contributing to increased risk of mortality in cow Moose across study areas began in summer of 2017, in collaboration with UNBC. We recommend monitoring survival of cow and calf Moose for a minimum of another five years (April 2018–2023) after completion of this project in March 2018 to gain a more comprehensive understanding of the factors affecting Moose population change in central BC, and to inform critical research gaps and management decisions.

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1. INTRODUCTION

Moose surveys conducted by regional wildlife biologists since the early 2000s documented Moose population declines of 50–70% in some areas of interior British Columbia (BC), while populations in other areas were thought to be stable or increasing (Kuzyk 2016). The declines in Moose abundance within central BC coincided with a mountain pine beetle (*Dendroctonus ponderosae*; MPB) outbreak and subsequent increased levels of salvage harvesting of beetle-killed timber, pine tree mortality, and road building (Alfaro et al. 2015). These landscape changes have the potential to influence the distribution and abundance of Moose, hunters and predators (Janz 2006; Ritchie 2008). In 2013, in response to the Moose declines, BC Ministry of Forests, Lands, and Natural Resource Operations (now Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and its partners initiated a 5-year (December 2013–March 2018) provincially-coordinated Moose research project (Kuzyk and Heard 2014). A Moose study with similar objectives began in February 2012 on the Bonaparte Plateau north of Kamloops, and was integrated as one of the five study areas in this project (Figure 1, Table 1). We also continue to collaborate with other Moose studies in BC (i.e., Sittler and McNay 2017).

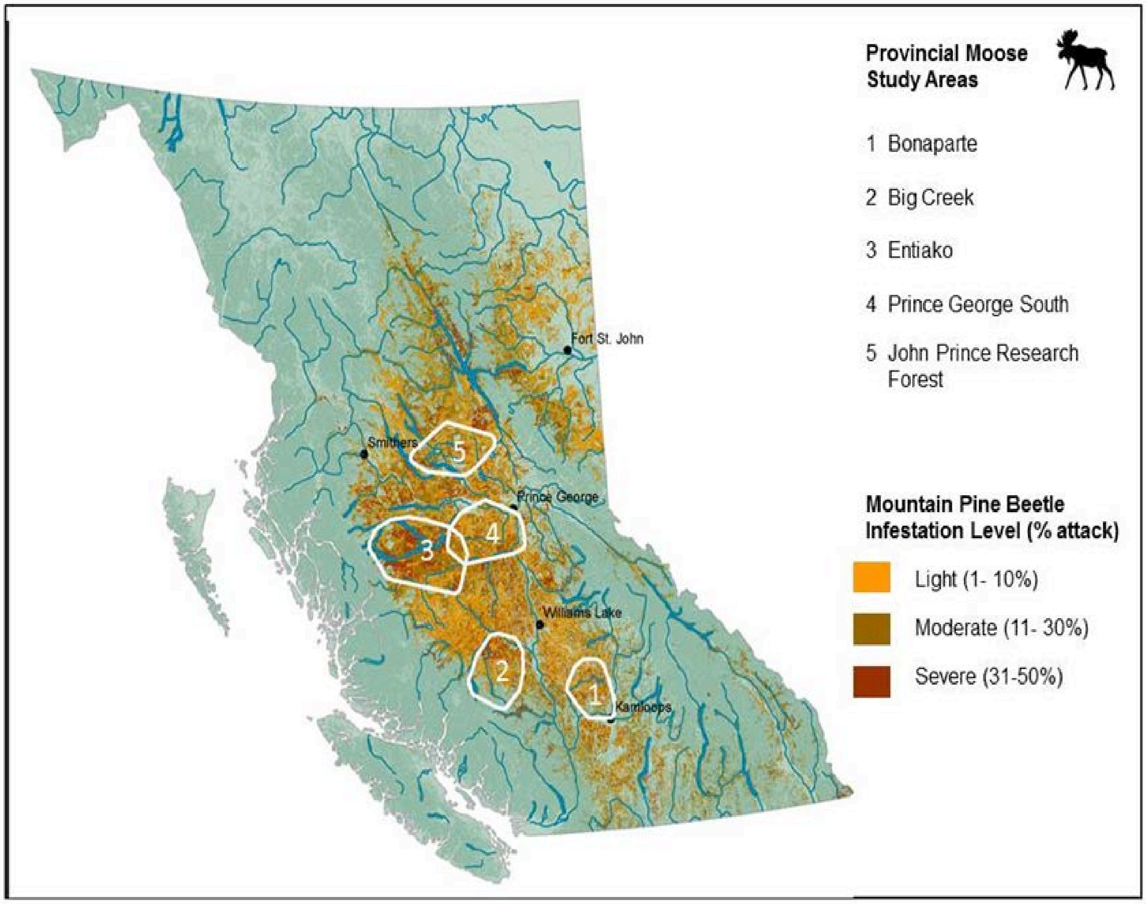


Figure 1. Provincial Moose research study areas in central BC, where cow Moose survival has been monitored in the Bonaparte study area since February 2012 and in the other four study areas since December 2013, overlaid on Mountain Pine Beetle Infestation spatial data layer (2016). The areas were selected to encompass a range of land cover types and disturbance levels.

Table 1. Description of landscape features and large mammals in five provincial Moose research study areas in central BC, where cow Moose survival has been monitored in the Bonaparte study area since February 2012 and in the other four study areas since December 2013.

Study Area/ Region/ Management Unit/ Landform	Landscape Feature Prevalence[1]		BEC Zones[2]	Moose Density ± 90% CI (year)[3]	Potential Predators and Relative Abundance[4]	Wild Ungulates and Relative abundance[4]	Domestic/ Feral Ungulates and Relative Abundance[4]
Bonaparte 6800 km^2 Region 3 (Thompson), 3-29, 3-30B, Interior Plateau	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted	Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Pervasive Mining: Restricted	IDF: 33% SBPS: 23% MS: 22% ESSF: 8% SBS: 7% BG/PP: 7%	430 ± 56/ 1000 km^2 (2013)	Wolves: M Black Bears: M/H Cougars: M/H Grizzly Bears: N	Mule Deer: H White-tailed Deer: M Elk: L Caribou: N	Cattle: H Domestic Sheep: L Feral Horses: N
Big Creek 9800 km^2 Region 5 (Cariboo), 5-04, Interior Plateau/Coast Mountains	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Small	Provincial Park: Restricted Agriculture: Restricted Crown Cattle Range: Large Mining: Negligible	SBPS: 48% IDF: 36% MS: 12% ESSF: 3% AT: <1% BG: <1%	220 ± 40/ 1000 km^2 (2016)	Wolves: M Black Bears: M Cougars: L/M Grizzly Bears: M	Mule Deer: L/M White-tailed Deer: L Elk: N Caribou: N	Cattle: H Domestic Sheep: L Feral Horses: H
Entiako 18,000 km^2 Region 6 (Skeena), 6-01, 6-02, Interior Plateau/Coast Mountains	MPB: Pervasive Logging: Small Roads: Small Wildfire (<30yrs): Small	Provincial Park: Large Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 48% ESSF: 32% SBPS: 12% AT: 4% MH: 2% CWH: 1% MS: <1%	267 ± 45/ 1000 km^2 (2013)	Wolves: M/H Black Bears: M/H Cougars: L Grizzly Bears: M	Mule Deer: L White-tailed Deer: N Elk: L Caribou: L/M	Cattle: L Domestic Sheep: N Feral Horses: N
Prince George South 11,000 km^2 Region 7A (Omineca), 7-10 to 7-12, Interior Plateau	MPB: Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted	Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Large Mining: Negligible	SBS: 93% ESSF: 7%	400 ± 38/ 1000 km^2 (2016)	Wolves: M Black Bears: M/H Cougars: L Grizzly Bears: L	Mule Deer: L White-tailed Deer: L Elk: L Caribou: N	Cattle: L Domestic Sheep: N Feral Horses: N
John Prince Research Forest 9600 km^2 Region 7A (Omineca), 7-14, 7-25, Interior Plateau	MPB: Large Logging: Large Roads: Pervasive Wildfire (<30yrs): Negligible	Provincial Park: Restricted Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 95% ESSF: 5%	490 ± 70/ 1000 km^2 (2016)	Wolves: M Black Bears: H Cougars: N Grizzly Bears: M	Mule Deer: L White-tailed Deer: L Elk: L Caribou: N	Cattle: N Domestic Sheep: N Feral Horses: N

[1]Estimated proportion of landscape affected: Pervasive = 71–100%, Large = 31–70%, Small = 11–30%, Restricted = 1–10%, Negligible = <1%.
[2]Biogeoclimatic Ecosystem Classification (BEC): Interior Douglas Fir (IDF), Sub-Boreal Pine and Spruce (SBPS), Montane Spruce (MS), Engelmann Spruce Sub-alpine Fir (ESSF), Montane Spruce (MS), Sub-boreal Spruce (SBS), Bunchgrass (BG), Ponderosa Pine (PP), Alpine Tundra (AT), Mountain Hemlock (MH), and Coastal Western Hemlock (CWH).
[3]Reported Moose densities are calculated from Stratified Random Block (SRB) surveys conducted over winter range in the study areas.
[4]Relative abundance/density: H = high, M = moderate, L = Low, N = nil or negligible.

The landscape change hypothesis assumes Moose population growth rates are influenced by habitat and anthropogenic changes associated with the MPB outbreak. The primary objective of this research is to evaluate this landscape change hypothesis that assumes Moose survival will increase when: a) forestry cutblocks regenerate to the point where vegetation obstructs the view of predators and hunters; b) resource roads created for logging are rendered impassable due to deactivation or forest ingrowth; and c) Moose become more uniformly dispersed on the landscape (Kuzyk and Heard 2014). In evaluating this landscape change hypothesis, we assume cow Moose survival has a greater proportional effect on population growth than calf survival (Gaillard et al. 1998), and thus, have focused primarily on directly monitoring survival of radio-collared cow Moose. Our research approach was to monitor survival of at least 30 GPS-radio-collared cow Moose in each of five study areas (*n* = 150 annually) for five years (i.e., to March 2018). We acknowledged that calf survival could contribute to Moose population change (Kuzyk and Heard 2014); however, financial and logistical constraints limited our ability to directly monitor survival of radio-collared calves across all study areas. To help fill this knowledge gap, in the winter of 2016/17, we radio-collared twenty 8-month old calves in one study area (Bonaparte Plateau) to measure their survival until they are recruited into the population at 1.5 years of age, which is the time when cow Moose may be bred (Kuzyk and Heard 2014; Kuzyk et al. 2015; Kuzyk et al. 2016). Building on the 2016/17 calf collaring pilot project, we plan to radio-collar and monitor 8-month old calf survival again in 2017/18, and to expand calf monitoring to a second study area. We are also planning to continue assessing survival rates of calves through late winter calf surveys of radio-collared cows in all study areas.

This 2017 progress report provides an update on fieldwork and preliminary results from February 2012–30 April 2017, and recommends future research directions, including expansion of the project to evaluate the role of Moose calf and yearling survival on population growth.

2. STUDY AREA

The study area was similar to the details provided in Kuzyk et al. (2016), as there was little annual variation in biotic or abiotic features within study areas. This research project was conducted on the Interior Plateau of British Columbia, Canada, in five study areas: Bonaparte; Big Creek; Entiako; Prince George South; and John Prince Research Forest (Figure 1). Most of the plateau lies between 1200–1500 m above sea level and was characterized by rolling terrain with a mosaic of seral stages, conifer forest and wetland areas. The climate is generally continental, with warm, dry summers and cold winters with complete snow coverage. Dominant ecological zones of the interior include Sub-Boreal Spruce (SBS) and Engelmann-Spruce Subalpine Fir (ESSF) in the north, and Sub-Boreal Pine-Spruce (SBPS) and Interior Douglas-Fir (IDF) in the south (Meidinger and Pojar 1991). The study areas, delineated using the cumulative distribution of radio-collared Moose locations in each of the study areas, ranged from 6700 km^2 – >18,000 km^2 (Table 1). Logging was the primary resource land use (see Figures 2, 3 and 4 for visual examples of logging extent), with an increase in salvage logging after the large-scale MPB outbreak occurring during the early 2000s (Alfaro et al. 2015). In addition to MPB, fire was a natural disturbance that was especially important in the Entiako study area in 2014, when the Chelaslie Fire burned ~1331 km^2. Natural variation in the dominant forest types, severity of the MPB attack (both within and among study areas), and differences in the extent of reserve areas that did not allow logging, resulted in differences in the degree of pine tree mortality, associated salvage logging and access among study areas (Figure 1, Table 1). Access for recreational use, such as hunting, all-terrain vehicle (ATV) use, and hiking, was primarily through resource roads created for logging. Free-ranging cattle (*Bos taurus*) are common in the Bonaparte and Big Creek, and to a lesser extent in Prince George South and Entiako study areas, and feral horses (*Equus caballus*) also occur in the Big Creek study area.

In addition to Moose, the Interior Plateau supports other large mammals including Elk (*Cervus canadensis*), Mule Deer (*Odocoileus hemionus*), White-tailed Deer (*O. virginianus*), Caribou (*Rangifer tarandus*), Grey Wolf (*Canis lupus*), Grizzly Bear (*Ursus arctos*), Black Bear (*U. americanus*) and Cougars (*Puma concolor*), all of which occur at varying densities and distributions (Shackleton 1999; Mowat et al. 2013; Kuzyk and Hatter 2014). Accordingly, all study areas contain multi-prey, multi-predator species assemblages (Table 1). Moose, however, were the primary wild ungulate in all study areas. At the initiation of the study, Moose densities ranged from 140–770 Moose/1000 km^2 among study areas, with stable Moose populations in three study areas (Bonaparte, Entiako, John Prince Research Forest) and declining Moose populations in two study areas (Big Creek, Prince George South). Stratified Random Block (SRB) surveys conducted in 2016 indicated Moose densities decreased in three study areas to between 220 and 490 Moose/1000 km^2 (Table 1).

Moose hunting by First Nations for food, social and ceremonial needs, and licensed hunting by BC residents and non-residents occurred in all study areas. Licensed Moose hunting in BC is regulated through sex- and age-specific General Open Season (GOS) or Limited Entry Hunting (LEH) opportunities, with harvest type and seasons generally managed at the Wildlife Management Unit (WMU) scale. Within their traditional territories, First Nations have the right to harvest any number of Moose for food, social and ceremonial needs without season, sex or age restrictions.

Figure 2. Aerial view of the Bonaparte study area, June 2017 (Photo Chris Procter).

Figure 3. Aerial view of the Prince George south study area, March 2017 (Photo Morgan Anderson).

Figure 4. Aerial view of the John Prince Research Forest study area, May 2014 (Photo Gabrielle Aubertin).

3. METHODS

Details of the field methods used to monitor cow Moose survival were presented in Kuzyk and Heard (2014), Kuzyk et al. (2015), and Kuzyk et al. (2016). Winter of 2016/17 was the first season to include calves in the study, and twenty 8-month old calf Moose were radio-collared. Captures were conducted in accordance with the British Columbia *Wildlife Act* under permit CB17-277227. Generally, we captured cow and calf Moose between December and March, using either aerial net gunning and physical restraint or chemical immobilization by aerial darting. Aerial darts were remotely delivered with either a Pneudart or Daninject darting system. Of the cows captured via aerial darting, we immobilized 143 animals with a combination of carfentanil citrate (3 mg/ml; Chiron Compounding Pharmacy Inc, Guelph, ON) and xylazine hydrochloride (100 mg/ml; Chiron Compounding Pharmacy Inc, Guelph, ON) and 108 Moose with BAM II (Chiron Compounding Pharmacy Inc, Guelph, ON), a premixed combination of butorphanol (27.3 mg/ml), azaperone (9.1 mg/ml) and medetomidine (10.9 mg/ml). BAM II was also used to immobilize 8-month old Moose and was delivered in 2 or 3 cc darts.

We examined and sampled captured Moose according to a standard protocol that included assessing for: 1) age class using tooth eruption, staining and wear as an index (Passmore et al. 1955; Appendix A); 2) body condition, using an index simplified from Franzmann (1977; Appendix B); 3) external parasite presence and prevalence; and 4) presence of calves. From each Moose, we drew 20 to 35 ml of blood using an 18 gauge x 1.5-inch needle for pregnancy and serological testing. Serological testing was for Johne's disease, bovine viral diarrhea, anaplasma, leptospira, neospora, parainfluenza virus, and respiratory syncytial virus. We also obtained fecal samples for parasitological assessment; key parasites for investigation were *Parelaphostrongylus tenuis* (meningeal worm), *Fascioloides magna* (giant liver fluke), and *P. odocoilei* (gastrointestinal nematodes). Each Moose was ear-tagged with a unique identifier and a 6 mm punch biopsy of the ear was air-dried and archived for genetics. We collected at least 100 hairs with roots from between the shoulders for genetic or other studies (e.g., cortisol levels). Key measurements of size (i.e., chest girth, total length, hind-foot length) were taken on Moose calves to assist in estimating weight; some calves were weighed in a body blanket lifted by a helicopter where the capture location was conducive to do so. Upon completion of handling, naltrexone hydrochloride (at 50 mg/ml) alone for carfentanil, or naltrexone with atipamezole hydrochloride (at 25 mg/ml) for BAM II immobilizations were used to reverse at doses corresponding to immobilizing dose as advised from manufacturers and the attending veterinarian.

We assessed the pregnancy status of 365 collared cows. Serum from a subsample of cow Moose captured in 2014/15 and from all cow Moose captured in 2015/16 and 2016/17 was analyzed for both serum progesterone and protein B levels. These dual pregnancy status indicators were used to further investigate the interpretation of pregnancy status. Serum was also screened for antibodies for Johne's disease, *Neospora*, Bovine Viral Diarrhea virus, and Parainfluenza 3 virus. Subsamples of hair from some Moose were used for preliminary assessment of stress through cortisol levels. Remaining hair and serum samples were archived for future analyses. Finally, serum from a subset of cow Moose was submitted for testing for exposure to *Erysipelothrix rhusipathiae* and *Toxoplasma*, and tissues were assessed for trace mineral levels.

We fitted each cow Moose with a GPS-radio-collar programmed to obtain either one or two positional fixes daily (Vectronic Aerospace VERTEX Survey Globalstar radio-collars, Berlin) or >2 locations per day (Advanced Telemetry Systems G2110E radio-collars, Isanti, MN or Vectronic Aerospace VERTEX Survey Iridium radio-collars, Berlin) (See Figures 5 through 9 for images illustrating captured Moose handling and sampling methods). We chose to use radio-collars with 1 or 2 positional fixes daily at the outset of the project to facilitate survival monitoring for up to five years. We started deploying radio-collars capable of collecting >2 fixes daily when funds were available to begin addressing other objectives, including calving rates and fine scale habitat use, as well as to improve fix rate success. Moose calves were fitted with expandable collars to collect >2 fixes per day (Vectronic Aerospace VERTEX Survey Iridium radio-collars, Berlin). Calf collars expanded from an initial size of 50 cm to 80 cm (average neck circumference of an adult female Moose) using protected expandable material. Calves will need to be recaptured after two years to either remove the collar or replace it with an adult-sized collar.

Figure 5. Wildlife Biologist Chris Procter checking incisor teeth condition of a captured calf Moose in the Bonaparte study area, January 2017 (Photo Gerald Kuzyk).

Figure 6. Wildlife Biologist Chris Procter fitting an expandable GPS-radio-collar to a captured calf Moose in the Bonaparte study area, January 2017 (Photo Gerald Kuzyk).

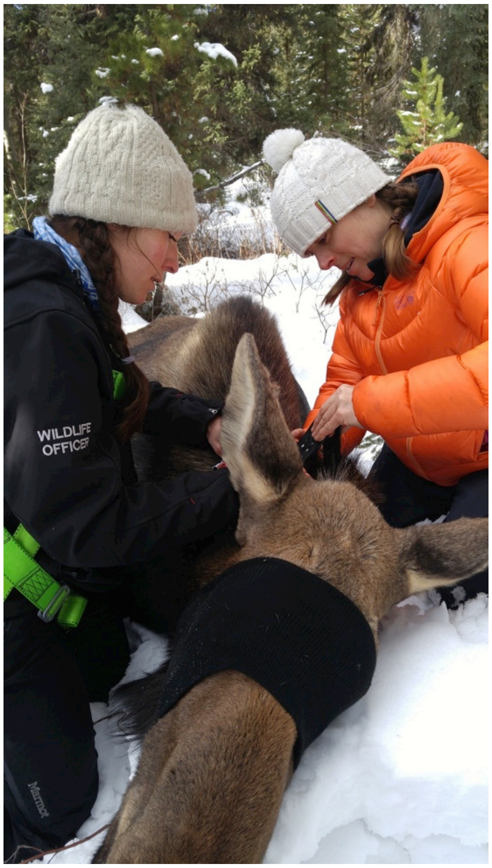


Figure 7. Wildlife Biologists Krystal Dixon and Heidi Schindler fitting a GPS-radio-collar to a captured cow Moose in Entiako study area, March 2017 (Photo Ryan Madley).

Figure 8. Preparing to weigh a newly collared calf Moose using a sling and helicopter in the Bonaparte study area, January 2017 (Photo Gerald Kuzyk).

Figure 9. Wildlife Biologist Krystal Dixon preparing reversal drugs following collar fitting and sampling of a cow Moose that was immobilized using BAM II in the Entiako study area, March 2017 (Photo Heidi Schindler).

The radio-collars contain an internal tip switch to detect animal movement rates, and were programmed to send a mortality alert via email and text message if no movement was detected for 4–24 hours. In some cases, collars remained in sufficient motion post-mortality to prevent the mortality signal from being triggered, particularly for predation events where the collar was frequently moved when predators were feeding. To assist in detecting these mortalities sooner, an Excel macro (developed by M. Gillingham) was used to examine each individual animal's location data and identify movement and collar performance patterns that may be indicative of potential mortalities. Collar movements that might be associated with a mortality but for which a collar alert might not be sent could include abnormally long movement between consecutive fixes, long collar movement followed by no fixes, long collar movement followed by little subsequent movement, many consecutive missed fixes, or many consecutive short movements.

Following receipt of a collar mortality signal, or detection of a potential mortality through assessment of recent movement data as detailed above, we conducted mortality site investigations as soon as logistically feasible, typically within 24–48 hours. Ground telemetry techniques may be used to determine the mortality location when concealed by thick vegetation or snow cover (Figure 10). We determined the probable proximate (i.e., direct) cause of mortality following a standardized protocol (Kuzyk and Heard 2014), and we continually refine the definitions for cause of mortality as new circumstances arise (Appendix C). Ultimate (i.e., indirect) causes of mortality that were not evident during mortality investigation may be determined later through testing of biological samples. The most recent mortality investigation data sheet was updated July 2017 (Appendix D).

Annual survival rates were calculated for cow Moose from 28 February 2012–30 April 2017, while survival rates for calves were calculated from 19 January-30 April 2017. We calculated survival rates by pooling survival of individual Moose across all study areas; study area specific survival rates are not presented due to relatively low sample sizes. Survival analysis and mortality summaries included only Moose that lived more than three weeks post-capture to avoid the potential bias or effects of capture-related stresses and physiological changes on survival (Keech et al. 2011). Survival rates were monitored weekly and summarized by biological year (1 May–30 April) using a Kaplan-Meier estimator (Pollock et al. 1989). We started the biological year on May 1 to coincide with the time immediately prior to the average time of parturition for Moose in northern (Gillingham and Parker 2008) and southern British Columbia (Poole et al. 2007). All cow Moose were assumed to have standardized behaviors and equal risk of mortality, i.e., no cow Moose were assumed to be predisposed to predation due to giving birth or the presence of a neo-natal calf.

Samples were identified for collection during mortality site investigations by field crews to help interpret the ultimate cause of death (Appendix D), though the samples collected for each mortality depended on what was available during the investigation (e.g., wolf kills typically have bones but no soft tissues remaining). For each mortality, we collected at least one long bone, usually the femur, or if none were available, the jaw, to assess body condition through bone marrow fat analysis (Neiland 1970). Bones were bagged and frozen as soon as practical to maintain representation of marrow when the Moose was alive. Marrow was removed from an approximately 10-cm long section from the center of each bone, dried in an oven at 80°C, and weighed daily until the weight stabilized, indicating all moisture had been evaporated (Figure 11). The final dry weight divided by the initial wet weight was an index of body condition. Marrow fat is the last fat store to be used as body condition deteriorates, therefore high dry weight proportions do not necessarily represent individuals in good body condition but low scores are a definitive indicator of poor nutritional status (Mech and Delgiudice 1985). We considered animals with a marrow dry weight <70% to be in poor body condition and those with <20% to have been experiencing acute malnutrition that would eventually lead to starvation mortality (Sand et al. 2012). When available, an incisor was extracted during mortality site investigations to determine the age of the Moose. Cementum aging was conducted by Matson's Lab (Manhattan, MT). A variety of frozen and fixed (in formalin) tissue samples from mortality site investigations were also collected when available, and were archived or sent for analysis to provide health-related information baselines and help interpret ultimate cause of death.

We located collared cow Moose to assess calf survival of uncollared calves in the late winter (mid-February – late March), specifically those: 1) that were determined to be pregnant the previous winter; 2) that had a calf present when collared earlier in the winter; 3) for which there was uncertainty regarding whether or not they had a calf present when collared earlier in the winter because they were in a mixed group of cows and calves; 4) that were collared in previous years; or 5) whose fine-scale movement data (if available) suggested that they were parturient in the previous spring/summer months. A follow up survey was conducted in PG South in early May to assess calf survival from mid-March to early May. During this survey, cows with calves in mid-March were relocated to assess calf status. The most recent GPS locations of cows were mapped prior to the survey to facilitate efficient search times in locating collared cows. Survey crews in a helicopter radio-tracked collared cows and determined if calves were present. Estimates of tick prevalence through hair loss were assessed for cows and calves. We developed a standardized calf survey data form in June 2017 (Appendix E).

4. RESULTS

4.1 GPS-Radio-collars

From February 2012–30 April 2017, we captured and radio-collared 388 cow Moose (Tables 2 and 3; 255 captured by aerial darting and 133 captured by aerial net gunning). Twenty calf Moose (12 female, 8 male) were captured and fitted with GPS-radio-collars in the Bonaparte study area during January 2017 with collars that collected more than two positional fixes/day. In the five study areas, there were 134 cow collars that collected more than two positional fixes/day, 107 cow collars that collected two fixes/day and 147 cow collars that collected one fix/day (Table 4). We censored collars when they released due to low battery voltage, collar malfunctions, or when they physically slipped from Moose.

Figure 10. Wildlife Biologist Heidi Schindler using ground-based telemetry to pinpoint the mortality location of collared cow Moose in Entiako study area, March 2017 (Photo Gerald Kuzyk).

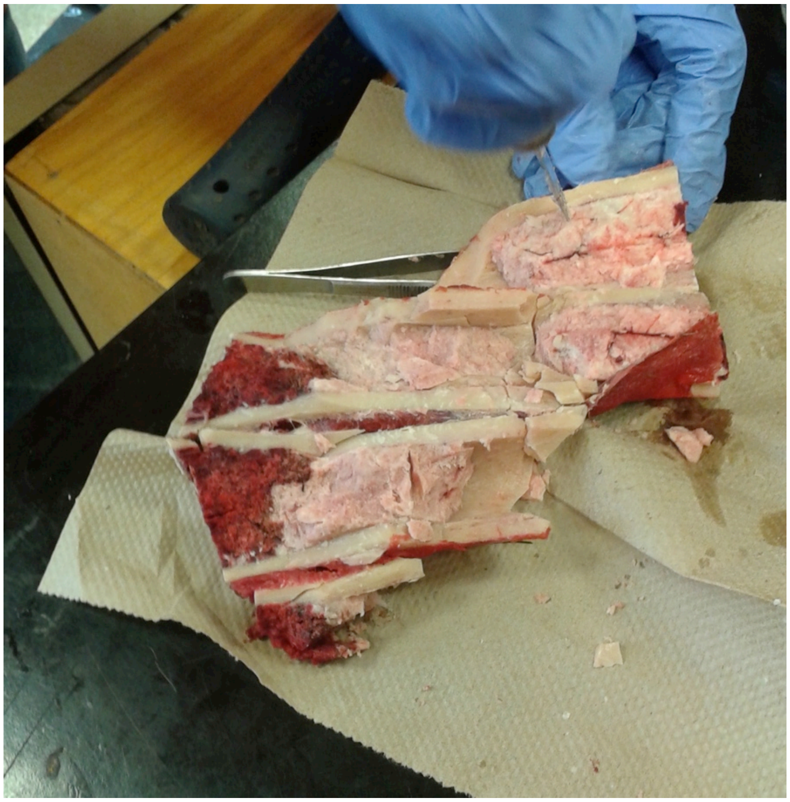


Figure 11. Example of a long bone sectioned for conducting marrow fat analysis in Prince George lab, May 2017 (Photo Doug Heard).

Table 2. Number and status of GPS-radio-collars deployed on Moose in all five study areas in central BC from February 2012–30 April 2017.

Study Year	Deployed Collars	Mortalities	Censored Collars	Active Collars*
2012	9	0	0	9
2012-2013	29	2	0	36
2013-2014	129	5	27	133
2014-2015	69	11	15	176
2015-2016	100	32	26	218
2016-2017	52	22	33	215
Totals	**388**	**72**	**101**	**215**

*Number of active collars at the end of each year is derived by modifying the number of collars active at the end of the previous year by the number of new collars deployed and lost through mortalities or censoring

Table 3. Number and status of GPS-radio-collars deployed on Moose in each study area in central BC from February 2012 – 30 April 2017.

Study Area	Study Year	Deployed Collars	Mortalities	Censored Collars	Active Collars
Bonaparte	2012	9	0	0	9
	2012-2013	29	2	0	36
	2013-2014	14	3	27	20
	2014-2015	30	2	7	41
	2015-2016	36	7	8	62
	2016-2017	20	5	27	50
	Totals	**138**	**19**	**42**	**50**
Big Creek	2013-2014	40	0	0	40
	2014-2015	13	3	8	42
	2015-2016	5	6	2	39
	2016-2017	6	4	0	41
	Totals	**64**	**13**	**10**	**41**
Entiako	2013-2014	44	0	0	44
	2014-2015	9	4	0	49
	2015-2016	17	10	16	40
	2016-2017	4	9	1	34
	Totals	**74**	**23**	**17**	**34**
Prince George South	2013-2014	16	0	0	16
	2014-2015	17	2	0	31
	2015-2016	16	6	0	41
	2016-2017	15	2	5	49
	Totals	**64**	**10**	**5**	**49**
John Prince Research Forest	2013-2014	15	2	0	13
	2014-2015	0	0	0	13
	2015-2016	26	3	0	36
	2016-2017	7	2	0	41
	Totals	**48**	**7**	**0**	**41**

Table 4. Programmed fix schedule for GPS-radio-collars deployed on cow Moose in each study area in central BC from February 2012–30 April 2017.

Study Area	>2 Fixes/Day	2 Fixes/Day	1 Fix/Day
Bonaparte	102	36	0
Big Creek	0	11	53
Entiako	17	19	38
Prince George South	15	16	33
John Prince Research Forest	0	25	23
Totals	**134**	**107**	**147**

4.2 Capture and Handling

Of the 388 cow Moose captured to date, 384 were assessed for age via tooth eruption, staining and wear patterns (Figure 12), with 81% (*n* = 314) classified as adults (4.5 – 7.5 years old), 15% (*n* = 56) as old (8.5 – 14.5 years old), and 4% (*n* = 14) as young (1.5 – 3.5 years old). Body condition for 344 of the animals assessed showed that 68% (*n* = 234) were in good body condition, 18% (*n* = 63) were in excellent body condition, 10% (*n* = 33) were in fair body condition, 3% (*n* = 11) were in poor body condition, and 1% (*n* = 3) were emaciated (Figure 13). All calves were assessed for body condition and were all classified as good. The average weight for calves, where it was feasible to weigh them using a body blanket and helicopter, was 182 kg (± 8 kg, SE; *n* = 8). Of the 325 cow Moose where we recorded calf status at capture, 68% (n = 222) were not accompanied by a calf, 31% (*n* = 101) had one calf and <1% (*n* = 2) had twins (Figure 14). This excludes the calf status of the 20 cows that were captured in Bonaparte in January 2017, because cows with calves were intentionally targeted to facilitate calf collaring.

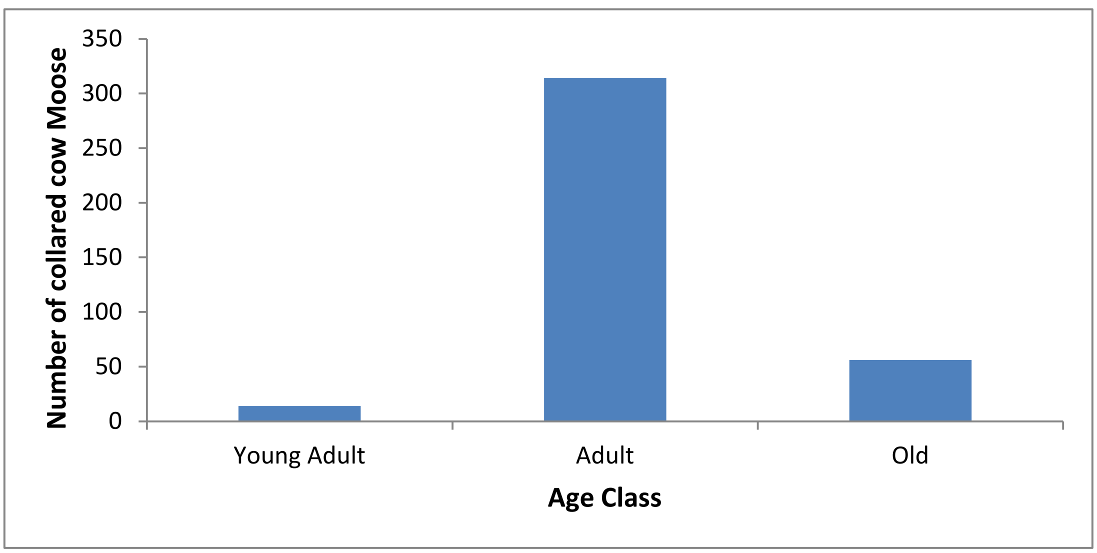


Figure 12. Age class summary of 384 cow Moose radio-collared in central BC from February 2012–30 April 2017 with ages estimated by tooth wear patterns. Young Adult Moose were estimated to be 1.5–3.5 years old, Adults as 4.5– 7.5 years old, and Old as 8.5–14.5 years old.

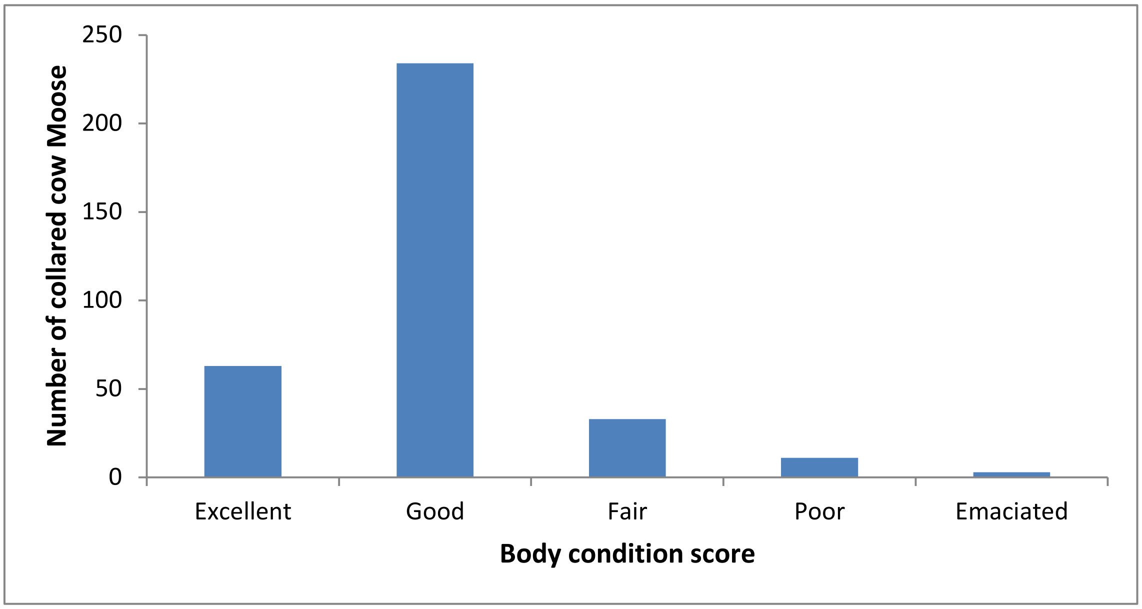


Figure 13. Body condition scores of 344 cow Moose radio-collared in central BC from February 2012–30 April 2017. Condition scores were assessed using external physical traits modified from Franzmann (1977).

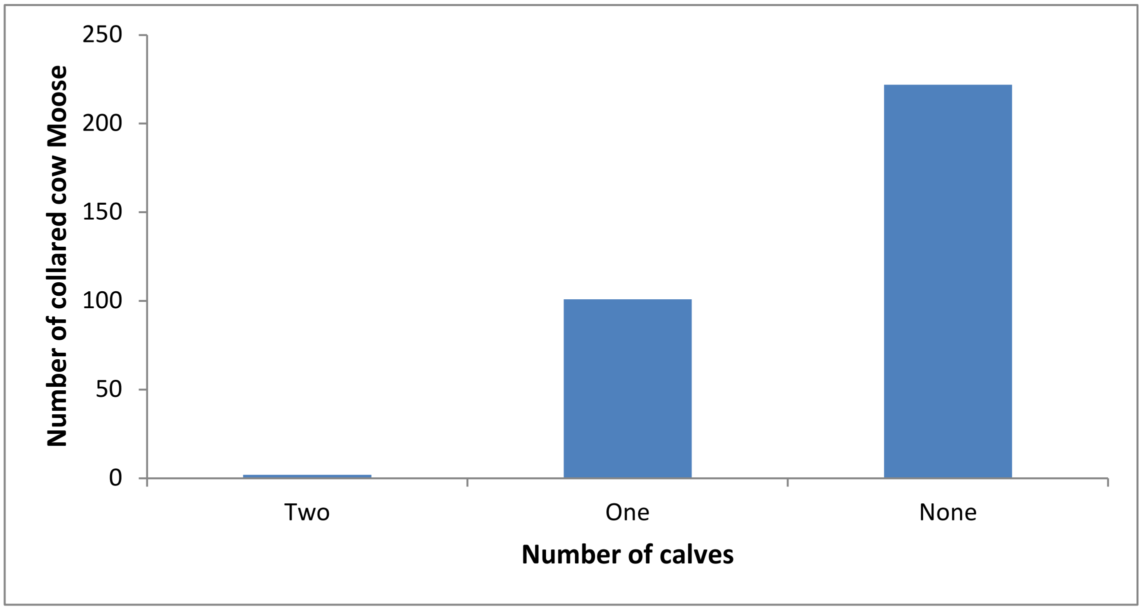


Figure 14. Calf status of 325 radio-collared cow Moose at time of capture in central BC from February 2012–30 April 2017.

Table 5. Survival rates of radio-collared cow Moose in central BC from February 2012–30 April 2017.

Year	Survival Estimate (± 95% CI)	Maximum Number of Active Collared Moose
2012	100 ± 0%	9
2012–2013	95 ± 7%	38
2013–2014	92 ± 8%	165
2014–2015	92 ± 5%	202
2015–2016	86 ± 5%	276
2016–2017	89 ± 7%	270

4.3 Biological Samples

Laboratories confirmed there was uncertainty when using serum progesterone levels to diagnose pregnancy in cow Moose when levels were low and advised us to compare the results with levels of serum Protein B. Our investigation into the interpretation of these results is ongoing. Initial serology screening of captured animals has indicated minimal exposure to pathogens. As such, screening is now focused on exposure to pathogens considered of high priority for impacts on production of ungulate populations, including *Neospora*, *Toxoplasma* and *Erysipelothrix rhusiopathiae*. We will continue to monitor and document winter tick (*Dermacentor albipictus*) prevalence during captures, mortality investigations and surveys, as ticks are known to cause a range of effects, including significant hair loss and loss of body condition of cows and calves.

Prompt mortality site investigations have resulted in maximum sample collection from several cases that were not caused by predation and had not been scavenged. Pathological investigations on those cases that included cows and calves in both good and poor body condition are ongoing. In addition, baseline hair cortisol levels (indicator of stress) and trace minerals levels are being determined for comparison among study areas.

4.4 Annual Survival Rates

From 2012–2017, the annual survival rate from all radio-collared cow Moose varied from 86–100% (Table 5). Survival of calves from date of capture in January or February 2017 to 31 May 2017 was 45 ± 22% (± 95% CI). The sample size for cows (n = 9) in 2012 and calves (n = 20) in 2017 was small, which suggests caution should be used when interpreting those survival estimates.

4.5 Mortality Causes

Seventy-two of the 388 radio-collared cow Moose died between February 2012 and 30 April 2017 (Table 6; Figures 15 and 16). Probable proximate causes of death (see Appendix C) were 49% from predation, 23% from health-related causes, 17% from hunting, 4% natural accident, and 7% unknown (Figure 15; see Figures 17–21 for images from mortality investigations). We classified mortalities as unknown when there was minimal evidence available at the mortality site to reliably assign a cause of death; these instances occurred when mortality site investigations were significantly delayed due to radio-collar malfunctions or predators moving the collar post-mortality such that a long delay occurred between the mortality event and the initiation of the mortality signal. Cow mortalities peaked in early spring with 39% of mortalities occurring in March and April

Table 6. Number of mortalities and probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2017.

Study Area	Mortalities	Probable Proximate Cause of Death
Bonaparte	19	4 predation (3 Wolf, 1 Cougar), 6 hunting (1 licensed, 5 unlicensed), 9 health-related (3 apparent starvation, 2 septicemia*, 4 unknown health-related)
Big Creek	13	6 predation (5 Wolf, 1 Cougar), 3 hunting (unlicensed), 3 health-related (1 apparent starvation, 1 septicemia, 1 peritonitis**), 1 natural accident
Entiako	23	17 predation (15 Wolf, 2 bear), 2 natural accident, 4 unknown
Prince George South	10	4 predation (3 Wolf, 1 Cougar), 2 hunting (unlicensed), 4 health-related (apparent starvation)
John Prince Research Forest	7	5 predation (Wolf), 1 hunting (unlicensed), 1 unknown
Totals	**72**	**36 predation (31 Wolf, 3 Cougar, 2 bear), 12 hunting (1 licensed, 11 unlicensed), 16 health-related (8 apparent starvation, 3 septicemia, 1 peritonitis, 4 unknown health-related), 3 natural accident, 5 unknown**

***Septicemia**: The presence of infective agents or their toxins in the bloodstream, sometimes called blood poisoning. It is characterized by elevated body temperature, chills, and weakness. Generally there is a primary site of infection that serves as the source of the pathogen. This is a serious condition that must be treated promptly otherwise the process of infection leads to circulatory collapse, profound shock and death.
****Peritonitis:** The inflammation of the peritoneum, the lining of the peritoneal cavity, or abdomen, by an infectious agent, usually bacteria but may be fungi or even a virus. The initiating cause may be a puncture of an organ, intestinal tract or the abdomen wall for entry of a pathogen. Left untreated, peritonitis can rapidly spread into the blood (sepsis) and to other organs, resulting in multiple organ failure and death.

(Figure 22, n = 72). Bone marrow fat (see examples in Figures 23 and 24) analysis conducted on cow Moose mortalities (n = 44) showed 20% with acute malnutrition (<20% marrow fat) and 20% in poor body condition (20–70% marrow fat; Figure 25).

Of the 20 calf Moose radio-collared in 2017, there were 11 mortalities between March 26 and 30 April 2017, with the proximate cause of mortality being 5 predation (4 Wolf, 1 bear), 5 health-related (4 apparent starvation, 1 unknown health-related with health tests pending) and 1 vehicle collision.

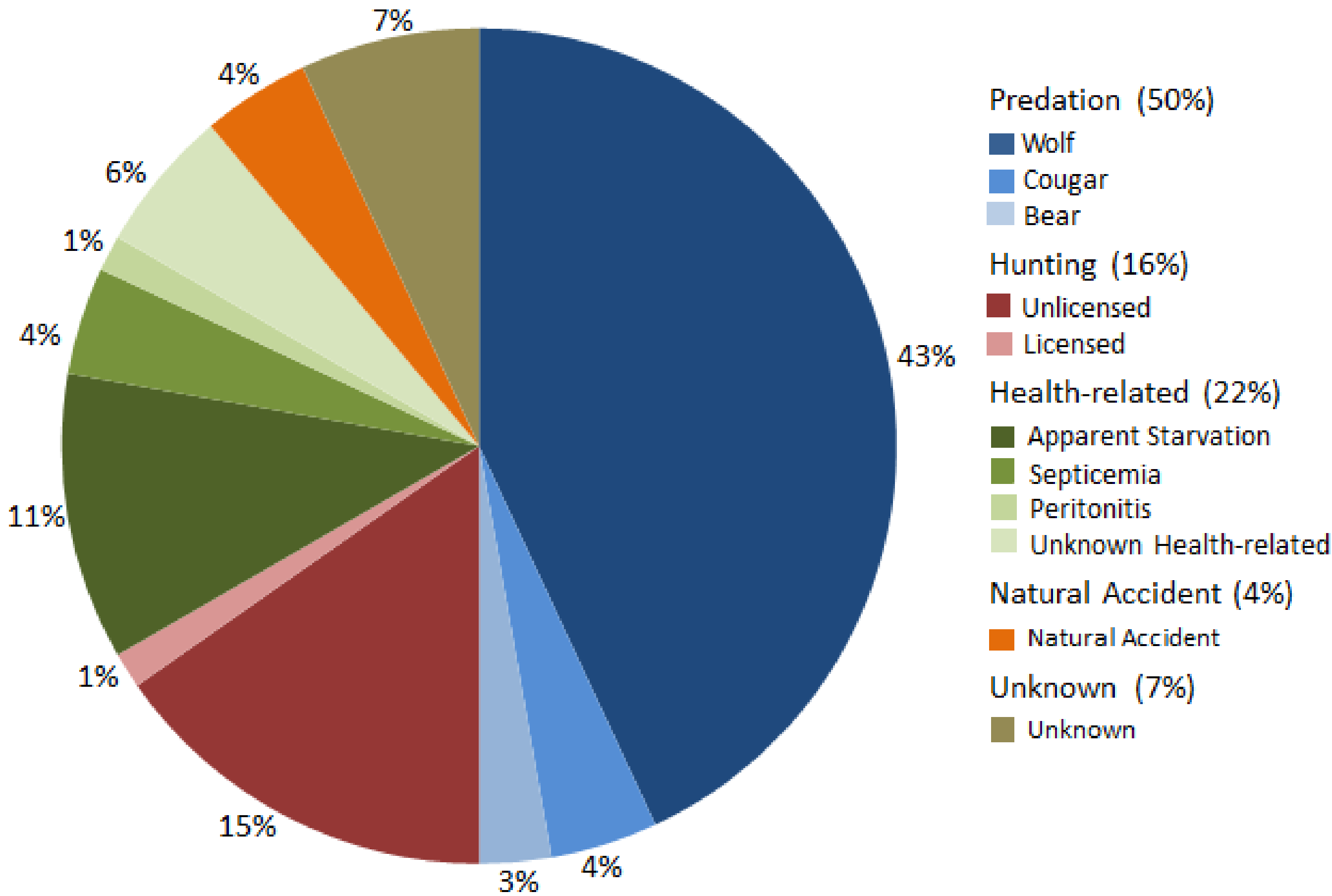


Figure 15. Probable proximate cause of death of radio-collared cow Moose (*n* = 72) in central BC from February 2012–30 April 2017.

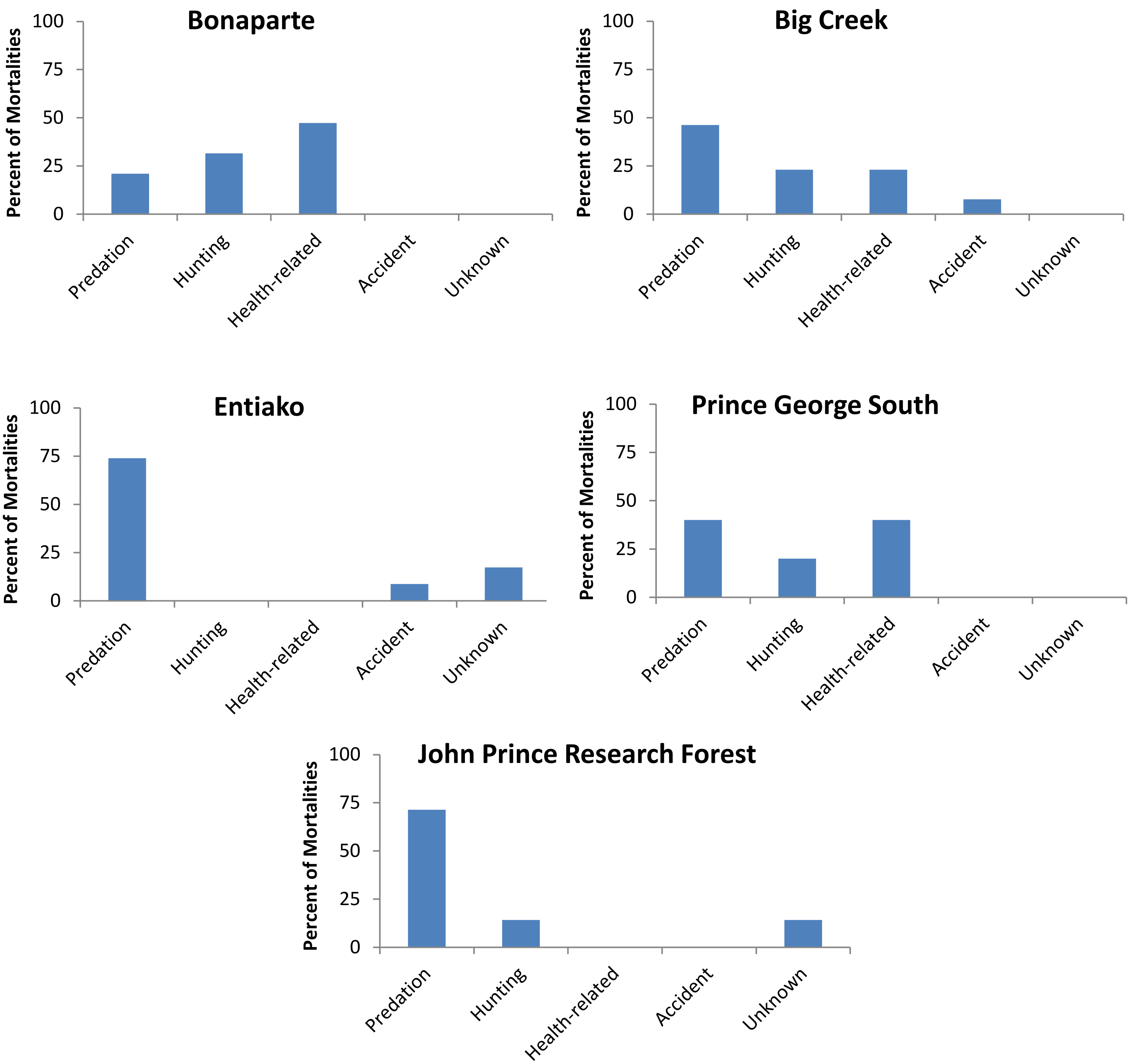


Figure 16. Probable proximate cause of death of radio-collared cow Moose (*n* = 72) by study area in central BC from February 2012–30 April 2017.

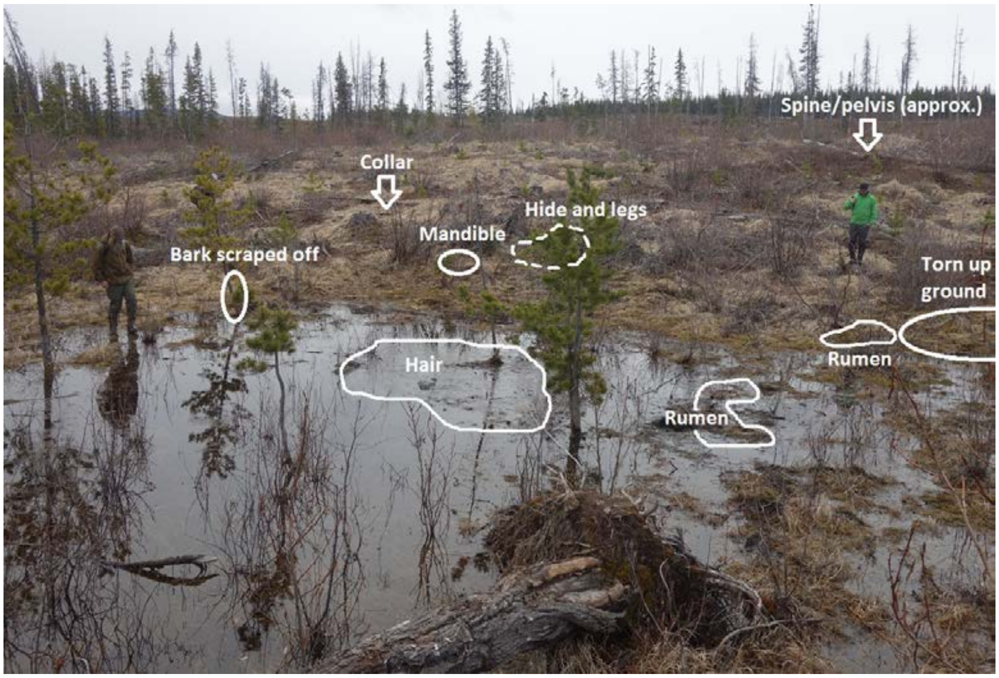


Figure 17. Example of a scene commonly found at a wolf-kill mortality site. In this scene Wildlife Biologist Doug Heard and helicopter pilot Rob Altoft investigate a cow Moose mortality in the Prince George South study area, May 2017 (Photo Morgan Anderson).

Figure 18. A mortality site investigation of a collared cow Moose within the Bonaparte study area. The proximate cause of death was a Cougar kill, April 2017 (Photo Chris Procter).

Figure 19. A mortality site investigation of a collared calf Moose mortality within the Bonaparte study area. The proximate cause of death was apparent starvation, March 2017 (Photo Chris Procter).

Figure 20. A mortality site investigation of a collared cow Moose in the Big Creek study area. A bullet wound was found in the right shoulder and the cause of death was determined to be unlicensed hunting, October 2016 (Photo Becky Cadsand).

Figure 21. Wildlife Biologist Heidi Schindler inspects a collar removed from a cow Moose that died in December 2016 following entrapment inside a deep (>7 feet) wetland pond within the Entiako study area, May 2017 (Photo Joey Chisholm).

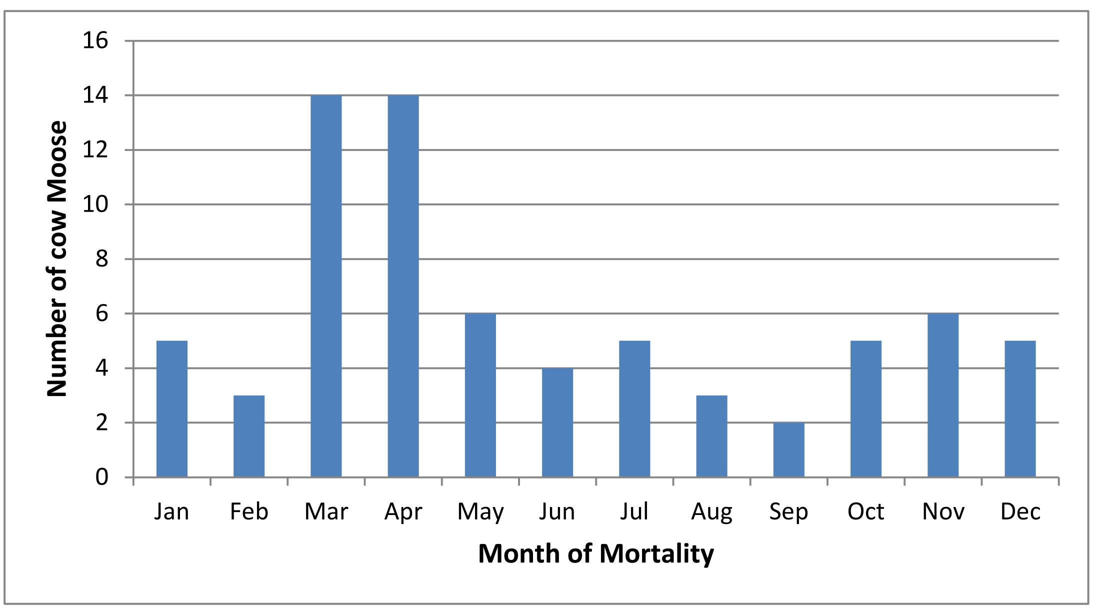


Figure 22. Month of death for radio-collared cow Moose (*n* = 72) in central BC from February 2012–30 April 2017. The biological year for determining survival rates was 1 May–30 April.

Figure 23. Example of long bone cross-section showing low marrow fat content collected during a mortality investigation in Entiako Study Area, May 2017 (Photo Heidi Schindler).

Figure 24. Example of long bone cross-section of high marrow fat content in a long bone cross-section collected during a mortality investigation in Entiako study area, May 2017 (Photo Heidi Schindler).

Table 7. Calf surveys to determine calf status of radio-collared cow Moose in central BC from March 2014–March 2017.

Study Area	# Calves/100 cows in Late Winter (n=# collared cows observed)			
	2014	2015	2016	2017
Bonaparte	not surveyed	25 (*n* = 40, Mar)	26 (*n* = 68, Mar)	16 (*n* = 32, Mar)
Big Creek	28 (*n* = 41, Mar)	37 (*n* = 43, Feb)	33 (*n* = 43, Mar)	27 (*n* = 41, Mar)
Entiako	not surveyed	not surveyed	14 (*n* = 44, Mar)	9 (*n* = 35, Mar)
Prince George South	not surveyed	39 (*n* = 18, Mar)	27 (*n* = 44, Mar)	40 (*n* = 49, Mar)
John Prince Research Forest	not surveyed	8 (*n* = 13, Feb)	17 (*n* = 36, Mar)	40 (*n* = 42, Mar)

4.6 Late Winter Calf Surveys

From 2014–2017, we conducted 15 late winter (February and March) surveys across the five study areas to assess the survival of calves associated with radio-collared cows. Results varied among study areas with calf/cow ratios ranging from 8–40 calves/100 cows (Table 7).

5. DISCUSSION

5.1 Data Collection – Biological Data

As of 30 April 2017, we have monitored survival of 388 cow Moose in five study areas. At the time of capture, the majority of cow Moose (predominately mid-aged adults - only 15% classed as old and 4% young) were assessed as in fair to excellent body condition (only 3% in poor condition and 1% emaciated), however condition varied by year and study area. All collared calves in the Bonaparte were assessed to be in good condition at time of capture. The combined calf ratio for all study areas at capture (25 calves/100 cows) for winter 2016/17 was similar to slightly lower than calf ratios found during comprehensive composition surveys conducted at the same time in or near our study areas, suggesting that our collared Moose sample is representative of the calf/cow ratio in the general population. This estimate excludes cows that were targeted to facilitate calf collaring.

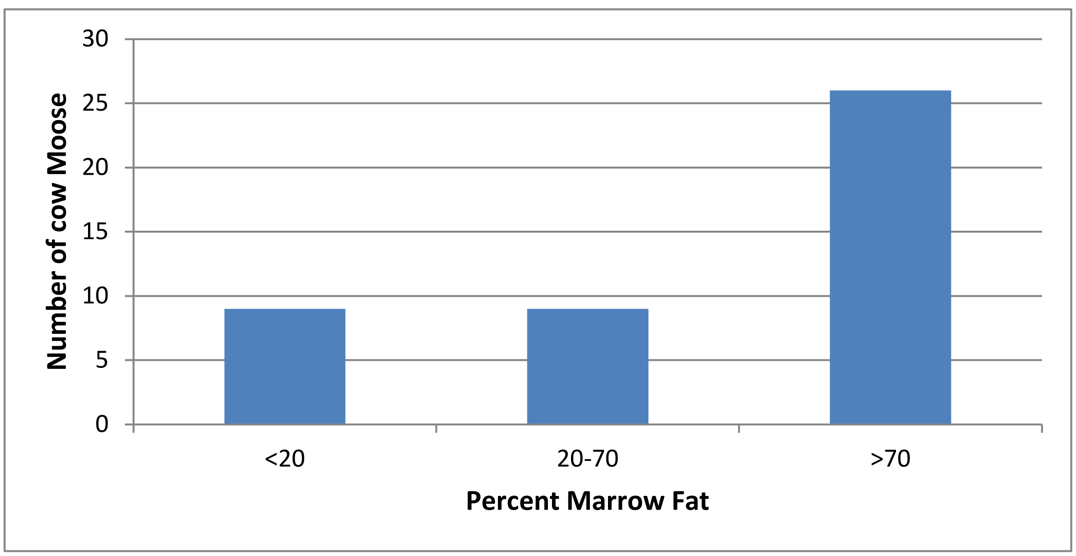


Figure 25. Percent marrow fat as a measure of body condition for radio-collared cow Moose mortalities (n = 44) in central BC from February 2012–April 30, 2017.

Capture methods and protocols used during this project are continually re-evaluated and refined over time by the project team. We use the most humane and effective methods possible and maximize the opportunity to collect appropriate biological samples while animals are immobilized or restrained. The recent development of a BC wild ungulate health assessment model and findings (FLNRORD, unpublished data) support the adjustments in protocols and the investigation of new measures of Moose health, including cumulative effects, the impact of winter ticks, nutrition and other factors leading to poor body condition. This has initiated collaborative work to further understand whether these factors are more widespread and their role, if any, in BC cervid populations.

The recent emphasis on assessing and monitoring Moose health, as well as standardization of procedures and increased experience and consistency in capture and mortality site investigation crews, has resulted in improved field methods and documentation. Examples of this include the recent use and evaluation of BAM II as an alternative drug combination to carfentanil/zylazine and to net gun captures without immobilization, and the addition of biological sample collection during mortality site investigations for hair cortisol, trace mineral levels and serological testing to further assess the role of health factors in live and dead Moose.

5.2 Survival of Collared Cows

The survival rates of radio-collared cow Moose (± 95% CI) range from 92 ± 5% in 2014/15 to 86 ± 5% in 2015/16 and was 89 ± 7% in 2016/17. These survival rates are within the range reported from other stable Moose populations (Bangs et al. 1989; Ballard et al. 1991; Bertram and Vivion 2002), and exceed the survival rates estimated for adult cow Moose in areas of the Northwest Territories (85%; Stenhouse et al. 1995) and northern Alberta (75–77%; Hauge and Keith 1981).

The probable proximate causes of death of radio-collared cow Moose have been variable within and among study areas. Probable causes were predation (wolves, bears, and Cougars), health-related issues (apparent starvation, septicemia), hunting, as well as natural accidents (getting mired in a wetland). The role of landscape features in influencing differential causes of mortality by study area is currently under investigation at UNBC. Forty percent (n = 18) of cow Moose mortalities where marrow fat could be assessed were in a state of poor condition or malnutrition. There was a peak in cow Moose mortality (n = 72) in early spring (March and April, n = 28). Of those spring mortalities, 60% were from predation, 32% were health-related, 4% were from unlicensed hunting, and 4% were from natural accident. Of those spring mortalities where marrow fat could be assessed (n = 19), 63% were in a state of poor condition or malnutrition that would have predisposed them to dying. For example, a radio-collared cow Moose in Big Creek died from myopathy resulting from intense muscle activity struggling in deep mud. The proximate cause of mortality was determined to be a natural accident, but her body condition showed she was in a state of malnutrition with 5% marrow fat.

Information and samples collected during mortality site investigations will help inform the ultimate cause of death in some cases. Further testing of samples collected from Moose during captures and mortalities may provide insight on pre-existing health conditions or other health indicators that may play a role in ultimate causes of death. At this time, there are an insufficient number of mortalities to draw reliable conclusions on the relative impacts of different probable causes of death on survival rates and Moose population growth. Further laboratory work is ongoing.

5.3 Calf Survival

Late winter survival of 20 calves (± 95% CI) from date of capture in January or February 2017 – 31 May 2017 was 45 ± 22%, and all of the mortality occurred between 26 March and 30 April 2017, when calves were approximately 300–335 days old. The typical pattern of Moose calf mortality consists of heavy mortality from birth through their first 60 days of age, largely due to predation, and generally negligible mortality later in the year (Hauge and Keith

1981; Larsen et al. 1989; Ballard et al. 1991; Bowyer et al. 1998; Testa 2004; Patterson et al. 2013) with the exception of significant winter mortality during years of severe winter conditions (Ballard et al. 1991). Two researchers have reported minor increases in calf mortality in late winter or early spring, but failed to provide details on causes (Larsen et al. 1989; Testa 2004). We observed significant mortality of calves during late winter (April), which was consistent with Moose calf mortality patterns observed in the northeastern United States in New Hampshire (Musante et al. 2010; Jones 2016) where winter tick infestation has been identified as being responsible for 100% of late winter calf mortality in recent years (Jones 2016). In our study, winter ticks were identified as a contributing cause in only one calf mortality. Laboratory analyses of samples collected from health-related mortalities are ongoing and may provide further insight into ultimate causes of death. Calf survival varies annually, even within stable populations, for a variety of reasons including the severity of winter weather, predation levels, winter tick infestation levels, exposure to disease, appropriate nutrition, and habitat condition (Murray et al. 2006; Gaillard et al. 1998). Further work is required in BC to understand spatial (i.e., across the landscape) and temporal (i.e., across years) variation in rates and causes of Moose calf mortality.

Given the compressed timeframe of Bonaparte calf mortalities, a survey to help inform late-year calf mortality was conducted in PG South. This survey was to assess calf survival from mid-March to early May to help determine if the Bonaparte calf mortalities were an anomaly among the broader sample of collared cow Moose. Survey results indicated that approximately 50% of calves found with collared cows in March were not located in early May, which is similar to losses observed among collared calves in the Bonaparte study area. The fate (i.e., died or dispersed) of PG South calves, however, is unknown because they were not collared. Data on collared calf/cow pairs in the Bonaparte shows a strong pairing association into mid- to late May, immediately prior to parturition of cows, suggesting that PG South calves likely died rather than dispersed. A low proportion of cows may have new calves in early May (e.g., one of 16 cows was estimated to have a calf on 7 May 2017 in the Bonaparte study area), which suggests a potential for bias when searching for 11–12 month old calves of collared cows in early May, as last year's calves may have already separated from maternal cows. However, this effect is expected to be negligible due to very low rates of cows having early calves. Ten of the 15 late winter calf surveys had calf/cow ratios at or above 25 calves/100 cows, which generally indicates stable Moose populations if adult female survival rates are above 85% (FLNRO 2015; Bergerud and Elliot 1986). However, despite our estimates of cow survival and observations of calf ratios exceeding 25 calves/100 cows in late winter, some populations appear to have declined based on survey data. Understanding the causes of these declines and the factors affecting Moose population change requires continued efforts to monitor Moose calf survival rates, timing, causes of calf mortality and calf recruitment to older age classes.

5.4 Landscape Change and Survival Analyses

A complementary analysis of habitat selection of radio-collared Moose is currently underway at UNBC (Big Creek, Entiako, Prince George South study areas) and the University of Victoria (Bonaparte study area). John Prince Research Forest intends to investigate seasonal migrations of collared cows and fine-scale winter occupancy patterns. Preliminary UNBC-based analyses suggest that cow Moose have shorter daily movements and smaller home ranges in areas with high-intensity clear-cutting. Further, selection by cow Moose within their seasonal home ranges appears to differ by study area and season. Cow Moose in high intensity clear-cut areas avoided new cuts only during the summer, and selected for mature conifer cover in all seasons except early winter. On the least clear-cut landscape, new cuts were avoided in all seasons, roads were avoided in the fall, early and late winter, and Moose were located closer to the edge of a mature forest than were random locations in all seasons. Deciduous cover was selected across all seasons and study areas.

The Habitat Conservation Trust Foundation is supporting a comprehensive two-year, cow-survival analysis with UNBC. This work began in May of 2017 rather than in spring of 2018 as originally scheduled, in part, due to increasing pressures around Moose management in BC (Kuzyk 2016). Our collaborators are using survival models, which can include covariates such as extent of salvage logging, road access, etc., to determine if there is support for different mortality agents within the different study areas. The completed analysis will examine similarities and differences in apparent causes for mortality across the project, and provide ranked support for hypotheses linking differences between surviving and dying animals to key management actions.

6. FUTURE RESEARCH DIRECTION

Our research to date has provided a better understanding of factors affecting cow Moose survival in the BC interior. Our work, however, has also highlighted important research gaps that should be examined to gain a more comprehensive understanding of Moose population change in central B.C. Recommendations for continued work are:

Continue monitoring cow survival indefinitely – This project is currently in its fifth year of a planned 5-year project. Benefits of long-term monitoring of cow Moose include: 1) assessment of temporal variation in causes and rates of cow Moose mortality and the ability to relate trends in survival with environmental variation; 2) provision of information to monitor population trends and data inputs to improve population models used to monitor Moose populations and determine sustainable harvest levels; and 3) provision of information essential to evaluating the effectiveness of management strategies aimed at Moose management both within and outside the study areas. Continuation of the study will also provide opportunities to experimentally assess effectiveness of enhancement strategies and health monitoring priorities.

Assess Moose calf and yearling survival/ behavior – The importance of assessing calf survival has been highlighted in the Moose research design (Kuzyk and Heard 2014), the 2015 and 2016 progress reports (Kuzyk et al. 2015; Kuzyk et al. 2016), and reflected in these recent 2016/17 preliminary results. Funding has been secured to collar an additional twenty 7–8 month old calves in both the Bonaparte and PG South study areas during the winter of 2017/18. To obtain reliable inferences on the role of calf and yearling survival on population growth and to understand temporal and spatial variation in calf survival and recruitment, calf monitoring should occur for a minimum of five years, with a minimum of 20–30 calves collared annually (see Boertje et al. 2007 and Jones 2016) in multiple study areas. Additionally, spring or early summer surveys can be conducted to assess parturition success and estimate young-of-year calf survival (compared to late-winter calf survey data) among collared cow Moose, particularly in study areas with low late-winter calf/cow ratios (e.g., Entiako).

Assess potential nutritional and health concerns – The role of nutrition and health in driving Moose population dynamics in central BC is currently unknown, but preliminary results in the 2016 and 2017 progress reports, e.g., cows in poor condition at capture, observations of apparent starvation mortalities, low pregnancy rates, and low calf survival, warrant further investigation into nutrition and other health indicators, particularly those relating to reproductive health. Projects are underway in 2017/18 that will investigate how potential changes in forage nutrition quality may influence Moose populations and will assess potential health concerns.

Assess importance of Moose in predator diet – Predation is currently being monitored through identification of cause of death and species of predator in mortalities, but only on cow Moose. Funding has been secured for multi-year (2017/18–2021/22) direct assessment of wolf predation rates and species selection through collaring wolves and conducting location cluster investigations in the PG South and JPRF areas that will help inform interpretation of predation pressure on these Moose populations. The importance of other predation types on Moose population dynamics remains a research gap.

7. LITERATURE CITED

Alfaro, R.I., L. van Akker, and B. Hawkes. 2015. Characteristics of forest legacies following two mountain pine beetle outbreaks in British Columbia, Canada. Can. J. For. Research 45:1387-1396.

Ballard, W.B., J.S. Whitman, and D.J. Reed. 1991. Population dynamics of moose in south-central Alaska. Wildl. Monogr. 114:3-49.

Bangs, E.E., T.N. Bailey, and M.F. Portner. 1989. Survival rates of adult female moose in the Kenai Peninsula, AK. J. Wildl. Manage. 53:557-563.

Bergerud, A.T., and J.P. Elliott. 1986. Dynamics of caribou and wolves in northern British Columbia. Can. J. Zool. 64:1515–1569.

Bertram, M.R., and M.T. Vivion. 2002. Moose mortality in eastern interior Alaska. J. Wildl. Manage. 66:747-756.

Boertje, R.D., K.A. Kellie, C.T. Seaton, M.A. Keech, D.D. Young, B.W. Dale, L.G. Adams, and A.R. Aderman. 2007. Ranking Alaska moose nutrition: signals to begin liberal antlerless harvest. J. Wildl. Manage. 71:1494-1506.

Bowyer, R.T., V. Van Ballenberghe and J.G. Kie. 1998. Timing and synchrony of parturition in Alaskan moose: long term versus proximal effects of climate. J. Mammal. 79:1332–1344.

British Columbia Ministry of Forests, Lands and Natural Resource Operations (FLNRO). 2015. Provincial Framework for Moose Management in British Columbia. Fish and Wildlife Branch, Victoria, BC.

Franzmann, A.W., 1977. Condition assessment of Alaskan moose. *In* Proc. North American moose Conference and Workshop. Vol. 13:119-127.

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

Gillingham, M.P., and K.L. Parker. 2008. The importance of individual variation in defining habitat selection by moose in northern British Columbia. Alces 44:7-20.

Hauge, T.M., and L.B. Keith.1981. Dynamics of moose populations in northeastern Alberta. J. Wildl. Manage. 45:573-597.

Janz, D.W. 2006. Mountain pine beetle epidemic – hunted and trapped species sensitivity analysis. B.C. Minist. Environ., Environ. Steward., Prince George, BC.

Jones, H. 2016. Assessment of health, mortality, and population dynamics of Moose in northern New Hampshire during successive years of winter tick epizootics. MSc. Thesis, Univ. New Hampshire, Durham, NH.

Keech, M.A., M.S. Lindberg, R.D. Boertje, P. Valkenburg, B.D. Taras, T.A. Boudreau, and K.B. Beckmen. 2011. Effects of predator treatments, individual traits, and environment on moose survival in Alaska. J. Wildl. Manage. 75:1361-1380.

Kuzyk, G., and D. Heard. 2014. Research design to determine factors affecting moose population change in British Columbia: testing the landscape change hypothesis. B.C. Minist. For., Lands and Nat. Resour. Operations. Victoria, BC. Wildl. Bull. No. B-126. 16pp.

Kuzyk, G., S. Marshall, M. Klaczek, and M. Gillingham. 2015. Determining factors affecting moose population change in British Columbia: testing the landscape change hypothesis. B.C. Minist. For., Lands and Nat. Resour. Operations. Victoria, BC. Wildl. Working Rep. No. WR-122. 9pp.

Kuzyk, G., S. Marshall, M. Klaczek, C. Procter, B. Cadsand, H. Schindler and M. Gillingham. 2016. Determining factors affecting moose population change in British Columbia: testing the landscape change hypothesis. 2016 Progress Report: February 2012 – 30 April 2016. B.C. Minist. For, Lands and Nat. Resour. Operations. Victoria, BC. Wildl. Working Rep. No. WR-123. 26pp

Kuzyk, G.W. 2016. Provincial population and harvest estimates of moose in British Columbia. Alces 32:1-11.

Kuzyk, G.W., and I.W. Hatter. 2014. Using ungulate biomass to estimate abundance of wolves in British Columbia. Wildl. Soc. Bull. doi: 10.1002/wsb.475.

Larsen, D.G., D.A. Gauthier and R.L. Markel. 1989. Causes and rate of mortality in the southwest Yukon. J. Wildl. Manage. 53:548–557.

Mech, L.D., and G.D. Delgiudice. 1985. Limitations of marrow-fat techniques as an indicator of body condition. Wildl. Soc. Bull. 13(2):204-206.

Meidinger, D., and Pojar, J., 1991. Ecosystems of British Columbia. B.C. Minist. For., Victoria, BC. Special Report Series 6.

Mowat, G., D.C. Heard, and C.J. Schwarz. 2013. Predicting grizzly bear density in western North America. PloS one, 8(12), e82757. doi: 10.1371/journal.pone.0082757

Murray, D.L., E.W. Cox, W.B. Ballard, H.A. Whitlaw, M.S. Lenarz, T.W. Custer, T. Barnett, and T.K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. Wildl. Monogr. 166:1-30.

Musante, A.R., P.J. Pekins, and D.L. Scarpitti. 2010. Characteristics and dynamics of a regional *Alces alces* population in the northeastern United States. Wildl. Biol. 16:185-204.

Neiland, K. 1970. Weight of dry marrow as indicator of fat in caribou femurs. J. Wildl. Manage. 34:904-907.

Passmore, R.C., Peterson, R.L., and A.T. Cringan. 1955. A study of mandibular tooth-wear as an index to age of moose. Pp. 223-238 *in* R.L. Peterson. North American moose. Univ. Toronto Press, Toronto, ON.

Patterson, B.R., J.F. Benson, K.R. Middel, K.J. Mills, A. Silver and M.E. Obbard. 2013. Moose calf mortality in central Ontario. J. Wildl. Manage. 77:832-841.

Pollock, K.H., S.R. Winterstein, C.M. Bunck, and P.D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. J. Wildl. Manage. 53:7-15.

Poole, K.G., R. Serrouya, and K. Stuart-Smith. 2007. Moose calving strategies in interior montane ecosystems. J. Mammal. 88:139–150.

Ritchie, C. 2008. Management and challenges of the mountain pine beetle infestation in British Columbia. Alces 44:127-135.

Sand, H., C. Wikenros, P. Ahlqvist, T. Stromseth, and P. Wabakken. 2012. Comparing body condition of moose (*Alces alces*) selected by wolves (*Canis lupus*) and human hunters: consequences for the extent of compensatory mortality. Can. J. Zool. 90:403-412.

Shackleton, D. 1999. Hoofed mammals of British Columbia. Royal B.C. Mus. handbook. Univ. B.C. Press, Vancouver, BC.

Sittler, K.L., and R.S. McNay. 2017. Moose Limiting Factors Investigation: Annual Report 2016-2017. Wildlife Infometrics Inc. Report No. 574. Wildlife Infometrics Inc., Mackenzie, BC.

Stenhouse, G.B., P.B. Latour, L. Kutny, N. Maclean, and G. Glover. 1995. Productivity, survival, and movements of female moose in a low-density population, Northwest Territories, Canada. Arctic 48:57-62.

Testa, J.W. 2004. Population dynamics and life history trade-offs of moose (*Alces alces*) in south-central Alaska. Ecol. 85:1439-1452.

Appendix A. Tooth Wear Index from Passmore et al. (1955) used to estimate age for captured cow Moose in central BC.

AGE CLASS ESTIMATE (Tooth wear)		
AGE CLASS	**AGE EST**	**DESCRIPTION OF TOOTH WEAR**
YOUNG ADULT	1 ½	Permanent teeth in place. Cheek teeth are visible in lower jaw. Third premolar may still have 3 cusps.
	2 ½	Third premolar has 2 cusps. Third molar has erupted. All premolars and molars show slight wear and stain. Outer canine teeth in final position. Incisors with little wear or staining.
	3 ½	Lower jaw has now elongated. Last cusp of third molar no longer cradled in lower jaw. Dentine now wider than enamel.
ADULT	4 ½	Wear on lingual crest and cupping of molars becomes increasingly pronounced.
	5 ½	
	6 ½	
	7 ½	
AGED	8 ½	Pit (infundibula) of 1st molar completely worn.
	9 ½	
	10 ½	
	11 ½	
	12 ½	Pit (infundibula) of 3rd premolar completely worn.
	13 ½	
	14 ½	

Appendix B. Body Condition Index modified for this project from Franzmann (1977) used to estimate body condition in adult cow Moose captured in central BC.

BODY CONDITION SCORING SYSTEM		
Modified Body Condition	**SCORE (Franzmann 1977)**	**PHYSICAL DESCRIPTION (Franzmann 1977)**
	10	Prime, fat animal with thick, firm rump fat by sight. Well fleshed over back and loin. Shoulders and rump round and full.
	9	Choice, fat Moose with evidence of rump fat by feel. Fleshed over back and loin. Shoulders round and full.
5	8	Good, fat Moose with slight evidence of rump fat by feel. Bony structures of back and loin not prominent. Shoulders well fleshed.
4	7	Average Moose with no evidence of rump fat, but well fleshed. Bony structures of back and loin evident by feel. Shoulders with some angularity.
3	6	Moderately fleshed Moose beginning to demonstrate one of the following conditions: (A) definition of neck from shoulders; (B) upper foreleg (humerus and musculature) distinct from chest; or (C) rib cage prominent.
2	5	Two of the characteristics listed in 6 are evident.
1	4	All Three of the characteristics in 6 are evident.
	3	Hide fits loosely about neck and shoulders. Head carried at a lower profile. Walking and running postures appear normal.
	2	Sings of malnutrition. Outline of the scapula evident. Head and neck low and extended. Walks normally but trots and paces with difficulty, cannot canter
	1	Point of no return. Generalized appearance of weakness. Walks with difficulty; cannot trot, pace or canter.
	0	Dead.

Appendix C. Definitions of probable proximate causes of Moose mortality in central BC.

- **Hunting:** Moose killed by humans for recreation, food, social or ceremonial purposes
    - **Licensed hunting:** Moose killed by licensed hunters in accordance with hunting regulations
    - **Unlicensed hunting:** Moose killed by hunters not in accordance with hunting regulations
- **Predation:** Moose that have been killed by a predator
- **Health-related:** Moose that died of an underlying health-related cause (starvation, parasitism, mineral deficiency, non-infectious disease, etc.) or pathogen (i.e., infectious disease) as identified through carcass field necropsy and/or subsequent pathology or no other clear causes of mortality was evident
    - **Apparent starvation:** Moose that have died in very poor condition and are emaciated as evidenced by extreme gross examination (lack of bone marrow fat and lack of visible body fat). Bony structures of shoulders, back, loins, ribs and hips are visually evident. No other clear causes of mortality are obvious or found.
    - **Septicemia:** Moose that have died from bacteria and/or their toxins have entered the blood and caused body-wide results.
    - **Unknown health-related:** Moose that were definitively not killed by predation, hunting or natural accident and no underlying health-related cause or pathogen was detected.
- **Natural accident:** Moose that have died naturally from a cause that was accidental in nature (i.e., drowning, mired in mud, avalanche, etc.).
- **Unknown:** Moose that have died and no clear cause of death was identified, which in most cases is due to lack of evidence at mortality site.

Appendix D. Mortality site investigation form used to assess cause of mortality for Moose in central BC (revised April 2016),

July 2017

BC Moose Research – Mortality Investigation Form

Date: _______________ Date of mortality (signal): _______________ Days elapsed since death: ________

Found dead ☐ or Euthanized ☐ Method of Euthanasia: ____

If euthanized, collect blood sample – 1 x yellow top tube

Personnel: ____

General Location: ____

Waypoint: _________ UTM: Zone _____ E: _____________________ N: _____________________

Lat: _____________________ Long: _____________________

WILDLIFE HEALTH ID: _________________________

Ear Tag #: _____________ Collar Recovered: Y / N VHF Freq: _________________ Ser. No.: ________________

Carcass Located: Y / N Collar Condition: _____________ Functional ☐ Damaged ☐ Destroyed ☐

DESCRIBE THE MORTALITY SITE and TAKE PHOTOS (Include Scale, Habitat Type, Tracks, Scat, Blood, Signs of Struggle, etc.)

____
____
____
____
____
____

Snow Crust: Heavy ☐ Light ☐ Fluffy ☐ No Snow ☐ Snow Depth (cm):_________ Sinking Depth (cm): __________

EXTERNAL EXAM– Describe abnormalities, collect samples, take photos (choose all that apply)

Decomposition State: Fresh ☐ Bloated ☐ Active Decay (w/maggots) ☐ Advanced (desiccated) ☐ Skeleton ☐

Carcass Location	Condition	Carcass State	Body Condition	Skin/Hair Coat	Eyes
In Open ☐	Fresh ☐	Intact ☐	Excellent ☐	Normal ☐	Cloudy ☐
Under cover ☐	Frozen ☐	Disarticulated ☐	Good ☐	Abnormal ☐	Swollen ☐
Buried ☐	Decomp. ☐	Scattered ☐	Fair ☐	Hide Inverted ☐	Discharge ☐
Other __________ ☐	_________ ☐	Scavenged ☐	Poor ☐	Missing Hair ☐	Blood ☐
		___________ ☐	Emaciated ☐	Ticks ☐	
			Unknown ☐	Lump/Wart ☐	
*** Discharge/Blood**	**Diarrhea/Feces**	**Hoof Condition**	**Bones/Joints**	**Mouth/Teeth**	**Reproductive**
None ☐	None ☐	Normal Wear ☐	Normal ☐	Normal Wear ☐	Lactating ☐
Mouth ☐	Normal ☐	Worn ☐	Chewed ☐	Irregular ☐	Vaginal d/c ☐
Nose ☐	Diarrhea ☐	Overgrown ☐	Fractured ☐	Broken ☐	Sheath d/c ☐
Anus ☐	_________ ☐	____________ ☐	Compound ☐	____________ ☐	
Other:_________ ☐			__________ ☐		

***If discharge (d/c) present,** choose appropriate descriptor(s): ☐ Clear ☐ Cloudy ☐ Blood ☐ Other __________

Calf/fetus present? Y / N ? Alive / Dead ? Age: _____________ Sex: ________ Single / Twin ?

Comments: If animal was found alive, describe symptoms (recumbent, circling, vocalizing, aggressive, dull, etc.)

____
____
____
____

Were any taken? Photos ☐ Video ☐ Back Fat Depth (mm): _________________

Ticks: ☐ None Obvious ☐ Few ☐ Moderate ☐ Heavy

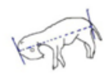
Collect tick sample – 10 engorged (70% EtOH)

Hair Loss: ☐ None ☐ Mild (5-20%) ☐ Moderate (20-40%) ☐ Severe (40-80%) ☐ Ghost (>80%)

INTERNAL EXAM – Note abnormalities, collect samples (see protocol below), **take photos** (heart/lungs, undisturbed abdominal cavity)

	Normal	Abnormal	Comments
Lungs/Trachea	☐	☐	______________________________
Heart	☐	☐	______________________________
Muscle	☐	☐	______________________________
Liver	☐	☐	______________________________
Kidney	☐	☐	______________________________
Spleen/Lymph Nodes	☐	☐	______________________________
Stomach/Intestines	☐	☐	______________________________
Skull/Spine	☐	☐	______________________________
Reproductive Tract	☐	☐	______________________________

If pregnant, record sex and crown-rump length(s) of fetus(es):



Sex: ______ CR Length (cm): _________
Sex: ______ CR Length (cm): _________

CAUSE OF DEATH (check appropriate boxes):

GENERAL		IF PREDATION	
COD	**Confidence**	**Species**	**Confidence**
Predation ☐	Definitive ☐	Wolf ☐	Definitive ☐
Collision ☐	Probable ☐	Bear ☐	Probable ☐
Hunter Kill ☐	Possible ☐	Cougar ☐	Possible ☐
Hunter Wound ☐		_________ ☐	
Accident ☐			
Other ☐			
Unknown ☐			
Scavenging? Y / N			

Comments (for proximate and ultimate COD):
____
____
____
____
____
____
____
____
____

SAMPLES TO COLLECT IN THE FIELD (Post-field sub-sampling described on processing sheet)
Must be processed ASAP at office or lab

☐ HEAD (or sample Obex and LN in the field if trained)
☐ TEETH (incisors or jaw – jaw preferred)
☐ INTACT LONG BONE #1 (femur or humerus)
☐ INTACT LONG BONE #2 (femur or humerus)
☐ MUSCLE (from leg, 1/4 apple size)
☐ HEART (1/4 apple size)
☐ LUNGS (1/2 apple size of right, front and back lobes)
☐ WHOLE KIDNEY + FAT
☐ WHOLE KIDNEY
☐ LIVER (apple size)
☐ INTESTINE *if abnormal and fresh
☐ SPLEEN (palm size)
☐ HAIR (100+ from top of shoulder; stuff 2 envelopes full)
☐ FECES (10-20 pellets)
☐ FETUS (whole if possible)
☐ CALF (if new born)
☐ PLACENTA OR UTERUS (portion)
☐ BLOOD (from heart/jugular vein in red top or EDTA)

☐ CYSTS (if unknown cause)
☐ TICKS
☐ LYMPH NODE *if abnormal
☐ OTHER ___________________________
☐ OTHER ___________________________

☐ PREDATOR DNA (hide with puncture marks)
Swab in field if possible
☐ PREDATOR HAIR
☐ PREDATOR SCAT

LABEL EACH SAMPLE WITH:
- WLH ID
- SPECIES
- SAMPLE TYPE
- DATE
- STUDY AREA

Appendix E. Calf survey form used during late-winter Moose surveys to monitor calf/cow ratios.

BC Moose Research Study – Winter Calf Survival Survey		
Study Area:	Personnel:	
Survey Date(s)	Weather Conditions (Temperature, Cloud cover, Precipitation, Snow coverage)	Survey Time (hours)

#	Frequency	SN	WLHID	Last Fix Date	GPS WPT #	UTM Zone	Easting or Latitude	Northing or Longitude	Cow Located (Y/N)	Calf Present (#/No)	Ticks[†] (Cow)	Ticks[†] (Calf)	Comments/Cow Condition/ Incidental Observations
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
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25													
26													
27													

[†]Hair loss classes: None; Mild (5-20%); Moderate (20-40%); Severe (40-80%); Ghost (>80%)