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

2018 Progress Report: February 2012–April 2018

by

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Cover Photo: Cow Moose observed during capture work in the Entiako study area (Photo: Heidi Schindler).

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EXECUTIVE SUMMARY

In 2013, the BC government initiated a research project to determine the factors affecting Moose population change in central BC by testing the landscape change hypothesis proposed by Kuzyk and Heard (2014). This report provides some preliminary results and some interpretation of the data collected from February 2012 to April 2018. This technical report was preceded by three annual reports: Kuzyk et al. (2015, 2016, 2017). This project was initiated because Moose numbers in central British Columbia (BC) had declined since the early 2000s, causing concern with First Nations and stakeholders. Much of the decline happened concurrently with a Mountain Pine Beetle outbreak that killed a large proportion of mature pine trees and resulted in increased salvage logging and road building. In response to the Moose decline, a 5-year provincially-coordinated Moose research project was initiated by the B.C. 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 (FLNRORD)]. In February 2012, a Moose study with similar objectives began on the Bonaparte Plateau and was integrated with this project. The primary research objective of this project is to evaluate a landscape change hypothesis, which states that Moose declines coincided with a mountain pine beetle (MPB) outbreak where habitat changes and increased salvage logging and road building resulted in greater vulnerability to Moose from hunters, predators, nutritional constraints, age/health and environmental conditions. It assumes Moose survival will increase when: a) forest cutblocks regenerate to the point where vegetation obstructs the view of predators and hunters; b) resource roads created for logging are rendered impassable; and c) Moose become more uniformly dispersed on the landscape. We evaluated that hypothesis by identifying causes and rates of cow Moose mortality, and examining factors that contributed to their vulnerability. To assess the causes and rates of calf mortality, an important research gap previously identified at the outset of this project, Moose calves were collared in Bonaparte and Prince George South in the winters of 2016/17 and 2017/18. This progress report provides data and a preliminary interpretation of the results from 28 February 2012 to 30 April 2018 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 GPS radio collars on a total of 460 individual Moose: 400 cows and 60 8-month old calves. There were 14 cow Moose that were recaptured to replace collars (total GPS radio collars = 414). Since 2016/17, we have collared sixty 8-month old calf Moose in the Bonaparte (n = 40) and Prince George South (n = 20) study areas. Three configurations of GPS radio collars were used: those programmed for one fix/day (n = 147), 2 fixes/day (n = 109), and >2 fixes/day (n = 158). As of 30 April 2018, 194 GPS collars were active on cow Moose, 110 censored (i.e., dropped at end of battery life, stopped collecting data or slipped from Moose), and 97 were associated with Moose that died.

We identified the probable proximate cause of death for the 97 cow mortalities as 52 predation (42 Wolf, 4 Cougar, 6 bear), 16 hunting (1 licensed, 15 unlicensed), 19 health-related (9 apparent starvation, 2 failed predation attempt, 1 chronic bacterial infection, 1 peritonitis, 1 prolapsed uterus, 5 unknown health-related), 3 natural accident, and 7 unknown. There were 21 calf mortalities which all occurred between 11 March and 23 May. Proximate probable cause of mortality of calves was 11 predation (9 Wolf, 1 Cougar, 1 Bear), 8 health-related (4 apparent starvation, 2 apparent starvation/tick, 1 failed predation attempt, 1 gastro-intestinal infection) and 1 vehicle collision. We recorded a significantly higher proportion of health-related (particularly apparent starvation) mortalities (i.e., 45%) in 2016/17 than in 2017/18.

The majority of cow and calf Moose were in good body condition at the time of capture; however, some cows captured in 2016/17 were assessed as in poor or emaciated body condition. A standard set of biological samples were collected that included age estimates and body condition estimation by live

animal assessment at capture or through marrow fat collection during mortality site investigations, as available. Six-year average pregnancy rates observed in this study ranged from 64–94%, with the lowest observed in the Bonaparte (64%) and Prince George South (75%) study areas. Average rates in the remaining study areas were 84–94%. Parturition (determined by analyzing cow movement rates) and pregnancy rates vary from each other in the same year but one metric is not consistently higher than the other. Bone-marrow-fat analysis from cow Moose mortalities (n = 63) showed 55% in good body condition (>70% marrow fat), 25% with acute malnutrition (<20% marrow fat), and 21% in poor body condition (20–70% marrow fat). The majority of mortalities involving cows with acute malnutrition and poor body condition occurred between March and June while mortalities in the remainder of the years typically involved cows in good body condition. 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.

The landscape change hypothesis assumes cow survival to be the primary driver influencing Moose population change because declines in some areas occurred rapidly. Our results were inconsistent with this hypothesis as cow survival rates were within the range reported from other stable Moose populations (i.e., >85%). The Bonaparte, Big Creek and John Prince study areas had cow survival >85% in all years, whereas Entiako was generally below 85% in most years and Prince George South below 85% in two of five years. These cow survival rates, indicative of stable population growth, have led to the increasing importance of evaluating Moose calf survival in relation to population declines. Our initial work on calf survival has determined a wide variation in the late winter survival of collared Moose calves from 2017/18 (75 ± 13%) relative to late winter 2016/17 (45 ± 22%).

Analyses on habitat selection patterns of radio-collared Moose for three years were completed in July 2018 at the University of Northern British Columbia (UNBC), and are currently underway at the University of Victoria and the John Prince Research Forest. 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 at UNBC. Final survival analysis is being completed at UNBC.

As of 1 May 2018, evaluating survival of cow and calf Moose is being led by FLNRORD staff and is planned to continue for another five years (April 2018–2023) to gain a more comprehensive understanding of the factors affecting Moose population change, and to inform important management decisions and research gaps.

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1. INTRODUCTION

Moose populations in some areas of interior British Columbia (BC) have declined by 50–70% since the early 2000s, while Moose populations in other areas of the province were stable or increasing (Kuzyk 2016; Kuzyk et al. in press). The Moose declines within central BC coincided with a mountain pine beetle (*Dendroctonus ponderosae*; MPB) outbreak and associated increased levels of mortality of pine trees>30years old, salvage logging of beetle-killed timber and road building (Alfaro et al. 2015). These landscape changes may have influenced the distribution and abundance of Moose, hunters and predators (Janz 2006; Ritchie 2008). In 2013, in response to these Moose declines, a 5-year (December 2013–March 2018) provincially-coordinated Moose research project was initiated by the BC Ministry of Forests, Lands, and Natural Resource Operations (now Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and its partners (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 collaborated with other Moose studies in BC (i.e., Sittler 2018) and other jurisdictions.

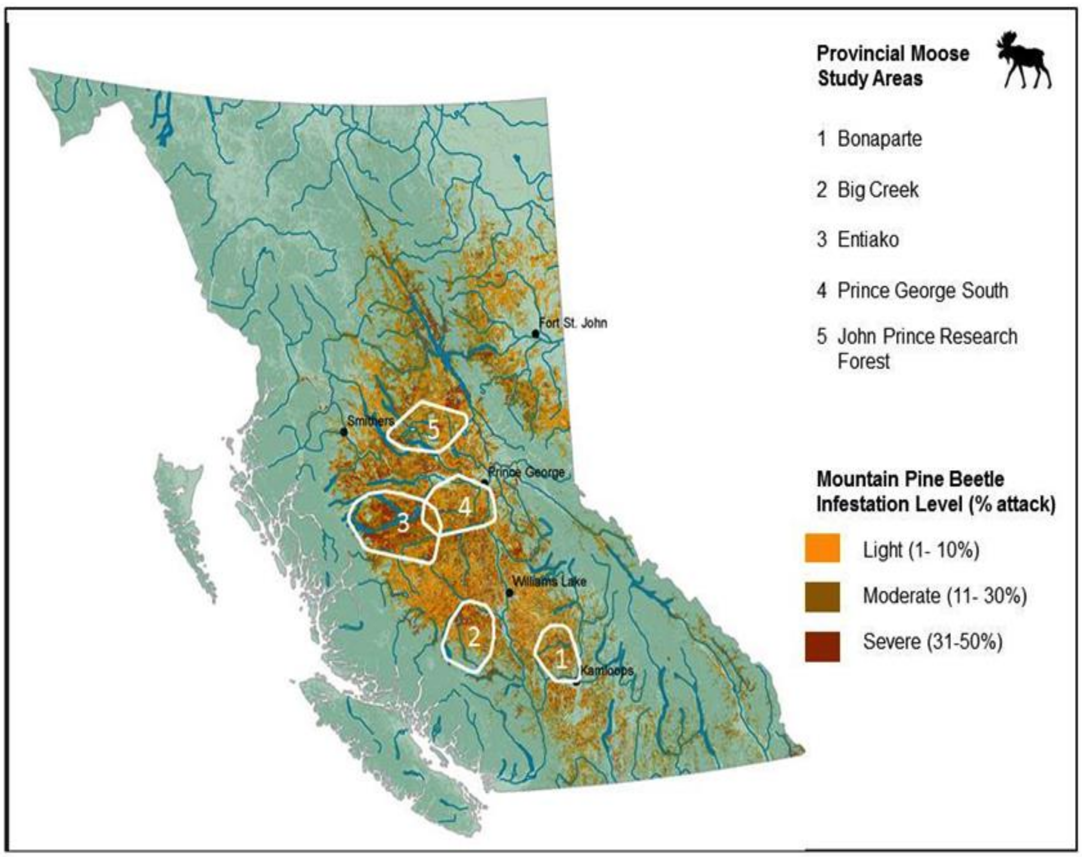

Figure 1. Moose research study areas in central British Columbia, where cow Moose survival has been monitored in the Bonaparte study area since February 2012 and in the other four study areas since December 2013, overlaid on Mountain Pine Beetle Infestation spatial data layer (2016). The areas were selected to encompass a range of land cover types and disturbance levels. Study area boundaries are described by minimum-convex polygons around locations of all collared cow Moose in each study area.

Table 1. Description of landscape features and large mammals in five 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[4]	Moose Density at Project Start ± 90% CI (winter year)[5]	Moose Density at Project End ± 90% CI (winter year)[5]	Potential Predators and Relative Abundance[6]	Wild Ungulates and Relative abundance[6]	Domestic/ Feral Ungulates and Relative Abundance[6]
Bonaparte 6800 km^2 Region 3 (Thompson), 3-29, 3-30B, Interior Plateau	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted Herbicide by Area Cut[2]: 0.03% Herbicide by THLB[3]: 0.02%	Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Pervasive Mining: Restricted	IDF: 33% SBPS: 23% MS: 22% ESSF: 8% SBS: 7% BG/PP: 7%	296 ± 18/ 1000 km^2 (2012/13)	254 ± 41/ 1000 km^2 (2017/18)	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 Herbicide by Area Cut[2]: 0.00% Herbicide by THLB[3]: 0.00%	Provincial Park: Restricted Agriculture: Restricted Crown Cattle Range: Large Mining: Negligible	SBPS: 48% IDF: 36% MS: 12% ESSF: 3% AT: <1% BG: <1%	170 ± 39/ 1000 km^2 (2011/12)	220 ± 38/ 1000km^2 (2016/17)	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

Study Area/ Region/ Management Unit/ Landform	Landscape Feature Prevalence[1]		BEC Zones[4]	Moose Density at Project Start ± 90% CI (winter year)[5]	Moose Density at Project End ± 90% CI (winter year)[5]	Potential Predators and Relative Abundance[6]	Wild Ungulates and Relative abundance[6]	Domestic/ Feral Ungulates and Relative Abundance[6]
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 Herbicide by Area Cut[2]: 0.71% Herbicide by THLB[3]: 0.24%	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)	Survey planned for Jan 2019	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 Herbicide by Area Cut[2]: 7.38% Herbicide by THLB[3]: 4.47%	Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Large Mining: Negligible	SBS: 93% ESSF: 7%	630 ± 102/ 1000 km^2 (2011/12)	400 ± 78/ 1000 km^2 (2016/17)	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 Herbicide by Area Cut[2]: 0.26% Herbicide by THLB[3]: 0.13%	Provincial Park: Restricted Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 95% ESSF: 5%	770 ± 93/ 1000 km^2 (2016/17)	490 ± 84/ 1000 km^2 (2016/17)	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%. Note that the amount of pine varies between study areas.
[2]Proportion of area harvested within each study area to which herbicide has been applied. Earliest date of herbicide application was in 1986.
[3]Proportion of timber harvest land base to which herbicide has been applied. Earliest date of herbicide application was in 1986.
[4]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).
[5]Reported Moose densities are from Stratified Random Block (SRB) surveys (RISC 2002) conducted in the study areas.
[6]Relative abundance/density: H = high, M = moderate, L = Low, N = nil or negligible.

Because the Moose population declines occurred concurrently with the MPB outbreak, a landscape change hypothesis was developed to evaluate Moose population change (Kuzyk and Heard 2014).

The landscape change hypothesis states that Moose declines coincided with a mountain pine beetle (MPB) outbreak where habitat changes and increased salvage logging and road building resulted in greater vulnerability to Moose from hunters, predators, nutritional constraints, age/health and environmental conditions. We assumed cow Moose survival would have a greater proportional effect on population growth than calf survival (Gaillard et al. 1998) because the declines occurred over a relatively short time period. To evaluate the landscape change hypothesis we determined both cow survival rates and probable causes of mortality. The primary assumptions of the landscape change hypothesis are 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). We acknowledged calf survival could be a substantial contributing factor to Moose population change either in conjunction with declining cow survival or on its own (Kuzyk and Heard 2014). Due to financial and logistical constraints we were initially limited to directly monitoring survival of radio-collared cow Moose across all study areas.

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., December 2013 to March 2018). We planned to determine mortality rates, causes and contributing factors in comparison to the predictions of the landscape change hypothesis with respect to horizontal screening cover roads, and spatial distribution of moose.

To help fill the knowledge gap of the influence of calf survival (Kuzyk and Heard 2014; Kuzyk et al. 2017) we radio-collared twenty 8-month old calves in one study area (Bonaparte) in the winter of 2016/17 and forty 8-month old calves in two study areas (Bonaparte and Prince George South) in 2017/18. The objective is to measure their survival, and causes of mortality, until they are recruited into the population at 1 year of age, which is when survival rates of calves appear to align with adult survival rates (Hickey 1955 cited by Bergerud and Elliott 1986). Building on the previous calf collaring initiatives, we plan to continue radio-collaring and monitoring 8-month old calf survival in the Bonaparte and Prince George South study areas. We are also planning to continue assessing survival rates of calves through late winter calf surveys of radio-collared cows in all study areas for the duration of this project.

This report provides a description of the fieldwork and some preliminary results from February 2012–30 April 2018. We continue to engage with a diversity of First Nations and stakeholders about the current status and future direction of this project. A study at UNBC recently completed a complementary analysis of habitat selection of radio-collared cow Moose (see Scheideman 2018). We are continuing this research project for another 5 years (2018–2023) and will be incorporating new components to help understand moose population change to enable sound management recommendations.

2. STUDY AREA

This study area description is similar to that provided in Kuzyk et al. (2017). In general, there was little annual variation in biotic or abiotic features within study areas. In 2017, wildfires burned a small portion of the Bonaparte study area and 15% of the Big Creek study area overlapped the Hanceville-Riske Creek fire perimeter boundary. In addition, fire burned ~1331 km^2 of the Entiako study area in 2014 (7%), when the Chelaslie Fire burned ~1331 km^2. 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 – >18000 km^2 (Table 1). Logging was the primary resource land use (Figure 2) with an increase in salvage logging after the large-scale MPB outbreak occurring during the early 2000s (Alfaro et al. 2015). The proportion of cutblock area sprayed with herbicide to promote regrowth of harvestable tree species in each study area ranged from 0% (Big Creek) to 7% (Prince George South) with the majority of herbicide application occurring after the year 2000. 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; 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 except Mule Deer are probably the most abundant ungulate in the Bonaparte. At the initiation of the study, Moose densities ranged from 170–770 Moose/1000 km^2 among study

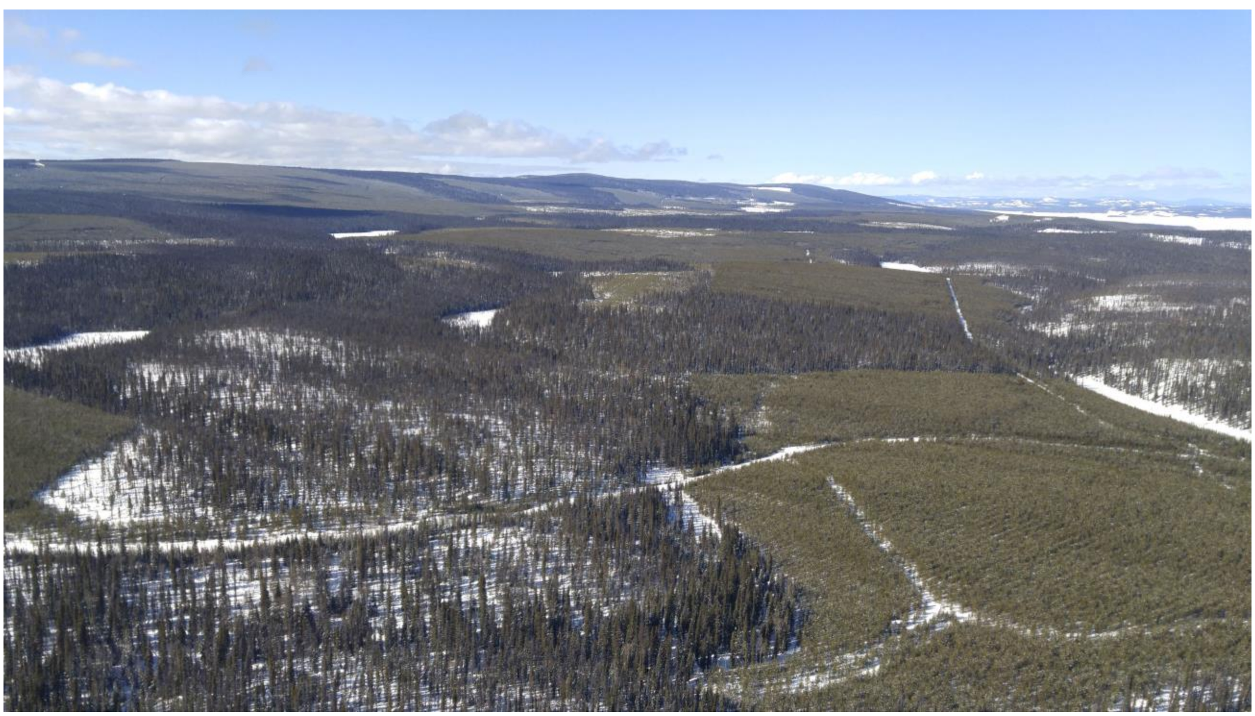

Figure 2. Aerial view of the Entiako study area, March 2018 (Photo: Heidi Schindler).

areas. Big Creek density estimate in 2011/12 was 170 Moose/1000km^2; this was incorrectly reported in Kuzyk and Heard (2014), Kuzyk et al. 2016 and 2017.

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.

3. METHODS

Details of the field methods were originally presented in Kuzyk and Heard (2014) and certain methodologies have been updated and presented in Kuzyk et al. (2015, 2016, 2017). Methods are generally the same as those presented in Kuzyk et al. (2017) as they have become standardized over the course of the project. Captures were conducted in accordance with the British Columbia *Wildlife Act* under permit CB17-277227. Winter of 2016/17 was the first season to include calves in the study, and twenty 8-month old calf Moose were radio-collared. 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 2–4 cc darts. Upon completion of handling, naltrexone hydrochloride (at 50 mg/mL) for carfentanil, or naltrexone hydrochloride with atipamezole hydrochloride (at 25 mg/mL) for BAM II immobilizations were used to reverse at doses corresponding to immobilizing dose.

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 20–35 mL of blood using an 18 gauge x 1.5-inch needle for pregnancy and serological testing. Testing focused on exposure to pathogens considered of high priority for impacts on survival and reproduction of wild ungulate populations, utilizing the experience of other research programs, including the BC Boreal Caribou Health Program. Serum was screened for antibodies for Johne's disease, *Neospora*, Bovine Viral Diarrhea virus, and Parainfluenza 3 virus. Serum from a subset of cow Moose was submitted for testing for exposure to *Erysipelothrix rhusipathiae* and *Toxoplasma.* Serum from a subset of cow Moose captured in 2014/15 and from all cow Moose captured in 2015/16 and 2016/17 was analyzed for both progesterone and pregnancy specific protein B levels (PSPB). These dual pregnancy status indicators were used to further investigate the interpretation of pregnancy status. In 2017/18, pregnancy status was assessed via PSPB only. Blood samples were also assessed for trace mineral levels (manganese, iron, cobalt, copper, zinc, selenium, and molybdenum).

We 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). The 6-mm punch biopsy of the ear from the application of an ear tag was air-dried and archived for genetics. We collected at least 100 hairs with roots from between the shoulders for cortisol testing. Some calves were weighed, to the nearest kilogram, in a body blanket lifted by a helicopter where the capture location was conducive to do so. Key morphological measurements (i.e., chest girth, total length, hind-foot length) were taken on Moose calves to assist in estimating weight when obtaining direct weights was not possible. A project-specific relationship between morphometrics and weight will be developed when sufficient sample size exists, and will be used to estimate calf weights where field weights were not possible.

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 3 through 9 for images illustrating captured Moose handling and sampling methods). We chose to use radio collars with one or two 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 that collected six fixes per day (Vectronic Aerospace VERTEX Survey Iridium radio collars, Berlin). Calf collars expanded from an initial size of 50 cm–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. Cotton spacers designed to rot-off within one year were put on collars deployed on bull calves because they could rapidly exceed the maximum expansion capable with these collars.

Figure 3. An example of a set of biological samples collected from a captured and radio-collared Moose. Samples include pellets, blood, hair and a tissue biopsy, February 2018 (Photo: Morgan Anderson).

Figure 4. Wildlife Biologist Matt Scheideman counting ticks on a captured cow Moose in the Prince George South study area, February 2018 (Photo: Morgan Anderson).

Figure 5. Wildlife Biologists Gerry Kuzyk and Chris Procter measuring hind foot length of a captured calf Moose in the Bonaparte study area, January 2017 (Photo: Kelly Croswell).

Figure 6. Wildlife Biologists Krystal Dixon and Jennifer Atkins fitting a GPS radio collar to a captured cow Moose in the Entiako study area, March 2018 (Photo: Heidi Schindler).

Figure 7. Wildlife Biologist Shane White preparing reversal drugs following collar fitting and sampling of a cow Moose that was immobilized using BAM II in the Big Creek study area, February 2018 (Photo: Chris Procter).

Figure 8. Wildlife Biologist Morgan Anderson and Wildlife Veterinarian Bryan Macbeth weigh a captured calf Moose in the Prince George South study area, February 2018 (Photo: Matt Scheideman).

The radio collars were programmed to send a mortality alert via email and text message if no movement was detected for 4–24 hours via the internal tip switch. 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. We determined the probable proximate (i.e., direct) cause of mortality following a standardized protocol (Kuzyk and Heard 2014), and we continually refined the definitions for probable proximate cause of mortality as new circumstances arose (Appendix C). Ultimate (i.e., indirect) causes of mortality that were not evident during mortality investigation will be determined later through testing of biological samples. The mortality investigation data sheet is currently undergoing reviews with the previous updated in December 2017 (Appendix D).

Figure 9. Wildlife Biologists Matt Scheideman, Morgan Anderson and Andrew Walker processing a captured cow Moose in the Prince George South study area, March 2017 (Photo: Rob Altoft).

Calf parturition rates and dates were calculated by summing daily cow movement rates through the parturition period (DeMars et al. 2013; McGraw et al. 2014; Severud et al. 2015; Obermoller 2017). Calving movements are generally classified by a long-distance movement followed by a reduction in movements due to low mobility of calves directly after birth. We used the first day that a reduction in movement rates was observed as the estimated birth date (Severud et al. 2015). Data from estimated calf parturition dates in Bonaparte and PG South were averaged annually from 2014–2018 to determine the mean birth date. Mean birth-date was 23 May ± 9 days (SD) and we used that date to calculate calf survival rates to their average first birthday. Given variability in movement patterns and associated uncertainty in determining if parturition occurred, we removed animals from the analysis when there was uncertainty whether calving-occurred. We used parturition rates to establish minimum calf:cow ratios (number of calves/100 cows) at birth and to compare with pregnancy rates estimated by blood serum analyses on captured cows in the Bonaparte study area.

Annual survival rates were calculated for cow Moose from 28 February 2012–30 April 2018. We calculated survival rates by pooling survival of individual Moose across all study areas and for each study area. Survival analysis and mortality summaries included only cow Moose that lived >3 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). The biological year started on 1 May 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 be representative of the population behaviour and have 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 calf).

Calf survival rates were calculated from date of capture (at about 8 months) to 23 May of the same year, the average date of their first birthday. We considered calves recruited to the population at their first birthday, following Bender (2006), as that is beyond the late winter/early spring mortality period typical of some ungulate populations and likely when survival rates begin to align with adult survival rates (Hickey 1955 cited by Bergerud and Elliott 1986). To calculate true recruitment rates, we first completed aerial composition surveys to estimate calf ratios that would be comparable to typical survey-based mid-winter calf ratios generally used by biologists as a recruitment index to inform Moose population management. We then corrected those calf ratios with survival rates estimated to their average first birthday from collared calves. We assume that cow deaths are too few to substantially increase the cow/calf ratios between mid-winter and recruitment when calves are one year of age. To understand the effect of true recruitment on Moose population trend, we calculated the rates of population change using cow survival rates, the mid-winter recruitment index and true recruitment at age 1 assuming half the calves were female and using the equation developed by Hatter and Bergerud (1991; lambda=S/(1-R) where S=survival as fraction and R is the proportion of female calves in the female population, i.e., cows + female calves. For surviving calves, we also calculated yearling survival rates from their first to second birthdays (i.e., 23 May of their first year to 23 May of their second year). We estimated summer calf survival by estimating calf ratios at birth from collared cows and comparing those ratios to mid-winter calf ratios measured from aerial composition surveys.

Samples were collected during mortality site investigations to understand the proximate and ultimate cause of death (Appendix D). Samples available for collection varied depending usually by proximate cause of death (e.g., wolf kills typically have bones but no soft tissues remaining while health related mortalities may have all samples available). 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). 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 lead to mortality from starvation (Sand et al. 2012). 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^{o}C, and weighed daily until the weight stabilized, indicating all moisture had been evaporated. The final dry weight divided by the initial wet weight was the index of body condition. 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) for 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. 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 2018, we captured and radio-collared 400 cow Moose of which 14 were recaptured to replace collars with dead batteries or close to anticipated battery end life (Tables 2 and 3). There were 281 cows 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 in January and February 2017. In January and February 2018, 20 calf Moose (6 female, 14 male) were collared in Bonaparte and 20 calf Moose (11 female, 9 male) in Prince George South study areas.

In the five study areas, of the 414 GPS radio collars deployed on cows, there were 158 collars that collected more than two position fixes/day (range 4-16 fixes/day), 109 cow collars that collected two fixes/day and 147 cow collars that collected one fix/day (Table 4). We censored collars (n = 110) when they released due to low battery voltage, collar malfunctions, or when they physically slipped from Moose. All calf collars deployed were programmed to collect six fixes per day.

Table 2. Number and status of all GPS radio collars (n = 414) deployed on Moose (n = 400 i.e., 14 recollars) in all study areas in central BC from February 2012– 30 April 2018

Study Year	Deployed Collars*	Individuals Collared**	Mortalities	Censored Collars	Active Collars***
2012	9	9	0	0	9
2012/13	29	29	2	0	36
2013/14	129	129	5	28	132
2014/15	69	69	11	15	175
2015/16	100	100	32	24	219
2016/17	52	49	22	35	211
2017/18	26	15	25	9	192
Totals	**414**	**400**	**97**	**111**	**192**

*Includes recaptures where the original collar was replaced by a new collar
**number of individual cows collared
***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 all GPS radio collars (n = 414) deployed on Moose (n = 400 i.e., 14 recollars) in each study area in central BC from February 2012–30 April 2018.

Study Area	Study Year	Deployed Collars*	Individuals Collared**	Mortalities	Censored Collars	Active Collars***
Bonaparte	2012	9	9	0	0	9
	2012/13	29	29	2	0	36
	2013/14	14	14	3	28	19
	2014/15	30	30	2	7	40
	2015/16	36	36	7	6	63
	2016/17	20	17	5	29	46
	2017/18	7	7	1	3	49
	Totals	**145**	**142**	**20**	**73**	**49**
Big Creek	2013/14	40	40	0	0	40
	2014/15	13	13	3	8	42
	2015/16	5	5	6	2	39
	2016/17	6	6	4	0	41
	2017/18	3	1	4	1	37
	Totals	**67**	**65**	**17**	**11**	**37**
Entiako	2013/14	44	44	0	0	44
	2014/15	9	9	4	0	49
	2015/16	17	17	10	16	40
	2016/17	4	4	9	1	34
	2017/18	10	2	6	3	27
	Totals	**84**	**76**	**29**	**20**	**27**

Study Area	Study Year	Deployed Collars*	Individuals Collared**	Mortalities	Censored Collars	Active Collars***
Prince George South	2013/14	16	16	0	0	16
	2014/15	17	17	2	0	31
	2015/16	16	16	6	0	41
	2016/17	15	15	2	5	49
	2017/18	6	5	12	1	41
	Totals	**70**	**69**	**22**	**6**	**41**
John Prince Research Forest	2013/14	15	15	2	0	13
	2014/15	0	0	0	0	13
	2015/16	26	26	3	0	36
	2016/17	7	7	2	0	41
	2017/18	0	0	2	1	38
	Totals	**48**	**48**	**9**	**1**	**38**

*Includes recaptures where the original collar was replaced by a new collar
**Total number of independent cows collared
***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 4. Programmed fix schedule for GPS radio collars (n = 414) deployed on cow Moose (n = 400 i.e., 14 recollars) in each study area in central BC from February 2012–30 April 2018.

Study Area	>2 Fixes/Day	2 Fixes/Day	1 Fix/Day
Bonaparte	107	38	0
Big Creek	3	11	53
Entiako	25	21	38
Prince George South	21	16	33
John Prince Research Forest	0	25	23
Totals	**156**	**111**	**147**

4.2 Capture and Handling

Of the 400 cow Moose captured to date, 396 were assessed for age via tooth eruption, staining and wear patterns (Figure 10), with 84% (*n* = 334) classified as adults (4.5–7.5 years old), 12% (*n* = 48) as aged (>8.5), and 4% (*n* = 14) as young (1.5– 3.5 years old). Body condition for the 358 animals assessed showed that 68% (*n* = 243) were in good body condition, 18% (*n* = 64) were in excellent body condition, 10% (*n* = 35) were in fair body condition, 4% (*n* = 13) were in poor body condition, and 1% (*n* = 3) was emaciated (Figure 11). Body condition assessments found poorer body condition overall in 2016/17 and also in Prince George South (Figs 12 and 13). Body condition of calves was assessed for 56 individuals and 80% (*n* = 45) were in good condition, 18% (*n* = 10) were in fair condition and 2% (*n* = 1) were in poor condition. The average weight of calves in the Bonaparte was 183 kg (± 19 kg, SD; *n* = 22); 182 (±22 kg, *n* = 8) in 2017 and 183 (±16 kg, *n* = 11) in 2018. Of the 355 cow Moose where we recorded calf status at capture, 63% (*n* = 223) were unaccompanied by a calf, 37% (*n* = 131) had one calf and <1% (*n* = 1) had twins (Figure 14). This excludes the calf status of the cows selectively collared to facilitate the calf-collaring program in Bonaparte and Prince George South.

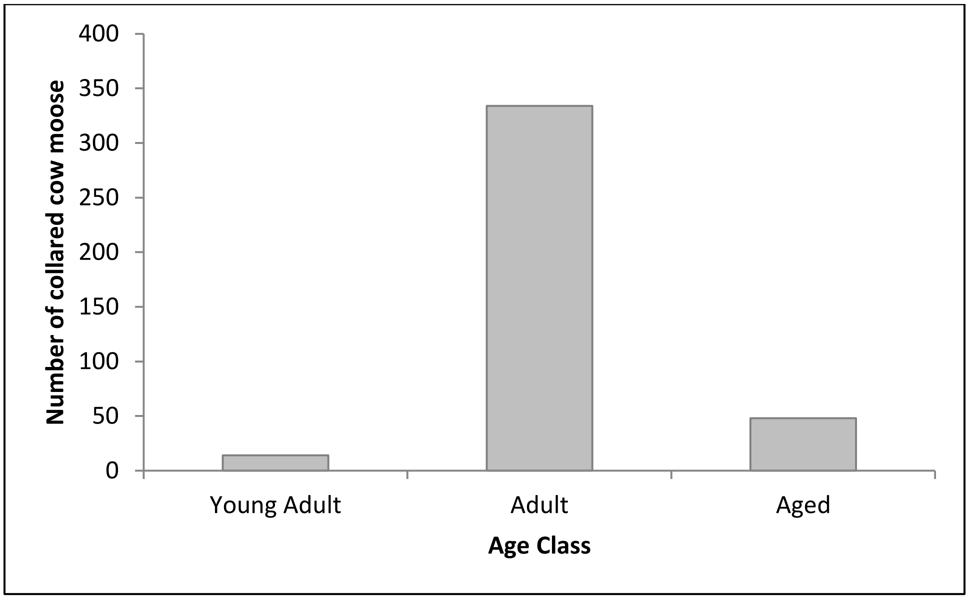

Figure 10. Age class summary of 396 cow Moose radio-collared in central BC from February 2012–30 April 2018 with ages estimated by tooth wear patterns. Young Adult Moose were estimated to be 1.5–3.5 years old, Adults as 4.5–7.5 years old, and Aged as >8.5 years old.

Figure 11. Body condition scores of 358 cow Moose radio-collared in central BC from February 2012–30 April 2018. Condition scores were assessed using external physical traits modified from Franzmann (1977).

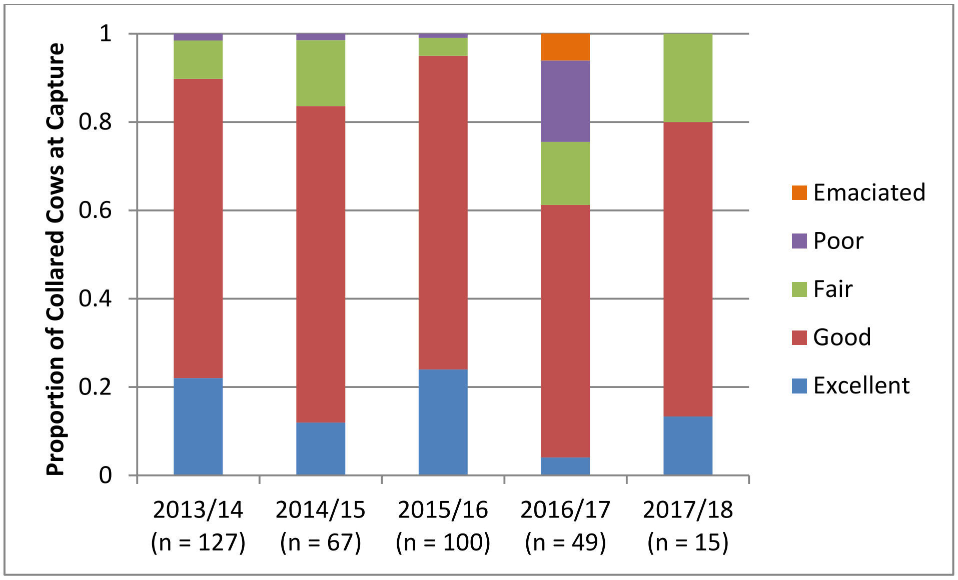

Figure 12. Annual body condition scores of 358 cow Moose radio-collared in central BC from February 2012-30 April 2018. Condition scores were assessed using external physical traits modified from Franzmann (1977).

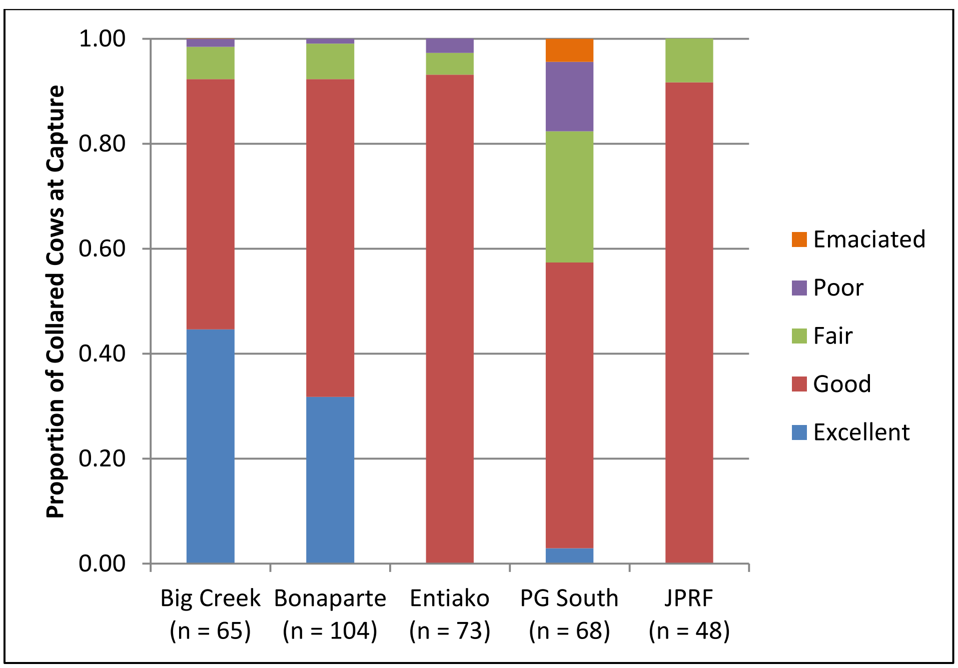

Figure 13. Study area specific body condition at time of capture scores of 358 cow Moose radio-collared in central BC from February 2012-30 April 2018. Condition scores were assessed using external physical traits modified from Franzmann (1977).

4.3 Biological Samples

There is uncertainty in diagnosing pregnancy in cow Moose via serum progesterone when progesterone levels are low. Therefore, we compared pregnancy status from progesterone and PSPB assessments and determined that PSPB was the best indicator of Moose pregnancy rates and will be our ongoing standard method used to assess pregnancy. All pregnancy results reported in Table 5 are from PSPB analyses. Estimated pregnancy rates ranged from 47–100% (Table 5). Differences between parturition (determined by analysing cow movement rates) and pregnancy rates estimated in the Bonaparte study area varied from 4–29% with the largest difference occurring when PSPB sample size was lowest (i.e., 2017/18, n = 6). No obvious trend existed. Given some probability of abortion, we expected estimated parturition rates to be lower than pregnancy rates, however, parturition rates exceeded pregnancy rates for the three of the six years. Overall, average parturition rates across the six year period was similar to the average pregnancy rate and the difference was not substantial.

Initial serological screening of cow Moose indicated minimal exposure to a suite of pathogens selected for assessment at the early stages of the project. Additional assessments have been added and serum samples are now divided for archiving to use for future health analyses as warranted. Trace nutrient requirements and metabolism are not well characterized for Moose; however, some nutrient levels appear to be sub-optimal in some Moose, with variation observed between study areas.

Health-related factors were identified as the probable cause of death in a number of Moose mortalities (Macbeth 2017). Preliminary evaluation of health data from capture and mortality samples suggested that the occurrence and potential impact of selected health determinants, including viral and bacterial pathogens, ectoparasites, endoparasites, and non-infectious measures (e.g., body condition, pregnancy rates, long-term stress and trace nutrient levels) may vary between study areas. Although most health determinants evaluated to date are within ranges reported in Moose populations elsewhere, there is evidence that

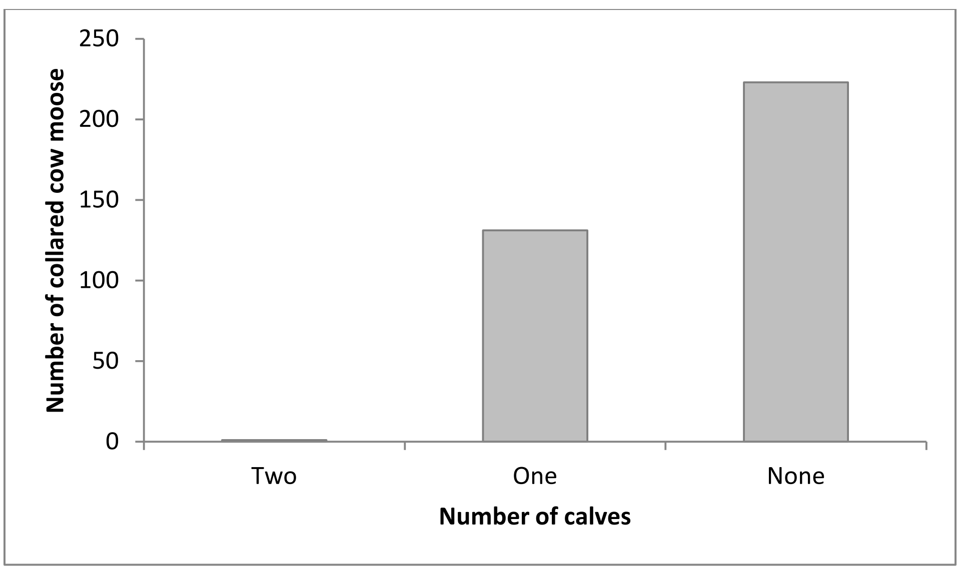

Figure 14. Calf status of 355 radio-collared cow Moose at time of capture in central BC from February 2012–30 April 2018.

Table 5. Pregnancy and parturition rates of radio-collared cow Moose in central BC from February 2012–30 April 2018.

Study Area	Analysis Type	Pregnancy/Parturition Rate (± 95% CI)						
		2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Mean
Bonaparte	Blood serum (PSPB)	72 ± 19% (*n* = 25)	85 ± 23% (*n* = 13)	71 ± 20% (*n* = 24)	47 ± 17% (*n* = 36)	68 ± 21% (*n* = 22)	50 ± 57% (*n* = 6)	64 ± 9% (*n* = 126)
Bonaparte	Movement rates	64 ± 16% (n = 34)	81 ± 20% (*n* = 16)	63 ± 16% (*n* = 38)	59 ± 13% (*n* = 59)	76 ± 12% (*n* = 46)	79 ± 12% (*n* = 47)	69 ± 6% (*n* = 240)
Big Creek	Blood serum (PSPB)	n/a	90 ± 10% (*n* = 38)	75 ± 39% (*n* = 8)	100 ± 0% (*n* = 5)	100 ± 0% (*n* = 4)	66 ± 143% (*n* = 3)	88 ± 9% (*n* = 58)
Entiako	Blood serum (PSPB)	n/a	86 ± 11% (*n* = 43)	63 ± 43% (*n* = 8)	83 ± 19% (*n* = 18)	100 ± 0% (*n* = 4)	90 ± 23% (*n* = 10)	84 ± 8% (*n* = 83)
Prince George South	Blood serum (PSPB)	n/a	86 ± 21% (*n* = 14)	64 ± 29% (*n* = 14)	75 ± 24% (*n* = 16)	87 ± 19% (*n* = 15)	50 ± 57% (*n* = 6)	75 ± 11% (*n* = 65)
John Prince Research Forest	Blood serum (PSPB)	n/a	100 ± 0% (*n* = 15)	n/a	89 ± 13% (*n* = 26)	100 ± 0% (*n* = 7)	n/a	94 ± 7% (*n* = 48)

Table 6. Survival rates of radio-collared cow Moose in central BC from February 2012–30 April 2018.

Year	Survival Estimate (± 95% CI)	Maximum Number of Active Collared Cow Moose
2012	100 %	9
2012/13	95 ± 7%	38
2013/14	92 ± 8%	165
2014/15	92 ± 5%	201
2015/16	85 ± 5%	275
2016/17	89 ± 7%	271
2017/18	89 ± 4%	228

some determinants (e.g., gastrointestinal parasitism) may be sporadically killing some age classes of Moose in some study areas. No single factor, however, can be identified as the cause of apparent differences in the overall health status and/or performance of populations in these study areas at the present time. Likewise, the scope of this current Moose health monitoring cannot adequately evaluate the potential sub-lethal or cumulative effects of various health determinants on the fitness of individual Moose or the performance of Moose populations in these study areas. Macbeth (2017) contains a detailed assessment of Moose health results from this project, providing the first comprehensive baseline herd health assessment of Moose populations in British Columbia.

4.4 Annual Survival Rates

From 2012–2018, the annual survival rate from all radio-collared cow Moose pooled across all study areas varied from 85–100% (Table 6). Figure 15 shows survival rates by study area from 2012–2018. Cow survival rates varied across study areas and were lowest in the Entiako and Prince George South study areas. Survival rates in some years in Prince George South and consistently in Entiako in recent years are below the 85% threshold typically used to assess for population stability. All survival rates in other study areas are consistently above 85%, though confidence intervals sometimes reach below 85%. Survival of calves from age 8 months to 12 months (age 1) varied from 45 to 85% and survival of yearlings (age 1 to age 2) was 78% (Table 7). The sample size for cows in 2012 (n = 9), calves in 2017 (n = 20) and yearlings (n = 9) in 2017/18 was small and requires that caution be used when interpreting those survival estimates.

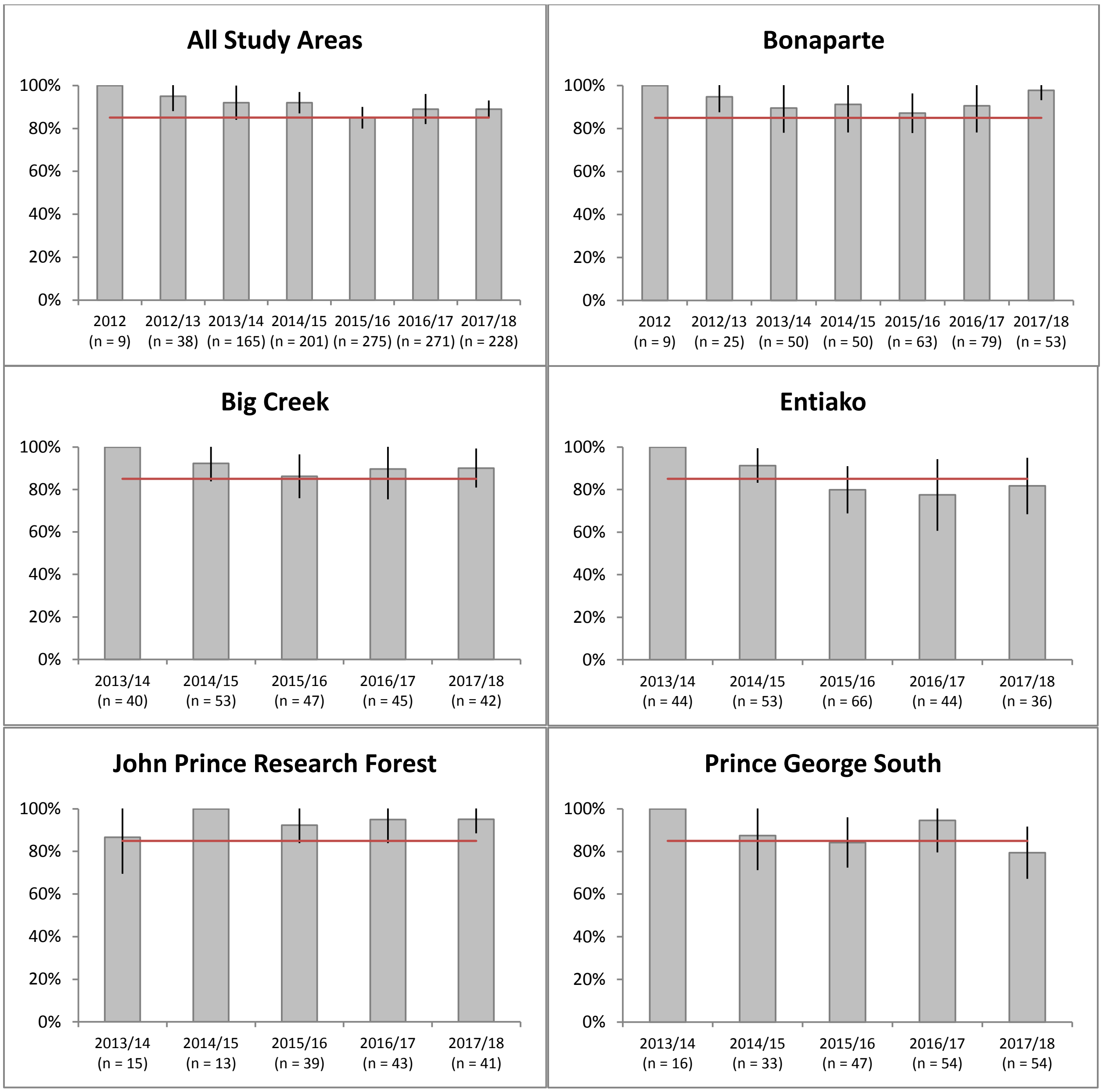

Figure 15. Survival rates of radio-collared cow Moose for all study areas combined and separated by study area, May 1 2012 – April 30, 2018. Red line indicated survival rate of 85%, which is generally indicative of a stable population.

Table 7. Survival rates of radio-collared calf Moose and those that survived to be yearlings in central BC from January 2017–23 May 2018.

Year	Study Area	Age Class	Survival Estimate (± 95% CI)	Maximum Number of Active Collared Moose
2016/17	Bonaparte	8-12 months	45 ± 22%	20
2017/18	Bonaparte and PG South	8-12 months	78 ± 13%	40
2017/18	Bonaparte	8-12 months	85 ± 16%	20
2017/18	PG South	8-12 months	70 ± 20%	20
2017/18	Bonaparte	age 1- age 2 (yearling)	78 ± 27%	9

Table 8. Calf production, summer calf survival and true calf recruitment in the Bonaparte and Prince George South study areas from May 2016 – June 2018. Estimates of error are 95% confidence intervals. Sample size (n) is the number of cows the estimate is derived from.

Year	Study Area	Minimum No. Calves/100 Cows at Birth[1]	No. Calves/100 Cows Mid-June[2]	No. Calves/100 Cows Mid-winter [3]	Maximum Calf Pre-Winter Survival (%)[4]	No. Calves/100 Cows Mar.31[2]	True Recruitment Rate (No. Calves/100 Cows at age 1)[5]
2016/17	Bonaparte	59 (46 – 72) (*n* = 59)	n/a	13 (7 – 19) (*n* = 184)	22% (15 – 26)	16 (*n* = 32)	6 (3 - 9)
2017/18	Bonaparte	76 (64 – 88) (*n* = 46)	64 (*n* = 47)	32 (23 – 41) (*n* = 194)	42% (36 – 47)	38 (*n* = 40)	27 (20 – 35)
2017/18	PGS	79 (71 – 87) (*n* = 24)	n/a	34 (29 – 39) (*n* = 280)	43% (39 - 46)	26 (*n* = 35)	24 (20 – 27)

[1] Estimated from movement analyses for collared cows and assumes all cows had only 1 calf (i.e., no twinning)
[2] Estimated from aerial searches of collared cows and their calves
[3] Estimated from aerial composition surveys in respective study areas
[4] Estimated by comparing survey-based calf ratio mid-winter to estimated calf ratio at birth; maximum calf survival estimate as twinning rate at birth not known
[5] True recruitment = mid-winter calf ratio x calf survival from mid-winter to age 1 (estimated from collared calves — see Table 7)

4.5 Calf Production, Summer Calf Survival and True Recruitment

In the Bonaparte study area, we observed significant variation across years in calf production, summer calf survival and true recruitment at age 1 (Table 8). Due to mortality of calves in the late winter period, actual recruitment was lower than recruitment indices measured in mid-winter from aerial surveys. Although based on only two years of data thus far, the data suggest that when calf production is higher, calves also survive better, both during summer and winter, and true recruitment is higher. More data are required to assess whether or not that trend persists.

Calf production, survival and recruitment parameters were similar between Bonaparte and Prince George South study areas in 2017/18. We will continue to monitor annual variation between study areas as calf monitoring continues over the years.

Differences between mid-winter recruitment indices and what we defined as true recruitment, i.e., the number of calves that survived to age 1, reduced estimates of population rate of change by approximately 4% (range 3%-5%; n=3; Table 9). Higher population growth rate in Bonaparte in 2017/18 resulted from higher cow and calf survival that year, while a negative population trend in Prince George South resulted from a relatively low 2017/18 cow survival (Figure 15).

Table 9. Comparison of Moose population rate of change (lambda) estimated using recruitment indices during mid-winter surveys and survival rates from collared cows and calves to recruitment at age 1. Lambda was calculated as S/(1-R) where S is cow survival and R is female calf:cow ratio (Hatter and Bergerud 1991).

Year	Study Area	Lambda – Survey-based Mid-winter (95% CI)	Lambda – True Recruitment Age 1 (95% CI)
2016/17	Bonaparte	0.98 (0.82 – 1.07)	0.93 (0.78 – 1.01)
2017/18	Bonaparte	1.14 (1.06 – 1.19)	1.11 (1.03 – 1.16)
2017/18	Prince George South	0.92 (0.79 – 1.04)	0.88 (0.75-1.01)

Table 10. Number of mortalities and probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2018.

Study Area	Mortalities	Probable Proximate Cause of Death
Bonaparte	20	4 predation (3 Wolf, 1 Cougar), 7 hunting (1 licensed, 6 unlicensed), 9 health-related (3 apparent starvation, 1 failed predation attempt, 1 chronic bacterial infection, 4 unknown health-related)
Big Creek	17	8 predation (7 Wolf, 1 Cougar), 5 hunting (unlicensed), 3 health-related (1 apparent starvation, 1 failed predation attempt, 1 peritonitis*), 1 natural accident
Entiako	29	20 predation (17 Wolf, 3 bear), 2 health-related (1 prolapsed uterus, 1 unknown health-related), 2 natural accident, 5 unknown
Prince George South	22	15 predation (10 Wolf, 2 Cougar, 3 bear), 2 hunting (unlicensed), 5 health-related (apparent starvation)
John Prince Research Forest	9	5 predation (Wolf), 2 hunting (unlicensed), 2 unknown
Totals	**97**	**52 predation (42 Wolf, 4 Cougar, 6 bear), 16 hunting (1 licensed, 15 unlicensed), 19 health-related (9 apparent starvation, 2 failed predation attempt, 1 chronic bacterial infection, 1 peritonitis, 1 prolapsed uterus, 5 unknown health-related), 3 natural accident, 7 unknown**

***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.

4.5 Mortality Causes

Ninety-seven of the 400 radio-collared cow Moose died between February 2012 and 30 April 2018 (Table 10; Figures 16 and 17). Probable proximate causes of death (see Appendix C) were 53% from predation, 19% from health-related causes, 16% from hunting, 3% natural accident, and 7% unknown (Figure 16; see Figures 19–23 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 or the collar being positioned underneath the dead Moose thus limiting its transmission success. Cow mortalities peaked in spring with 49% of mortalities occurring between March and May (Figure 18, n = 97).

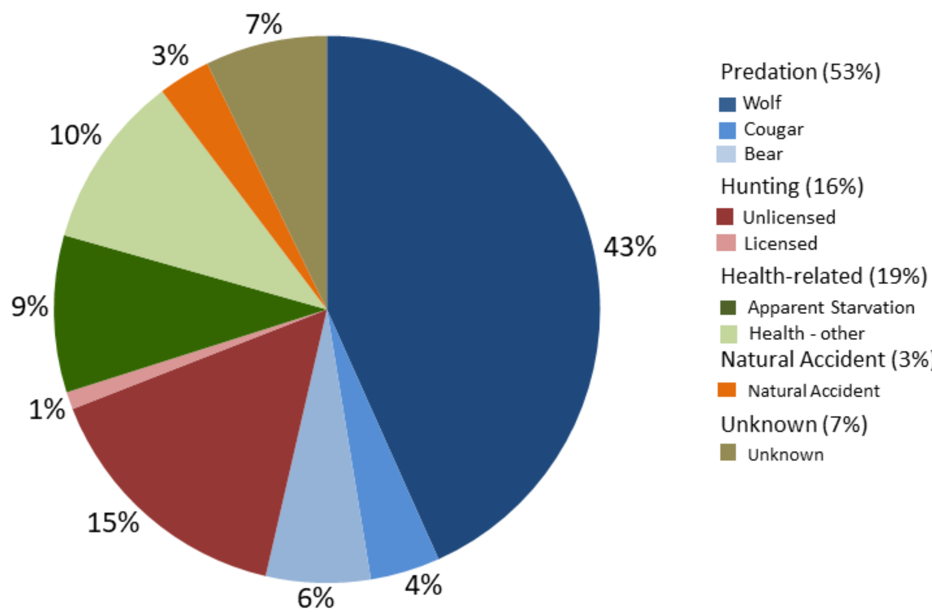

Figure 16. Probable proximate cause of death of radio-collared cow Moose (*n* = 97) in central BC from February 2012–30 April 2018. Cause of death proportions are not shown summing to 100% because of rounding.

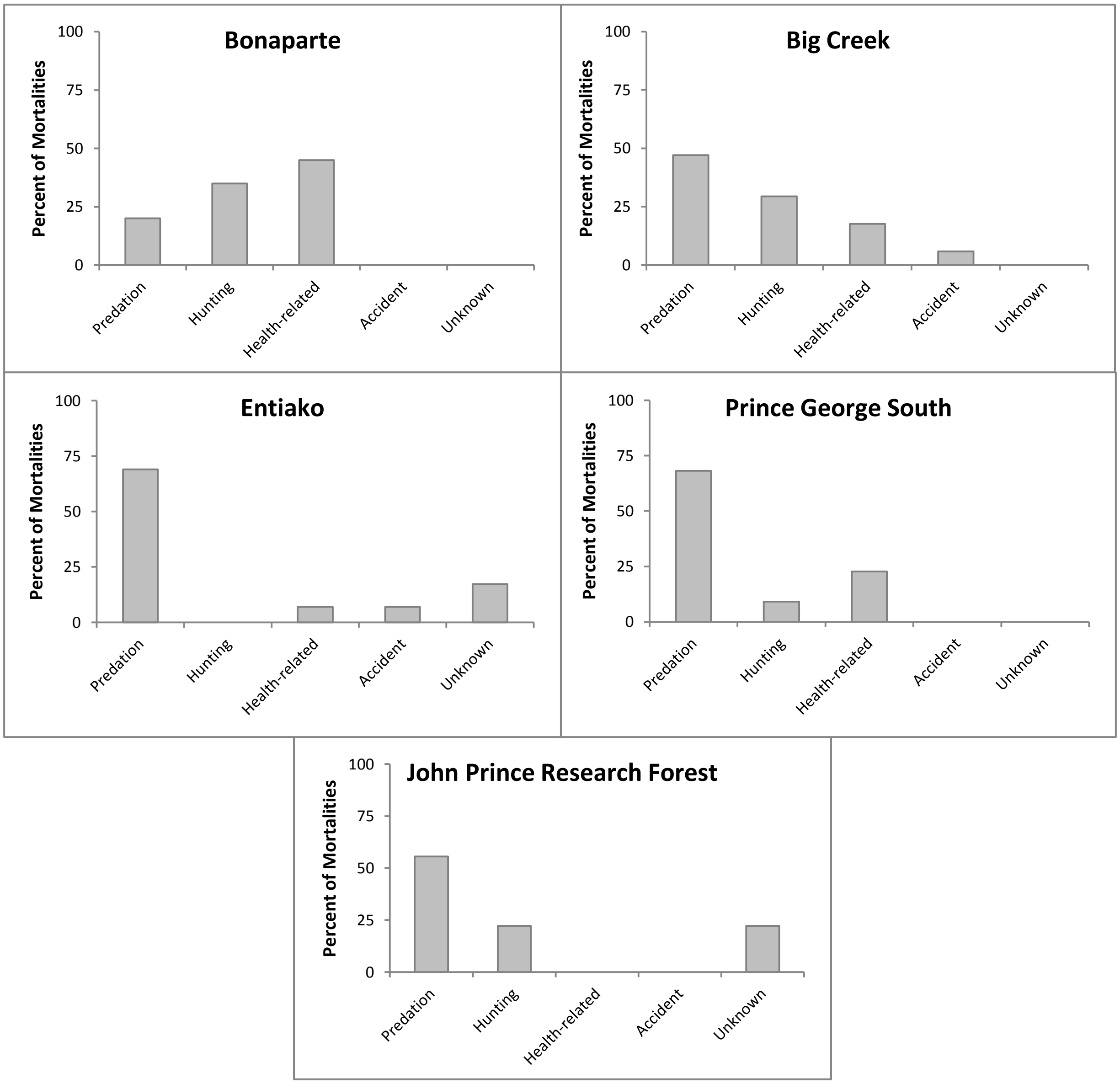

Figure 17. Probable proximate cause of death of radio-collared cow Moose (*n* = 97) by study area in central BC from February 2012–30 April 2018.

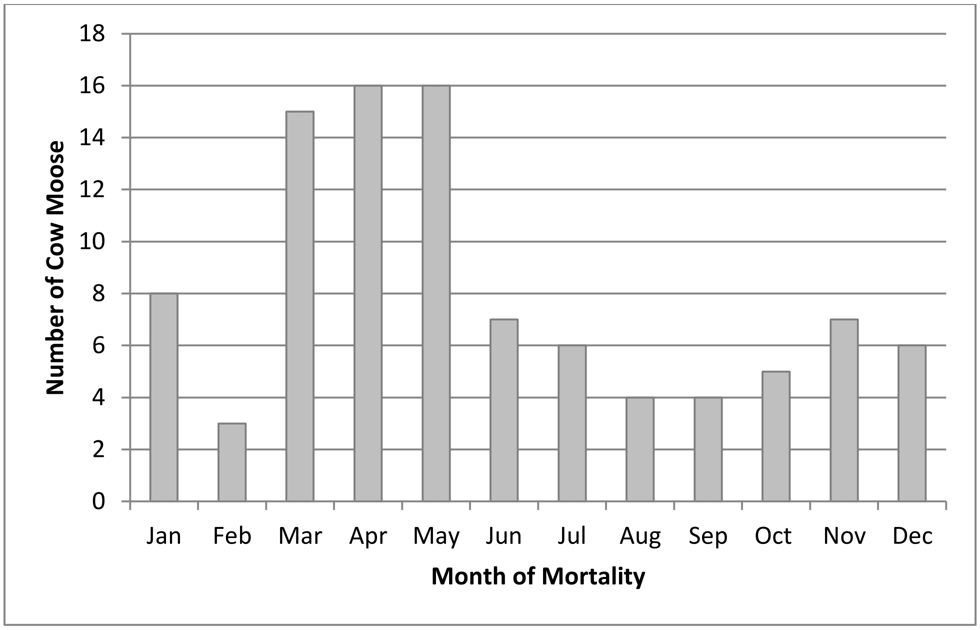

Figure 18. Month of death for radio-collared cow Moose (*n* = 97) in central BC from February 2012–30 April 2018.

Figure 19. A mortality site investigation of a collared cow and calf Moose pair within the Prince George South study area. The proximate cause of death was wolf predation, April 2018 (Photo: Morgan Anderson).

Figure 20. A mortality site investigation of a collared cow Moose within the Entiako study area. The proximate cause of death was dystocia following a uterine prolapse, May 2017 (Photo: Heidi Schindler).

Figure 21. Aerial telemetry tracking to locate a Moose mortality site within the Bonaparte study area. The proximate cause of death was unlicensed harvest, January 2018 (Photo: Chris Procter).

Figure 22. A mortality site investigation of a collared cow Moose within the Entiako study area that was in poor condition. The proximate cause of death was unknown health-related, July 2017 (Photo: Conrad Thiessen).

Of the 60 calf Moose radio-collared in winter of 2016/17 and 2017/18, there were 21 calf mortalities and 2 yearling mortalities (Table 11). All calf mortalities occurred between March 11 and May 23. Proximate probable cause of mortality of calves was 12 predation (9 Wolf, 1 cougar, 2 bear), 8 health-related (4 apparent starvation, 2 apparent starvation/tick, 1 failed predation attempt, 1 gastro-intestinal infection) and 1 vehicle collision. We recorded a significantly higher proportion of health-related, particularly apparent starvation, mortalities (i.e., 45%) in 2016/17. Licensed hunters legally killed both yearlings in the fall.

4.6 Relationships between Body Condition and Age and Causes of Mortality

Bone marrow fat (see examples in Figures 24 and 25) analysis conducted on cow Moose mortalities (*n* = 63) showed 55% in good body condition (>70% marrow fat), 25% with acute malnutrition (<20% marrow fat) and 21% in poor body condition (20–70% marrow fat). The majority of mortalities involving cows with acute malnutrition and poor body condition occurred between March and June while mortalities in the remainder of the years typically involved cows in good body condition (Figure 26). Mortality causes associated with

Figure 23. A mortality site investigation of a collared cow Moose within the Big Creek study area. The proximate cause of death was unlicensed harvest, December 2017 (Photo: Shane White).

Table 11. Number of mortalities and probable proximate cause of death of radio-collared calf Moose in central BC from January 2017 – 24 May 2018.

Study Area	Age Class	Mortalities	Probable Proximate Cause of Death
Bonaparte	Calf	14	Female: 2 predation (1 Cougar, 1 bear), 4 health-related (1 apparent starvation, 2 apparent starvation/tick, 1 failed predation attempt), 1 vehicle collision Male: 4 predation (Wolf), 3 health-related (2 apparent starvation, 1 gastro-intestinal infection)
Prince George South	Calf	6	Female: 1 health-related (apparent starvation) Male: 5 predation (4 Wolf, 1 bear)
Bonaparte	Yearling	2	Female: n/a Male: 2 hunting (licensed)
Totals		**23**	**Female: 2 predation (1 Cougar, 1 bear), 5 health-related (2 apparent starvation, 2 apparent starvation/tick, 1 failed predation attempt), 1 vehicle collision** **Male: 9 predation (8 Wolf, 1 bear), 2 hunting (licensed), 3 health-related (2 apparent starvation, 1 gastro-intestinal infection)**

Figure 24. Example of long bone cross-section showing low marrow fat content collected during a mortality investigation of an adult cow in Bonaparte Study Area, May 2018 (Photo: Francis Iredale).

Figure 25. Example of long bone cross-section of high marrow fat content in a long bone cross-section collected during a mortality investigation of a male calf in Bonaparte study area, April 2017 (Photo: Chris Procter).

Moose in good body condition included predation, non-apparent starvation health related and hunting. Mortality causes associated with Moose in poor condition and acute malnutrition included predation, apparent starvation, health-other, hunting and natural accident (Table 12). No obvious trends existed with most mortality causes, but all hunting kills, except for one, were of Moose in good condition and all apparent starvation mortalities were characterized by having marrow fat levels <10%. Sixty-two percent of predation kills were of Moose in good condition and 25, 83, and 100% of direct mortalities by wolves, bears and cougars respectively were of Moose in states of poor condition or malnutrition.

Table 12. Body condition (as indexed by marrow fat) by probable proximate cause of death for collared cow Moose that died in central BC from February 2012–30 April 2018.

Probable Proximate Cause of Death	*n*	Average Marrow Fat %	Marrow Fat % Range
Predation – all	45	64.1	6 – 95
Predation – wolf	36	71.9	8 – 95
Predation – bear	6	31.4	8 – 78
Predation – cougar	3	35.3	6 – 70
Apparent Starvation	7	6.8	5 – 9
Health – Other	6	37.2	8 – 85
Hunting	6	77.3	43 – 88
Natural Accident	1	5	5

Average age of cow Moose at death was 11. Age ranged from 2 to 18 years and varied by probable proximate cause of death (Table 13). There was no apparent trend associated with age and probable proximate cause of death, but those killed by predators and health-related factors tended to be slightly older. We currently have no information on the age structure of living moose.

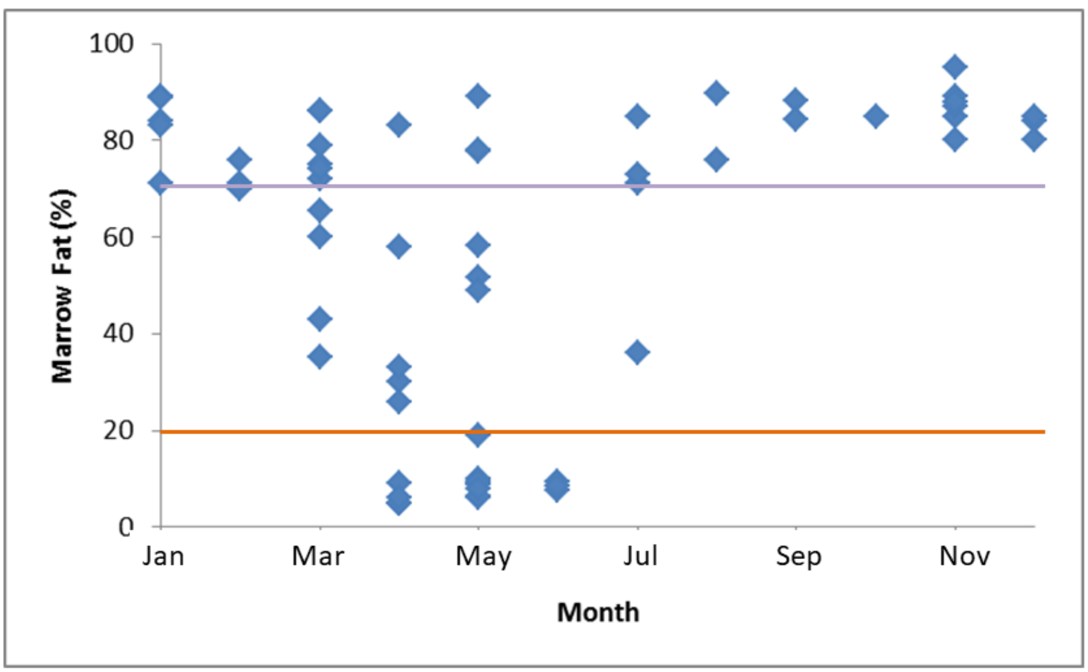

Figure 26. Body condition (as indexed by marrow fat) for each individual collared cow Moose mortality shown by month of mortality (*n* = 63) in central BC from February 2012–30 April 2018. Acute malnutrition is associated with marrow fat <20% (below orange line), poor body condition is associated with marrow fat between 21 and 70% (between orange and purple lines), and good body condition is associated with marrow fat >70% (above purple line).

Table 13. Average and range of age at death for collared cow Moose by probable proximate cause of death for collared cow Moose that died in central BC from February 2012–30 April 2018.

Probable Proximate Cause of Death	*n*	Average Age	Age Range
Predation – All	34	11.4	2 – 18
Predation – Wolf	28	11.2	2 – 18
Predation – Bear	4	11.3	10 – 14
Predation – Cougar	2	14.0	14 – 14
Apparent Starvation	8	9.6	5 – 15
Health – Other	7	11.4	3 – 17
Hunting	3	9.7	8 – 12
Natural Accident	2	10	9 – 11

Table 14. Calf surveys to determine calf status of radio-collared cow Moose in central BC from March 2014–March 2018. The number of collared cows observed and the survey month are presented parenthetically.

Study Area	# Calves/100 cows in Late Winter				
	2014	2015	2016	2017	2018
Bonaparte	not surveyed	25 (40, Mar)	26 (68, Mar)	16 (32, Mar)	38 (40, Mar)
Big Creek	28 (41, Mar)	37 (43, Feb)	33 (43, Mar)	27 (41, Mar)	32 (37, Mar)
Entiako	not surveyed	not surveyed	14 (44, Mar)	9 (35, Mar)	15 (26, Mar)
Prince George South	not surveyed	39 (18, Mar)	27 (44, Mar)	40 (49, Mar)	26 (35, Mar)
John Prince Research Forest	not surveyed	8 (13, Feb)	17 (36, Mar)	40 (42, Mar)	37 (38, Mar)

4.7 Late Winter Calf Surveys

From 2014–2018, we conducted 20 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 14).

5. DISCUSSION

5.1 Collection of Biological Data

As of April 2018, we have monitored the survival of 400 cow Moose in five study areas. At the time of capture, the majority of cow Moose (predominately mid-aged adults, i.e., only 12% classed as old and 4% young) were assessed as being in fair to excellent body condition (4% were in poor condition and 1% was judged to be emaciated). However, condition varied by year and study area, with a higher proportion of Moose in poorer condition captured in 2016/17 over all study areas and in the Prince George South study area over all years. Although a standard condition evaluation protocol exists, it is possible that observer bias during captures has some degree of influence over body condition assessments between study areas. Based on these results, Moose populations overall in these study areas do not seem to be in poor condition, but we have concerns that subjective measures of body condition are not sensitive enough to detect variation in condition that may influence the fitness of individual Moose. For example, low pregnancy rates in some study areas suggest cow Moose may be in poor enough condition that pregnancy rates are low. We plan to objectively measure body fat with ultrasonography where possible during future capture events to help with characterizing the condition of these Moose populations.

Six-year average pregnancy rates observed in this study ranged from 64 – 94%, with the lowest observed in the Bonaparte (64%) and Prince George South (75%) study areas; average rates in the other three study areas were 84–94%. Although it is possible that parturition analyses suggested that pregnancy rates might have been higher than estimated in the Bonaparte study area, they were still below rates typically observed in many North American Moose populations. The relatively low pregnancy and parturition rates and at least one abortion suggest reproductive failure of some Moose in Bonaparte, and is the most notable health difference compared to the other study areas. However, caution should be used in interpreting results, as reported pregnancy rates were based on relatively small sample sizes in many cases. Boer (1992) reported an average of 84% from various studies around North America, but pregnancy rates reported in the literature vary widely, often due to variation in nutritional status. Ruprecht et al. (2016) reported an average rate of 74% in Utah, along the southern edge of Moose distribution, and Jensen et al. (2018) reported a pregnancy rate of over 95% in North Dakota during a period of Moose population growth. In Alaska, reported pregnancy rates for several populations were 76–97% (Schwartz 1998), and Gasaway et al. (1992) reported pregnancy rates that varied from 60–100% in accordance with nutritional status. In Minnesota, Murray et al. (2006) documented chronically low pregnancy rates, between 38 and 59%, in a nutritionally-stressed Moose population. These data may indicate that some Moose populations in British Columbia are experiencing nutritional limitations. Further investigation is warranted as pregnancy rates alone may not be sensitive enough to infer nutritional status (Boertje et al. 2007) and there are other factors that can influence average pregnancy rates (e.g., age) for Moose (Heard et al. 1997; Murray et al. 2006). As discussed below, there are indications that our studies of Moose populations are trending toward older age distributions due to lower recruitment rates. Health-related factors can also influence Moose reproduction, including pregnancy (Macbeth 2017).

Eighty percent of collared Moose calves were judged to be in good condition at time of capture, 18% were in fair condition and 2% were in poor condition. We weighted only 22 of 60 captured calves. Weighting calves at capture was challenging due to weather (e.g., wind, snow depths >1.2 m) and other logistical constraints (i.e., location of immobilized calf). Mean weight of the 22 calves at 8–9 months old was 183 kg which in the middle of the range reported in Alaska over several years for 9–10 month old calves (167.5–191.4 kg, Keech et al. 2011) but larger than average weights of 9–10 month old calves reported elsewhere in Alaska (148.9 kg, Keech et al. 1999; 157–170 kg, Boertje et al. 2007) and less than the average weight of 7 month old calves reported in North Dakota (196kg, Jensen et al. 2013). Keech et al. (1999) attribute their low average weight of 9–10 month old calves to poor nutritional status of their study Moose population due to high Moose densities. Similarly, Jensen et al. (2013) attribute their higher average weight of calves to high nutritional status of their Moose population arising from use of high quality forage in agricultural areas. Boertje et al. (2007) also indicated their average weights varied with nutritional status, and suggested that average calf weights of >190 kg are predictive of high nutritional status. Thus, calves in this study appear to be in good condition, which contrasts with indications (e.g., low pregnancy rates) that some cows are in poor condition and further highlights the need to objectively characterize the body condition of cow Moose at capture. As calf weights in the literature are reported at different ages (i.e., 7–10 months) and during a period of time when Moose are generally losing weight (i.e., early to late winter), caution is required in interpreting these data as the time of the year calves were weighed may introduce variation that is reflective of the time of year as opposed to true differences in the weights of calves. We recommend continuing to measure calf weights wherever possible to gain understanding of how weights may vary over time and across study areas. Due to challenges in weighing calves, we also hope to continue refining relationships between body measurements (i.e., total length and chest girth) and weight so that calf weights can be reliably estimated from measurements alone. More samples are required in this regard. Further, once sample sizes are sufficient, we will investigate relationships between weight at capture and probability of survival.

We will continue to evaluate and refine capture methods and protocols used during this project, and will use the most humane and effective methods possible to maximize opportunities to collect appropriate biological samples while animals are immobilized or restrained. The BC wild ungulate health assessment model (FLNRORD, unpublished data) supports investigation of new measures of Moose health, including cumulative effects, the impact of winter ticks, nutrition and other factors influencing overall health, and has initiated collaborative work to further understand their importance and whether or not these factors are more widespread. 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.

5.2 Cow Survival

The landscape change hypothesis states that Moose declines coincided with a mountain pine beetle outbreak where habitat changes and increased salvage logging and road building resulted in greater vulnerability to Moose from hunters, predators, nutritional constraints, age/health and environmental conditions. We assumed cow Moose survival would have a greater proportional effect on population growth than calf survival (Gaillard et al. 1998) because the declines occurred over a relatively short time period.

The first evaluation of the landscape change hypothesis was to determine cow survival rates as Moose populations would decline concurrent with increased salvage logging as cow survival has the greatest proportional effect on population change (Kuzyk and Heard 2014). Our results from monitoring survival rates of 400 cow Moose over the course of five years are sufficient to evaluate this hypothesis. Cow survival rates were greater than 85%, which is within the range reported from stable Moose populations, i.e., >85% (Bangs et al. 1989; Ballard et al. 1991; Bertram and Vivion 2002). These rates were higher than survival rates estimated for cow Moose from the Northwest Territories (85%, Stenhouse et al. 1995) and northern Alberta (75–77%, Hauge and Keith 1981). The Bonaparte, Big Creek and John Prince study areas had cow survival above 85% in all years whereas Entiako was below 85% in three of five years, and Prince George South was below 85% in two of five years (Figure 15). Therefore survival rates over these five years were not indicative of Moose population declines and were inconsistent with the cow survival rate component of the landscape change hypothesis.

The second evaluation of the landscape change hypothesis was to determine the mechanisms influencing vulnerability of cow survival (Kuzyk and Heard 2014). . Over these five years, approximately half of the cow Moose died from predation (proximate cause of death), with the majority of those killed by wolves. Predation by wolves occurred in all study areas, whereas predation from bears and Cougar occurred only in Bonaparte, Prince George South and Big Creek. The second most frequent proximate cause of death of cow Moose was from health-related issues (19%). Proximate cow Moose mortalities from hunting were 17%, and this was initially assumed to be one of the main factors influencing Moose population change as increased number of roads and reduced visual cover from cutblocks would make Moose more vulnerable to hunters. The mortality-specific assignment of ultimate cause of death, and determination of the role of landscape features in influencing differential causes of mortality by study area is currently under investigation at UNBC.

Nearly half (*n* = 29) of all cow Moose that died and had samples suitable for analysis were in a state of poor condition or malnutrition, and these mortalities mainly occurred between April and June. As such, these data may reflect the natural or typical annual cycle of body condition as Moose commonly experience seasonal lows in body condition during late winter/early spring (Franzmann and Arneson 1976; Fong 1981; Ballard 1995). We recognize the limitations of analyzing marrow fat as an index to body condition (Mech and Delgiudice 1985), particularly where marrow fat levels may be judged high, and we continue to explore options to characterize the overall seasonal condition of Moose populations in our study areas to assist with interpreting these data. Ballard (1995) suggests that one can infer the body condition of the larger moose population (not just those that are dead) by comparing the condition of those dead by natural and unnatural causes. In our project, we did not have sufficient unnatural mortalities to do this.

Although age at death varied between 2–18 years of age, there appeared to be no differences in proximate cause of death by age. The ages at death that we observed in this study suggest the majority of Moose died at an old age, regardless of cause, which suggests we may have captured and monitored older Moose or that older Moose are more vulnerable to all causes of mortality (Peterson 1977; Montgomery 2014).

Our data suggest that calf survival is the more important factor than cow survival in explaining Moose population change. If so, then our study of Moose populations may have been trending towards an age distribution skewed towards older females. Survival rates and fecundity of cow Moose decline with age (Montgomery 2014). We did know the age distribution of cow Moose in our study areas or how it may have changed over time (see Heard et al 1997). As indicated above, we were unable to compare ages of Moose that died in ways unlikely unrelated to their age (i.e., accidents, hunter kills) due to insufficient sample size. We are currently investigating methods to characterize the age distribution of Moose populations in the study areas to assist in understanding whether or not age is a factor driving mortality patterns and survival rates estimated in this study (e.g., analyzing age distribution of hunter-harvested Moose throughout BC). Related to this, a process is currently underway to review biological data available from analyses of mortality samples to assign ultimate cause of death to these mortalities. This process recognizes that larger factors (ultimate cause of death) may have driven the actual (proximate) cause of death. This process combines the results from body condition analysis, tooth aging, and results from health testing. 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, which may have predisposed her to being unable to free herself from this hazard.

5.3 Calf Survival and Recruitment

At the outset of this study, cow survival was thought to be the primary driver (Galliard et al. 1998) influencing Moose population change because declines in some areas occurred rapidly (i.e., 50% in 10 years) and calf survival is known to be a proportionally less important factor influencing ungulate populations (Gaillard et al.2000) and calf cow ratios were reasonably high. Over the course of this study, however, we determined overall cow survival to be >85% or equivalent to that needed for stable and/or increasing populations. Some survival estimates in some study areas in some years are sufficient to cause rapid population growth (e.g., 98% in the Bonaparte study area in 2017/18). We also acknowledge there is important regional variation. In two study areas (i.e., Entiako and Prince George South) low cow survival may not have been high enough to maintain the population in some years. At the start of this project we used March calf surveys as an index of calf survival and recruitment. Ten of the 15 late winter calf surveys had calf/cow ratios at or above 25 calves/100 cows, which would generally indicate stable Moose populations if adult female survival rates are above 85% (Bergerud and Elliot 1986; FLNRO 2015). Despite our estimates of cow survival and observations of calf ratios exceeding 25 calves/100 cows in late winter, however, survey data suggest some study populations have continued to decline through the research period. Understanding the causes of these declines and the factors affecting Moose population change requires increased efforts to monitor Moose calf survival rates, timing of calf mortality (Bowyer et al. 1999), causes of calf mortality (Larsen et al. 1989), calf recruitment to older age classes and drivers of calf survival (Patterson et al. 2013).

In 2017/18, late winter survival of collared Moose calves was much higher than in 2016/17 (78 ± 13% and 45 ± 22%, respectively). As a result, recruitment rate in the Bonaparte study area was four times higher in 2017/18 relative to 2016/17, which likely had a big influence on population growth. Higher calf production and summer survival also contributed to higher recruitment observed in 2017/18. Large annual variation in juvenile recruitment is not surprising and is typical of many ungulate populations (Gaillard et al. 1998; Gaillard et al. 2000). Long-term monitoring of recruitment is required to understand the factors responsible for variation in this parameter.

Causes of calf mortality observed in 2017/18 also differed from 2016/17. In the Bonaparte study area, 66% (n=2) of the mortalities were due to predation (1 wolf kill and 1 cougar kill) and 33% (n=1) were attributed to tick-related apparent starvation. We recorded a significantly higher proportion of health-related, particularly apparent starvation, mortalities in 2016/17 (i.e., 45%). In the Prince George South study area, we observed higher levels of calf mortality (n = 6) relative to Bonaparte, but similar rates of predation (83%) and health-related causes (17%). The lack of apparent starvation mortalities in late winter/early spring 2018, relative to 2017, is of interest as it may relate to our maternal body condition hypothesis that describes a potential driver of calf survival (see Section 6.5). In 2017/18, several reproductive parameters that are all known to vary with maternal body condition, including pregnancy rates, calf production, summer and winter calf survival and ultimately, recruitment, were higher in 2017/18 relative to 2016/17. These observations together provide support for our hypothesis, but further research is required to assess the importance of various mortality factors and to test this and alternative hypotheses.

Data generated in this research so far suggest that mid-winter calf/cow ratios, typically measured by biologists during aerial surveys and used to inform population management and infer population trends, consistently overestimates actual recruitment. In some years, the magnitude of the difference can change population trajectories, particularly when mid-winter calf recruitment rates are below or near the minimum required to maintain population stability. Given the extent of variability observed with two years of data, and the strong potential to change Moose population trends, a longer-term understanding of the variation in this parameter is required to fully understand Moose population dynamics in British Columbia. Having cow survival estimates through the same timeframe will be particularly useful as Moose population trend may be sensitive to the frequency of overlap between years of lower cow survival and years of poor recruitment. Gaining an understanding of both the timing of calf mortality and causes of mortality is important, as we noted significant annual variation in summer calf survival and associated effects on recruitment, and also, mid-winter calf/cow ratios appear to reflect early and summer calf survival more than recruitment at age 1.

5.4 Landscape Change and Survival Analyses

Other research is complementing the FLNRORD-led work. Analyses of habitat selection of radio-collared Moose has been completed at UNBC for the Big Creek, Entiako, Prince George South study areas (Scheideman 2018), and at the University of Victoria for the Bonaparte study area. The John Prince Research Forest is investigating seasonal migrations of collared cows and fine-scale winter occupancy patterns.

Scheideman (2018) quantified seasonal home range selection, home range size and daily movements, and within home range selection of

GPS radio-collared female Moose in the Big Creek, Entiako, and Prince George South study areas. Individual variation among cow Moose was evident at both home range and within home range scales. Collared female Moose selected lodgepole pine-leading stands at both spatial scales despite the die-off of pine due to MPB. Clear-cuts following the MPB outbreak were avoided in drier locations, and there were trade-offs between cover and browse evident where disturbance due to salvage logging was highest. Generally, MPB salvage logging reduced Moose habitat, and thereby, influenced selection by female Moose (see Scheideman 2018 for details).

The Habitat Conservation Trust Foundation is supporting a comprehensive 2-year, cow-survival analysis with UNBC, which will be completed in April of 2019. This work includes assigning an ultimate cause of death to each mortality (i.e., integrating condition, health, and necropsy data) based on consultations with project staff and veterinarians, and assembling all available data layers including vegetation, cutblock and salvage logging, and fire and spraying histories. 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

This project is currently in its sixth year of a planned 10-year project. Our research to date has provided a better understanding of factors affecting cow Moose survival, and initial insights into the importance of calf survival and recruitment, and variation in that parameter, in the BC interior. We have reconfirmed that important areas to focus on for the next five years (2018–2023) are: 1) continuing to monitor cow survival indefinitely; 2) initiating forest management trials to benefit Moose populations; 3) continuing to monitor true calf recruitment rates; 4) assessing calf survival in relation to landscape change; 5) assessing calf survival in relation to body condition of cow Moose; 6) investigating the role of nutrition and health in influencing cow and calf Moose; and 7) investigating the role of wolf predation on Moose populations. These important research areas should be investigated to broaden our understanding of factors influencing Moose population dynamics and facilitate the development of management recommendations to benefit Moose populations in the province.

6.1 Monitoring Cow Survival Indefinitely

Benefits of long-term monitoring of cow Moose include: 1) understanding of longer-term annual and seasonal variation in causes and rates of cow Moose mortality, how it relates to variation observed in calf recruitment in terms of explaining Moose population dynamics, and understanding trends in survival relative to environmental variation; 2) continuing to contribute to and build long-term data sets of biological samples and various reproductive and health parameters; 3) providing opportunity to evaluate the effectiveness of management strategies that can benefit Moose management around the province; and 4) provision of data that can be used to monitor population trends and improve population models used to monitor Moose populations and inform harvest management.

6.2 Forest Management Trials to Benefit Moose Populations

There is a need to generate science-based guidelines to inform forest management strategies and habitat management to benefit Moose populations. This need is supported by increased pressure from First Nations and stakeholders to implement forestry practices benefit moose populations. Guidelines or Best Management Practices currently exist in various Land and Resource Management Plans, habitat management handbooks and regional offices around the province; however, these were developed with best available information at the time and need to be updated. There are opportunities to undertake experimental “forest management trials” in some study areas that would form the scientific basis for informing and updating guidelines for Moose habitat management. We will investigate Moose responses (at multiple spatial scales) to forest management factors such as cutblock size and shape (relative to security cover), appropriate buffering of key habitat elements (e.g., riparian wetlands, deciduous stands, etc.), optimal cover/forage ratios, optimal distribution of mature timber cover, optimal road densities and locations of roads relative to key habitat features, screening cover along roads, stand tending silviculture practices (e.g., stocking densities, chemical control of deciduous competing vegetation, etc.), and effects of different timber harvesting systems.

This approach will use fine-scale movements and behaviour of Moose equipped with high-fix rate GPS collars (i.e., 4-6 fixes/day) in addition to previous collar data to test for differences in selection/use of features in relation to forest management practices on the landscape. This will allow comparisons of Moose responses to historic forest management practices to current experimental manipulations (including forest harvesting and silviculture treatments). First Nations and stakeholders regularly communicate that they believe there is a direct link between some of these practices and Moose survival. While measuring the direct impacts of forest management on Moose survival is difficult, assessing changes in resource selection can be a suitable alternative approach, as the basic tenet behind resource selection theory is that animals would be expected to select resources and features that promote fitness and survival, and similarly, avoid those features that may be detrimental to their fitness and survival (Manly et al. 2002). We will explore the effects of forest management practices on Moose resource selection; however, we accept that it may be challenging to draw wide-ranging conclusions on survival due to the relatively small temporal and spatial scales of some of these experiments. Improved forest/habitat management practices (informed by Moose resource selection patterns) should result in more resilient landscapes for Moose.

The John Prince Research Forest (JPRF) study area has suitable conditions and management control to alter or employ forestry practices that can be evaluated for effects on moose. JPRF and the adjacent First Nation tenures have well-used Moose habitat, and both parties are interested in this approach to inform Moose management. In addition, these tenures have high-resolution habitat data derived from LiDAR inventories that will make fine-scale resource selection models more appropriate. The Bonaparte study area has another landscape manipulation underway where 60km of spur roads have been rehabilitated (i.e., total removal and impassable) in a large portion of the study area in fall 2017, and another 100+km are slated for rehabilitation in summer 2018. This provides a unique opportunity for a before and after study design using existing collared Moose to assess effects of roads, road locations and road densities on Moose habitat selection patterns. Other opportunities may exist in other study areas and from a research design perspective, we would prefer to use spatial information from high-fix rate GPS collars in all five study areas because that approach incorporates additional controls to assess treatment effects and increases the applicability, strength and rigor of analyses.

The use of herbicides (e.g., glyphosate) in silviculture practices and their potential influence on Moose populations is a concern continually raised by stakeholders and First Nations. Glyphosate is used to kill and discourage competing deciduous growth in recently logged settings to encourage crop tree growth and maximize timber production. Research has produced conflicting results on the effects of glyphosate on Moose habitat use (Kennedy and Jordan 1985; Hjeljord and Grønvold 1988; Connor and McMillan 1990; Hjeljord 1994; Santillo 1994; Escholz et al. 1996; Raymond et al. 1996) and Moose browse (Cumming 1989). As part of our investigation into the effects of forestry practices on Moose populations, we are investigating ways to assess how Moose are influenced by the application of herbicides (i.e., habitat selection, health parameters). Herbicide use in study areas ranged from 0 – 7%. Research challenges include understanding the impacts of herbicide use on Moose forage, as often only portions of cutblocks are treated and the intensity in which treatments have been applied is variable, and ensuring adequate treatments occur, or have occurred in the past, in areas where we have Moose collared with appropriate radio collars to adequately assess our research questions.

The intended outcome from these forest management trials is the development of science-based forest and wildlife habitat management guidelines and recommendations to benefit Moose in BC and elsewhere.

6.3 Monitoring True Calf Recruitment Rates

The importance of assessing calf survival in relation to Moose population change has been highlighted in the Moose project research design (Kuzyk and Heard 2014) and the 2015, 2016 and 2017 progress reports (Kuzyk et al. 2015; Kuzyk et al. 2016; Kuzyk et al. 2017), and is supported by the 2017/18 preliminary results reported here. As of March 2018, information from surveys and current research (Klaczek et al 2017; FLNRORD unpublished data) suggests Moose populations continue to decline despite cow survival rates capable of supporting stable to increasing populations in most study areas, which implies calf survival, and ultimately recruitment, is a main factor driving Moose population declines.

Early evidence from monitoring survival of Moose calves indicates that recruitment indices measured in mid-winter during surveys (i.e., calf/cow ratios) do not reflect actual recruitment into the adult, breeding population of Moose in some years and the difference can have significant ramifications on Moose population trends. As such, continued monitoring of survival and recruitment of older Moose calves is recommended to understand longer-term variation in this parameter and consequences for Moose population dynamics. We plan to continue calf monitoring 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.

6.4 Assess Calf Survival in Relation to Landscape Change

Identifying factors affecting calf survival and recruitment is a key research need for this project. We hypothesize there are several factors involved, including those that cause direct mortality, such as predation or health-related factors, and indirect contributing factors that predispose calves to higher mortality rates, such as landscape change and maternal condition of cows (see section five below). We hypothesize that landscape change has increased mortality risk to calves by: 1) reducing security cover (e.g., screening cover, increased open early seral habitat) and making Moose more visible; 2) fragmenting Moose habitat into fewer smaller patches of functional cover that Moose use extensively at certain times of the year (e.g., through the calving and late winter periods); and 3) increasing access (i.e., roads associated with timber harvest) to those patches and Moose habitat in general for predators.

We propose to assess the effects of landscape change on calf survival by radio-collaring older calves (7–8 months of age) and directly monitoring their survival, causes of mortality and locations of mortality, and to use existing radio-collared cows to indirectly estimate calving sites and early calf mortality sites by analyzing their movement rates and patterns. Location data from cows may also be useful for comparisons of selection patterns between cows successful in recruiting young to those that are unsuccessful. Retrospective analyses with existing data sets on cows may also be possible. Calving sites can be identified by monitoring daily movement rates of cow Moose with higher fix-rate collars (>2 fixes per day; DeMars et al 2013; Severud et al. 2015) and the survival and mortality locations of young calves can be estimated using movement patterns of cows when they repeatedly return to a calf mortality site (Obermoller 2017). Monitoring these movements in near real-time may also allow ground checks to potentially gain understanding of causes of early calf mortality, that is, prior to the age at which they are currently radio-collared. Identification of calving sites, calf mortality sites and causes of mortality will enable analysis of relationships with landscape or disturbance features related to landscape change to inform the development of science-based forest management recommendations. Currently, we have radio-collared 60 Moose calves at 7–8 months of age in two study areas (Bonaparte and Prince George South) and have monitored their survival and mortality causes and locations. Funding has been secured to radio-collar an additional twenty 7–8 month old calves in both the Bonaparte and PG South study areas during the winter of 2018/19 (total n = 100).

6.5 Assess Calf Survival in Relation to Body Condition of Cow Moose

Over the past five years, we found evidence that some Moose were in poor condition, as evidenced by one aborted fetuses in late gestation (i.e., documented in Bonaparte), low productivity (i.e., low pregnancy rates, higher than expected proportion of barren cows and/or alternating reproductive years), low calf survival, and observations of Moose in poor condition at time of capture. A more complete assessment of the condition of cows is necessary to understand the overall condition of Moose populations. We hypothesize that the fitness of cows (i.e., fertility and productivity), rates and causes of mortality of their calves, and recruitment of their calves will vary as a function of their body condition entering winter. We predict that cows with higher body condition (fat stores) will have higher pregnancy, fetal, and parturition rates. and their calves will have higher probability of survival to recruitment. We also predict that calves of fatter females will be less likely to die from health-related causes, particularly apparent starvation.

Winter is typically the time of year that nutritional limitation is assumed to occur for ungulates in the northern hemisphere; however, much recent research suggests reduced spring/summer/fall nutrition may be negatively influencing survival and reproduction of ungulates (see Cook et. al. 2013 for a review). Further, recent research suggests spring/summer/fall nutrition, relative to winter, may be the more important predictor of ungulate survival and productivity due to its direct relationship with reproduction and juvenile growth and survival (Cook et. al. 2004, 2013; Hurley et. al. 2014; Hurley 2016) and the ability of ungulates to mitigate winter effects, regardless of their condition (Cook et al. 2013; Monteith et al. 2013). Poor body condition of adult females contributes to reduced calf survival and recruitment in ungulates in many ways, including delayed birth dates (Testa and Adams 1998; Keech et al. 1999; Monteith et. al. 2014), reduced pregnancy rates (Heard et al. 1997; Keech et al. 1999; Cook et al. 2004), lower fetal rates (Keech et al. 1999), higher incidence of abortion (Testa and Adams 1998), reduced birth mass of young (Clutton-Brock et al. 1987; Keech et al. 1999; Cook et al. 2004; Lomas and Bender 2007; Monteith et al. 2009), and reduced growth of young in their first summer (Cook et al. 2004). Less thrifty young (i.e., those born smaller, in poor condition or suffer poor growth rates) are more prone to mortality at a younger age (Testa and Adams 1998; Keech et al. 1999; Lomas and Bender 2007) and during their first winter (Cook et al. 2004). Furthermore, age of first reproduction for less thrifty juveniles, should they survive, may be compromised, which can further constrain population productivity (Keech et al. 1999; Cook et al. 2004).

To test our hypothesis, we will assess correlations between the late autumn/early winter body condition (i.e., % total body fat) and fitness (i.e., pregnancy, twinning and parturition rates) of collared cows, rates and causes of mortality of their calves, and ultimately, recruitment of calves to age 1. We will focus calf captures on those calves of existing collared cows, and recapture cows at the same time to assess their body condition by measuring depth of rump fat using ultrasonography (Stephenson et al. 1998). Estimates of total body fat will be developed using equations developed by Cook et al. (2010). For comparison purposes, we will also recapture a proportion of existing collared cows that do not have calves and will collect the same measurements. We will also use ultrasonography to determine pregnancy and fetal rates for captured individuals. Parturition rates will be determined by analyzing movement rates of collared cows through the parturition period and by conducting aerial searches for calves.

6.6 Role of Nutrition and Health in Influencing Moose Populations

The role of nutrition 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) suggest further investigation into nutrition and health parameters, particularly those relating to reproductive health, is warranted. Projects are underway that investigate diet content of Moose in all seasons (JPRF and Prince George South) and how forage nutrition quality (examining differences in forage quality between cutblocks and forested habitats) and health factors (Macbeth 2017) may influence Moose populations. As discussed above, we also plan to begin estimating body fat of collared cows in some study areas in the late fall/early winter to characterize summer and fall nutritional status. Also, there is evidence of a link between nutrition and predation through predator-sensitive foraging, with the indirect foraging effects of predation usually outweighing the direct effect of killing (Montgomery et al. 2014).

We are actively assessing the factors affecting and methods to measure Moose herd health. The development of a health baseline is important for understanding Moose health and survival. Future areas of investigation include integrating current health monitoring with studies evaluating thermal stress, the quality and quantity of Moose forage, and winter tick effects on calf (Jones et al. 2017) and adult Moose survival (Samuel 2004, 2007) and health determinants. Continuing with the current study and continuing to build data sets of biological samples and other information on individual Moose and populations of Moose will contribute to the development of long-term longitudinal health programs. The development of community and/or harvester-based Moose sampling programs and health assessments will be of assistance with obtaining samples from a wider area, and provides a means to actively engage external stakeholders.

6.7 Role of Predation on Moose Populations

Predation is currently being monitored through identification of cause of death and species of predator in mortalities for cow and 7-month old calf Moose. A 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 is underway (Figure 27). This project will help inform interpretation of predation pressure on these Moose populations by providing more detailed assessment of territory size, pack numbers, predation rates, prey species selection, an increased sample size to assess age/condition of Moose selected and habitat selection information will result in a habitat risk layer for moose. Although this type of information is valuable to understanding these predator-prey systems, these projects are costly and require significant personnel time. As such, it is not possible to replicate this work in all study areas. The importance of other predation types on Moose population dynamics remains a research gap but could be addressed with new technological advances with camera trapping (Burton et al. 2015). The use of camera traps to develop a predation risk layer based on different types of predator species would be helpful to inform cow and calf survival. It would also provide important information on Moose habitat selection and behavior for the Forest Management Trial. Having a more detailed understanding of the role of predation and predator species in Moose survival could help develop priorities for management recommendations to benefit Moose survival.

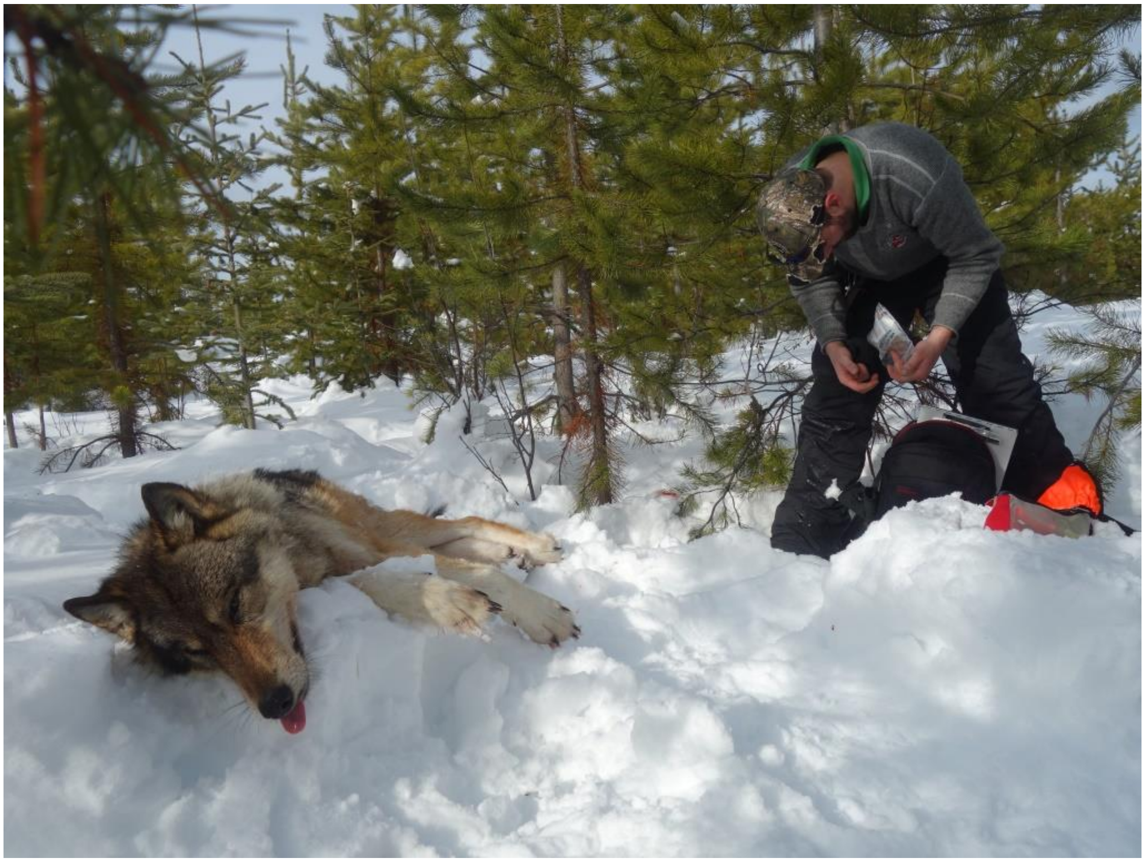

Figure 27. Wildlife biologist Matt Scheideman packing up after fitting a GPS collar to a female wolf in the Prince George South study area, February 2018 (Photo: Morgan Anderson).

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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	Signs 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.
    - **Failed Predation Attempt**: Moose that have died from a failed predation attempt. Causes of death may include shock associated with blood loss, trauma and pain, dehydration, septicemia and other sequella of extreme exertion such as myopathy.
    - **Chronic Bacterial Infection**: A bacterial infection of more than several days duration of subcutaneous and deeper tissues.
    - **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
    - **Prolapsed Uterus**: The uterus is everted (inside out) from the abdominal cavity through the pelvic canal during a complicated parturition or calving, due to a misrepresentation or severe straining from other reasons.
    - **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.).
- **Vehicle Collision:** Moose that have died as a direct result of a motor vehicle strike.
- **Unknown:** Moose that have died and <u>no</u> 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 December 2017).

Dec 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: Number of ticks sample 1 __________
Number of ticks sample 2 __________

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

Dec 2017

BC Moose Research – Sample Processing and Tracking

WLHID:	S/N:	Study Area:	Mort Date:

PROCESSING SAMPLES IN THE LAB

FORMALIN (FIXED) SAMPLES – DO NOT FREEZE
- TOGETHER IN HARD PLASTIC JARS
- 1:10 RATIO OF TISSUE TO FORMALIN
- MUST BE < 1CM THICK TO FIX PROPERLY

FROZEN SAMPLES
- SEPARATELY IN WHIRLPAKS

SAMPLE	STORAGE	PURPOSE	SENT TO	DATE SENT
HEAD (or sample Obex and LN)	FROZEN	CWD	☐ HOLD FOR SAMPLING	
TEETH (incisor required - jaw optional)	DRY	AGE / GROWTH	☐ PRINCE GEORGE	
INTACT LONG BONE #1 (intact)	FROZEN	MARROW (BCI) AND ERYSIP	☐ PRINCE GEORGE	
INTACT LONG BONE #2	FROZEN	ARCHIVE	☐ NANAIMO	
MUSCLE (1/4 apple size)	FROZEN	CONTAMINANTS / TRACE	☐ NANAIMO	
HEART (1cm x 1cm)	FORMALIN	HISTOLOGY	☐ NANAIMO	
LUNGS (1/4 apple size of each lobe)	FROZEN	CULTURE	☐ NANAIMO	
LUNGS (1cm X 1cm of each lobe)	FORMALIN	HISTOLOGY	☐ NANAIMO	
WHOLE KIDNEY + FAT	FROZEN	KIDNEY FAT (BCI)	☐ PRINCE GEORGE	
KIDNEY (1/2 apple size)	FROZEN	CULTURE	☐ NANAIMO	
KIDNEY (1/4 apple size)	FROZEN	CONTAMINANTS / TRACE	☐ NANAIMO	
KIDNEY (1cm x 1cm)	FORMALIN	HISTOLOGY	☐ NANAIMO	
LIVER (1/2 apple size)	FROZEN	CULTURE	☐ NANAIMO	
LIVER (1/4 apple size)	FROZEN	CONTAMINANTS / TRACE	☐ NANAIMO	
LIVER (1cm x 1cm)	FORMALIN	HISTOLOGY	☐ NANAIMO	
INTESTINE *see below	FROZEN	CULTURE	☐ NANAIMO	
INTESTINE **see below	FORMALIN	HISTOLOGY	☐ NANAIMO	
SPLEEN (palm size)	FROZEN	CULTURE	☐ NANAIMO	
SPLEEN (1cm x 1cm)	FORMALIN	HISTOLOGY	☐ NANAIMO	
LYMPH NODE * if abnormal	FORMALIN	HISTOLOGY	☐ NANAIMO	
HAIR (100+ from top of shoulder)	DRY	GENETICS / HORMONES	☐ NANAIMO	
FECES (10-20 pellets)	FROZEN	PARASITES	☐ NANAIMO	
FETUS (whole if possible)	FROZEN	POST MORTEM	☐ ANIMAL HEALTH CENTRE	
CALF (if new born)	FROZEN	POST MORTEM	☐ ANIMAL HEALTH CNETRE	
PLACENTA OR UTERUS (portion)	FROZEN	CULTURE	☐ NANAIMO	
BLOOD (heart/jugular) – do not spin	FROZEN	ANTIBODIES	☐ NANAIMO	
CYSTS	FROZEN	PARASITE ID	☐ NANAIMO	
TICKS	ETHANOL	PARASITE ID	☐ NANAIMO	
PREDATOR DNA SWAB (coin envelope)	DRY	PREDATOR ID	☐ PRINCE GEORGE	
PREDATOR HAIR	DRY	PREDATOR ID	☐ PRINCE GEORGE	
PREDATOR SCAT	FREEZE	PREDATOR ID	☐ PRINCE GEORGE	

*FROZEN: in separate whirlpaks: 2" colon with contents, 2" small intestine, ½ cup contents of abomasum.
**FORMALIN: separate from other formalin samples: 2" colon

BC Moose Research – Mortality Investigations

HOW TO PROCESS SAMPLES FROM THE FIELD - please post this in the lab

<u>Immediately on returning to office</u>:

1. **FRESH SAMPLES for FREEZING**
   (FRESH SAMPLES for microbiological culture OR for contaminant analysis)

   - NOTE THE PIECES ARE LARGER SO THAT ANY ORGANISMS CAN LIVE INSIDE THE TISSUE
   - PACKAGE EACH TISSUE SEPARATELY IN WHIRLPAKS
   - PLACE INTO ONE ZIPLOCK LABELLED WITH WLH ID

2. **FIXED IN FORMALIN SAMPLES**
   (FIXED IN FORMALIN FOR MICROSCOPIC EXAMINATION - FREEZING INTERFERES WITH THE EXAM)

   - FORMALIN IS TOXIC, DO NOT BREATHE IT, USE ONLY WHEN THERE IS GOOD VENTILATION
   - WEAR GLOVES
   - TISSUES MUST BE FIXED AS SOON AS POSSIBLE AFTER COLLECTION
   - TISSUES MUST BE TRIMMED TO A SMALLER SIZE - MUST BE < 1CM THICK TO FIX PROPERLY. 1 X 1 CM SIZE IS IDEAL
   - IF ABNORMAL TISSUE, CAN TAKE SEVERAL SECTIONS AND INCLUDE THE EDGE OF WHERE ABNORMAL MEETS NORMAL TISSUE
   - PLACE IN WHITE HARD PLASTIC CONTAINERS (MUST BE LEAK PROOF) AT A 1:10 RATIO OF TISSUE TO FORMALIN
   - LABEL JARS WITH WLH ID

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													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													

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