Determining Factors Affecting Moose Population Change in British Columbia: Testing the Landscape Change Hypothesis

2016 Progress Report: February 2012 – 30 April 2016

by

G. Kuzyk, S. Marshall, M. Klaczek, C. Procter,
B. Cadsand, H. Schindler and M. Gillingham

Ministry of Forests, Lands and Natural Resource Operations

Victoria, B.C.
Wildlife Working Report No. WR-123
2016

Wildlife Working Reports frequently contain preliminary data, so conclusions based on these may be subject to change. Working Reports receive little review.

This publication is available through our e-library at http://www.env.gov.bc.ca/eirs/bdp/

ISBN 978-0-7726-6988-9

Authors' Addresses

Gerald Kuzyk, British Columbia Ministry of Forests, Lands and Natural Resource Operations, 205 Industrial Road G, Cranbrook, BC V1C 7G5

Shelley Marshall, British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2000 S Ospika Boulevard, Prince George, BC V2N 4W5

Michael Klaczek, British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2000 S Ospika Boulevard, Prince George, BC V2N 4W5

Chris Procter, Ministry of Forests, Lands and Natural Resource Operations, 1259 Dalhousie Drive, Kamloops, BC V2C 5Z5

Becky Cadsand, Ministry of Forests, Lands and Natural Resource Operations, Suite 400 - 640 Borland Street, Williams Lake, BC V2G 4T1

Heidi Schindler, Ministry of Forests, Lands and Natural Resource Operations, 3726 Alfred Avenue, Smithers, BC V0J 2N0

Michael Gillingham, Ecosystem Science and Management Program, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9

Cover Photo: Dexter Hodder

Recommended Citation:

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

ACKNOWLEDGEMENTS

This progress report was developed collaboratively with the Provincial Moose Management Team. Helen Schwantje, her staff (Cait Nelson, Adam Hering and Caeley Thacker), and Bryan Macbeth advised on capture and mortality-site investigation protocols, issues related to Moose health, and provided the team with supplies and handling samples. Adrian Batho and Doug Heard coordinated purchasing and programming Vectronic radio-collars. Mike Bridger and Matt Scheideman assisted with data management. Many other people assisted with components of fieldwork, including the skilled pilots and those that assisted with mortality-site investigations. We acknowledge support from the following funding agencies and collaborators: Government of British Columbia, University of Northern British Columbia (Doug Heard and Matt Scheideman), University of Victoria (Dennis Jelinski and Alexandra Francis), John Prince Research Forest (Dexter Hodder), Habitat Conservation Trust Foundation, Tl'azt'en Nation, Nak'azdli Band, Skeetchestn Indian Band, Tk'emlups Indian Band, Tsilhqot'in Nation, West Fraser Timber Company, and University of Calgary. We appreciate the constructive reviews from Doug Heard, Helen Schwantje and Patrick Stent that improved this report.

EXECUTIVE SUMMARY

This technical report is preceded by Kuzyk and Heard (2014) and Kuzyk et al. (2015). In response to declining Moose numbers in central British Columbia (BC), the BC Ministry of Forests, Lands and Natural Resource Operations (FLNRO) initiated a 5-year (December 2013–March 2018) provincially-coordinated Moose research project. A Moose study with similar objectives that began in February 2012 on the Bonaparte Plateau was integrated with this project. The primary research objective is to test the landscape change hypothesis that assumes Moose survival will increase when: a) forestry cutblocks regenerate to the point where vegetation obstructs the view of predators and hunters; b) resource roads created for logging are rendered impassable due to deactivation or forest ingrowth; and c) Moose become more uniformly dispersed on the landscape. We will address that hypothesis by identifying the causes and rates of cow Moose mortality and examining factors that contributed to their vulnerability. This progress report provides an update of field studies and preliminary interpretation of results from February 2012 to 30 April 2016 for Moose in five study areas in central BC: Bonaparte; Big Creek; Entiako; Prince George South; and the John Prince Research Forest. Within these five study areas, characterized by varied landscape features and conditions, cow Moose were fitted with GPS radio-collars and monitored for survival and habitat use and in some areas movement behaviour.

To date, 336 cow Moose have been fitted with GPS radio-collars during annual December to March captures. There were 203 Moose captured by chemical immobilization using aerial darting and 133 by physical restraint using aerial net gunning. Three configurations of GPS radio-collars were used: those programmed for one fix/day (n = 147), 2 fixes/day (n = 90), and >2 fixes/day (n = 99). Collar performance of single fix collars for all study areas averaged 69% (range 32–96%), 2 fixes/day averaged 85% (range 45–98%), and >2 fixes/day averaged 96% (range 75–100%). As of April 30, 2016, of the 336 radio-collars deployed: 223 were active, 64 failed (i.e., stopped collecting data or slipped from Moose), and 49 were recovered from Moose that died. We identified the probable proximate cause of death for the 49 mortalities as: 21 predation (18 Grey Wolf, 2 Cougar, 1 Bear), 9 hunting (1 licensed, 8 unlicensed), 14 health-related (8 apparent starvation, 2 septicemia, 4 unknown health-related), 1 natural accident, and 4 unknown. The majority of cow Moose were assessed as being in good body condition at the time of capture. Biological samples were collected at capture and during mortality-site investigations as available. Serological screening and ancillary testing did not demonstrate significant exposure to pathogens; however some cows were emaciated at death with no apparent additional cause(s) of death. Future testing of biological samples may provide insight on pre-existing health conditions or other health-related factors that could have contributed to poor body condition and their death. The annual survival rate of cow Moose for all study areas was 92 ± 8% in 2013/14, 92 ± 5% in 2014/15 and 86 ± 5% in 2015/16.

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

TABLE OF CONTENTS

1. INTRODUCTION 1
2. STUDY AREA 2
3. METHODS 5
4. RESULTS 8
4.1 GPS Radio-collars and Fix-rate Success 8
4.2 Capture and Handling 11
4.3 Biological Samples 12
4.4 Mortalities of Radio-collared Moose 13
4.5 Annual Survival Rates 16
4.6 Late Winter Calf Surveys 16
5. DISCUSSION 16
5.1 Data Collection – Biological Data 16
5.2 Data Collection – Radio-collar Data 17
5.3 Survival of Collared Cows 17
5.4 Calf Surveys of Collared Cows 18
6. FUTURE RESEARCH DIRECTION 18
7. LITERATURE CITED 20

LIST OF FIGURES

Figure 1. Provincial Moose research study areas in central BC where cow Moose survival has been monitored since February 2012 in the Bonaparte study area and December 2013 in the other four study areas. The areas were selected to encompass a range of land cover types and disturbance levels. 1
Figure 2. Aerial view of the Big Creek study area, February 2015 (Photo: Gerald Kuzyk). 4
Figure 3. Aerial view of the Entiako study area and a portion of the 2014 Chelaslie fire, March 2014 (Photo: Conrad Thiessen). 4
Figure 4. Feral horses observed near the Big Creek Study area, January 2013 (Photo: Gerald Kuzyk). 5
Figure 5. Wildlife Biologist Chris Procter preparing to deploy a dart during Moose capture in the Bonaparte study area, winter 2013 (Photo: Chris Procter). 6
Figure 6. Wildlife Biologist Chris Procter obtaining a blood sample from a cow Moose in the Bonaparte study area, January 2016 (Photo: Gerald Kuzyk). 7
Figure 7. Wildlife Biologist Chris Procter fitting a GPS radio-collar to a captured Moose in the Bonaparte study area while Provincial Wildlife Veterinarian Helen Schwantje draws blood, January 2015 (Photo: Chris Procter). 8
Figure 8. A radio-collared cow with her calf observed during a calf survey in the Prince George South study area in March 2016. The calf shows a moderate to heavy level of winter tick infestation (Photo: Michael Klaczek). 9
Figure 9. Age class summary of 332 cow Moose radio-collared in central BC from February 2012 – 30 April 2016 with ages estimated by tooth wear patterns. Young Adult Moose were estimated to be 1.5–3.5 years old, Adults as 4.5– 7.5 years old, and Old as 8.5–14.5 years old. 11
Figure 10. Summary of body condition scores of 292 cow Moose radio-collared in central BC from February 2012 – 30 April 2016. Condition scores were assessed using external physical traits modified from Franzmann et al 1977. 12
Figure 11. Calf status of 293 radio-collared cow Moose at time of capture in central BC from February 2012 – 30 April 2016. 12
Figure 12. Probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2016. 13
Figure 13. Wildlife Biologist Pat Dielman conducting a mortality-site investigation on a radio-collared cow Moose killed by Cougar in the Big Creek study area, February 2016 (Photo: S. Sellars). 14
Figure 14. A mortality-site investigation within the Prince George South study area that occurred approximately two days after the cow Moose died, April 2016. The proximate cause of death was apparent starvation potentially advanced by winter tick infestation (Photo: Doug Heard). 14
Figure 15. Accidental death of radio-collared cow Moose in Big Creek study area. Cause of death was myopathy resulting from intense muscle activity struggling in deep m ud, April 2016 (Photo: Becky Cadsand). 15
Figure 16. Wildlife Biologist Heidi Schindler conducting a mortality-site investigation of a wolf-killed cow Moose in the Entiako Study area, April 2016 (Photo: Conrad Thiessen). 16

LIST OF TABLES

Table 1. Description of landscape features and large mammals in five provincial Moose research study areas in central BC where cow Moose survival has been monitored since February 2012 in the Bonaparte study area and December 2013 in the other four study areas. 3
Table 2. Total number and status of GPS radio-collars deployed on Moose in five study areas in centralBC from February 2012 – 30 April 2016. 9
Table 3. Number and status of GPS radio-collars deployed on Moose in each study area in central BC from February 2012 – 30 April 2016. 10
Table 4. Programmed fix rates for GPS radio-collars deployed on Moose in each study area in central BC from February 2012 – 30 April 2016. 10
Table 5. Fix-rate success for Vectronic GPS radio-collars deployed in this study from collar deployment through 30 April 2016. Collars record one or two locations each day. 11
Table 6. Number of mortalities and probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2016.. 13
Table 7. Survival rates of radio-collared cow Moose in central BC from February 2012 – 30 April 2016. 15
Table 8. Calf surveys to determine calf status of radio-collared cow Moose in central BC f rom February 2012 – 30 April 2016.. 15

LIST OF APPENDICES

Appendix A. Tooth wear index from Passmore et al. (1955) used to estimate moose age for captured cow moose in central BC... 22
Appendix B. Body Condition Index modified for this project from Franzmann (1977) used to estimate body condition in of adult cow moose captured in central BC......................... 23
Appendix C. Definitions of probable causes of proximate moose mortality in central BC. 24
Appendix D. Mortality site investigation form used to assess cause of mortality for Moose in Central BC (revised April 2016)... 25

1. INTRODUCTION

Surveys conducted by regional wildlife biologists within the last decade suggest that Moose population declines of 50–70% had occurred in some areas of interior BC while populations in other areas were stable or increasing (Kuzyk 2016). The declines in Moose abundance within central BC coincided with a mountain pine beetle (MPB) outbreak (Alfaro et al. 2015) and subsequent increased levels of pine tree mortality, salvage harvesting of beetle-killed timber, and road building; landscape changes that have the potential to influence the distribution and abundance of Moose, hunters and predators (Janz 2006; Ritchie 2008). In response to the Moose decline, BC Ministry of Forests, Lands and Natural Resource Operations and its partners initiated a 5-year (December 2013–March 2018) provincially coordinated Moose research project (Kuzyk and Heard 2014). A Moose study with similar objectives began in February 2012 on the Bonaparte Plateau north of Kamloops and was integrated as one of the five study areas in this project (Figure 1, Table 1). The Ministry is collaborating with other wildlife studies in BC that include Moose (e.g., Sittler and McNay 2015).

The key objective of this research project is to test the landscape change hypothesis that assumes Moose survival will increase when: a) forestry cutblocks regenerate to the point where vegetation obstructs the view of predators and hunters; b) resource roads created for logging are rendered impassable due to deactivation or forest ingrowth; and c) Moose become more uniformly dispersed on the landscape (Kuzyk and Heard 2014). In testing this landscape change hypothesis, we assume cow Moose survival has a greater effect on population growth than calf survival (Gaillard et al. 1998), and thus, are directly monitoring radio-collared cow Moose. We acknowledge this assumption may be incorrect (Kuzyk and Heard 2014).

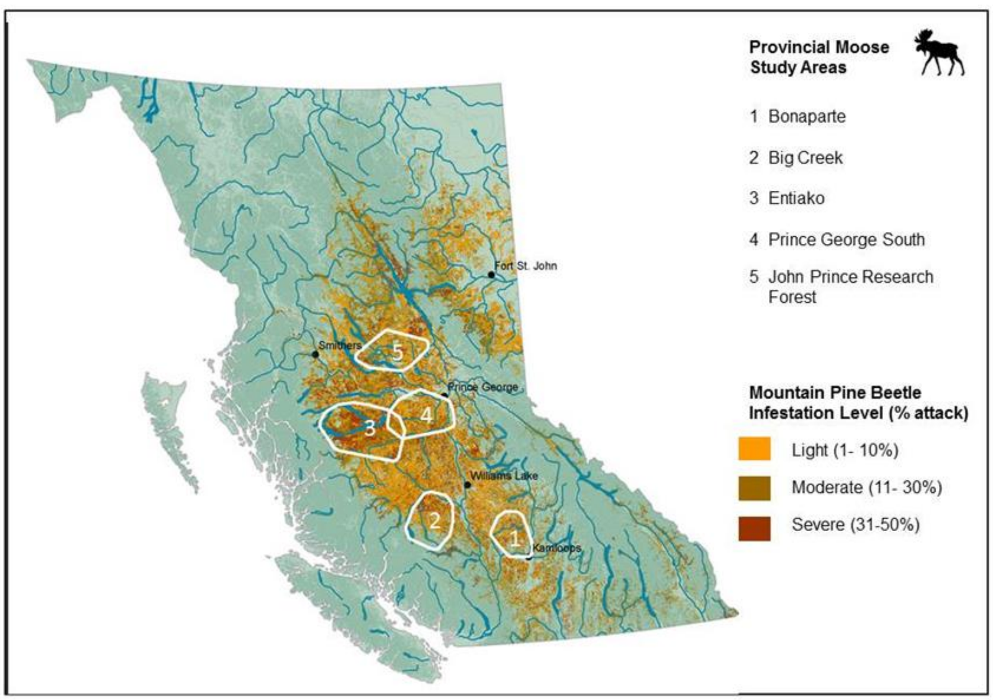


Figure 1. Provincial Moose research study areas in central BC where cow Moose survival has been monitored since February 2012 in the Bonaparte study area and December 2013 in the other four study areas. The areas were selected to encompass a range of land cover types and disturbance levels.

Although financial and logistical limitations have prevented direct monitoring of calves, we are indirectly assessing the survival of calves through late winter calf surveys of radio-collared cows. Our research approach has been to monitor survival of at least 30 GPS radio-collared cow Moose in each of five study areas (n = 150 annually) for five years (i.e. to March 2018). This 2016 progress report provides an update on fieldwork and preliminary results from February 2012 – 30 April 2016 and recommends future research directions, including expansion of the project to evaluate the role of Moose calf and yearling survival on population growth.

2. STUDY AREA

This research project is being 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 and 1500 m above sea level and is 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, range in size from 6700 to over 18,000 km^2 (Table 1). Logging is the primary resource land-use (see Figure 2 for example of logging disturbance within a study area), with a recent increase in salvage logging activity due to a large-scale MPB outbreak occurring during the 2000s (Alfaro et al. 2015). In addition to MPB occurrence as a primary natural disturbance, fire has occurred to some degree and at various time intervals in each study area including the extensive 2014 Chelaslie Fire (~13,000 hectares) in the Entiako study area (see Figure 3 for an example of the burn within this study area). Natural variations in the dominant forest types, severity of the MPB attack, (both within and among study areas), and differences in the extent of reserve areas which do not allow logging, results in relative 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, is primarily through resource roads created for logging. Free-ranging cattle (*Bos taurus*) are common in the Bonaparte, Big Creek, and Prince George South study areas, and feral horses (*Equus caballus*) also occur in the Big Creek study area (see Figure 4).

The Interior Plateau supports a diversity of wildlife species, including a range of large mammals: Moose, Elk (*Cervus canadensis*), Mule Deer (*Odocoileus hemionus*), White-tailed Deer (*Odocoileus virginianus*), Caribou (*Rangifer tarandus*), Grey Wolf (*Canis lupus*), Grizzly Bear (*Ursus arctos*), Black Bear (*Ursus americanus*) and Cougar (*Felis concolor*) which all 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, are the primary ungulate in all study areas. At the initiation of the study in 2014, Moose densities ranged from 250–770 Moose/1000 km^2 among study areas (Table 1), with stable Moose populations in three study areas (Bonaparte, Entiako, John Prince Research Forest) and declining Moose populations in two study areas (Big Creek, Prince George South). Moose densities for Prince George South and John Prince Research Forest were 630 and 770 Moose/1000 km^2 (Table 1); these were incorrectly reported in Kuzyk and Heard (2014).

Moose hunting for First Nations food, social and ceremonial needs and licensed hunting (BC residents and non-residents) occurs in all study areas. Licensed Moose hunting in BC is regulated through sex- and age-specific General Open Season or Limited Entry Hunting opportunities, generally managed at the Wildlife Management Unit (WMU) scale. Within their traditional territories, First Nations have the right to harvest Moose for food, social and ceremonial needs within and outside of regulated seasons and sex/age requirements.

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

Study Area/ Region/ Management Unit/ Landform	Landscape Features*	BEC Zones **	Moose Density (2014) ***	Predators ****	Wild Ungulates ****	Domestic/ Feral Ungulates ****
Bonaparte 6776km^2 Region 3 (Thompson), 3-29, 3-30B, Interior Plateau	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Pervasive Mining: Restricted	IDF: 33% SBPS: 23% MS: 22% ESSF: 8% SBS: 7% BG/PP: 7%	430/ 1000km^2	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 9799km^2 Region 5 (Cariboo), 5-04, Interior Plateau/Coast Mountains	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Small Provincial Park: Restricted Agriculture: Restricted Crown Cattle Range: Large Mining: Negligible	SBPS: 48% IDF: 36% MS: 12% ESSF: 3% AT: <1% BG: <1%	251/ 1000km^2	Wolves: M Black Bears: M Cougars: L/M Grizzly Bears: M	Mule Deer: L/M White-tailed Deer: L Elk: N Caribou: N	Cattle: H Domestic Sheep: L Feral Horses: H
Entiako 18,009km^2 Region 6 (Skeena), 6-01, 6-02, Interior Plateau/Coast Mountains	MPB: Pervasive Logging: Small Roads: Small Wildfire (<30yrs): Small Provincial Park: Large Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 48% ESSF: 32% SBPS: 12% AT: 4% MH: 2% CWH: 1% MS: <1%	268/ 1000km^2	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 11,060km^2 Region 7A (Omineca), 7-10 to 7-12, Interior Plateau	MPB: Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Large Mining: Negligible	SBS: 93% ESSF: 7%	630/ 1000km^2	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 9620km^2 Region 7A (Omineca), 7-14, 7-25, Interior Plateau	MPB: Large Logging: Large Roads: Pervasive Wildfire (<30yrs): Negligible Provincial Park: Restricted Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 95% ESSF: 5%	770/ 1000km^2	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

*Estimated proportion of landscape affected: Pervasive = 71-100%, Large = 31-70%, Small = 11-30%, Restricted = 1-10%, Negligible = <1%.

**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).

***Reported Moose densities are calculated from Stratified Random Block (SRB) surveys conducted over winter range in the study areas.

****Relative abundance/density: H = high, M = moderate, L = Low, N = nil or negligible.

Figure 2. Aerial view of the Big Creek study area, February 2015 (Photo: Gerald Kuzyk).

Figure 3. Aerial view of the Entiako study area and a portion of the 2014 Chelaslie fire, March 2014 (Photo: Conrad Thiessen).

Figure 4. Feral horses observed near the Big Creek Study area, January 2013 (Photo: Gerald Kuzyk).

3. METHODS

We describe details of the research approach and field methods to monitor cow Moose survival in Kuzyk and Heard (2014) and Kuzyk et al. (2015). We captured cow Moose between December and March using either aerial net gunning and physical restraint or chemical immobilization by aerial delivered dart. 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 60 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). We examined and sampled captured Moose according to a standard protocol that included assessing for: age class using tooth wear as an index (Passmore et al. 1955; Appendix A), body condition modified for this project from Franzmann et al. 1977 (Appendix B), external parasite presence and prevalence, and presence of calves. From each Moose, we drew 20 to 35 ml of blood and collected serum for progesterone levels and serological screening. We also obtained fecal samples for parasitological assessment. Each Moose was ear-tagged with a unique identifier, and a 6 mm punch biopsy of the ear was air-dried and archived for genetics. We also collected at least 30, but generally more, hairs with roots from each Moose for genetic or other studies.

We assessed pregnancy status of 313 collared cows from which serum samples were collected. Serum from a subsample of Moose captured from 2014/15 and from all Moose captured in 2015/16 was analyzed for both serum progesterone and protein B levels. These dual pregnancy status assessments were used to further investigate the interpretation of pregnancy status. Serum was also screened for antibodies for Johne's disease, Neospora, Bovine Viral Diarrhea virus, and Parainfluenza 3 virus. A subsample of hair was used for preliminary assessment of stress through cortisol levels. Remaining serum was archived for future analyses.

Each Moose was fitted 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) (See figures 5 through 7 for images illustrating capture and sampling methods). Study area-specific research objectives directed the trade-off between collar fix-rate acquisition and battery life. For example, we chose to mainly deploy lower fix-rate radio-collars (one location per day) at the outset of this study because the main objective was survival monitoring; in this case, collar batteries would last for the duration of the study, thus not requiring recapture of the same Moose. Conversely, we deployed a subset of collars with multiple fixes per day in the Bonaparte and Entiako study areas where the objectives were tomonitor survival as well as examine fine-scale habitat selection and movements. Fix-rate success was evaluated for collars active on 30 April 2016 (initial deployment dates varied from January 2013–February 2016). Unsuccessful fixes occurred when the collar was unable to obtain a GPS fix and/or transfer the location data for remote download. GPS positions stored on the collar but not successfully uploaded are directly downloaded from recovered collars (i.e., following a Moose mortality or recovery of a failed collar).

The radio-collars contain an internal tip switch to detect animal movement rates, and are programmed to send a mortality alert via email and text message if no movement is detected for a sustained period of time (4–12 h). In some instances, however, including predation events where the collar is moved by the predator feeding, the collar may remain in sufficient motion post-mortality to prevent the mortality signal from being triggered. For these cases, an Excel macro was developed by M. Gillingham that examines each individual animal's location data and identifies movement and collar performance

Figure 5. Wildlife Biologist Chris Procter preparing to deploy a dart during Moose capture in the Bonaparte study area, winter 2013 (Photo: Chris Procter).

patterns that may be indicative of potential mortalities. Collar movements that might be associated with a mortality but for which an 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 as a potential mortality through assessment of recent movement data as detailed above, we conducted mortality-site investigations as soon as logistically feasible, typically within 24–48h. We determined the probable cause of proximate mortality following a standardized protocol (Kuzyk and Heard 2014), and continual to refine the cause of mortality definitions as new circumstances arise (Appendix C). The most recent update to the mortality investigation data sheet was in April 2016 (Appendix D).

Annual survival rates were calculated for cow Moose from 28 February 2012 – 30 April 2016. Due to small sample sizes, we calculated survival rates by pooling survival of individual Moose across all study areas, rather than by individual study area. Survival analysis and mortality summaries included only cow Moose that lived more than three weeks post-capture to avoid the potential bias or effects of capture-related stresses and physiological changes on survival (Keech et al. 2011). Survival rates were monitored weekly and summarized by biological year (1 May–30 April) using a Kaplan-Meir estimator (Pollock et al. 1989). We started the biological year on May 1, the time immediately prior to an average time of parturition for Moose in northern (Gillingham and Parker 2008) and southern British Columbia (Poole et al. 2007).

Figure 6. Wildlife Biologist Chris Procter obtaining a blood sample from a cow Moose in the Bonaparte study area, January 2016 (Photo: Gerald Kuzyk).

To assess calf survival in the late winter (mid-February to late March), we located collared cow Moose 1) that had one or two calves present when collared earlier in the winter; 2) for which there was uncertainty in whether they had a calf present when collared earlier in the winter because they were in a mixed group of cows and calves; 3) that were collared in previous years; and 4) whose fine-scale movement data (if available) suggested that they were parturient (Figure 8). 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.

4. RESULTS

4.1 GPS Radio-collars and Fix-rate Success

From February 2012 – 30 April 2016, we captured and radio-collared 336 cow Moose (Table 2 and 3; 203 captured by aerial darting and 133 captured by aerial net gunning). In the five study areas, there were 99 collars that collected more than two positional fixes/day, 90 collars that collected two fixes/day and 147 collars that collected one fix/day (Table 4). Fix-rate success varied by study area, collar type, and fix-rate programming (Table 5). For the 105 collars collecting one fix/day, fix-rate success averaged 69% (range 32–96%; Table 5), while the 84 collars collecting two fixes/day averaged 85% (range 45–98%; Table 5).

Figure 7. Wildlife Biologist Chris Procter fitting a GPS radio-collar to a captured Moose in the Bonaparte study area while Provincial Wildlife Veterinarian Helen Schwantje draws blood, January 2015 (Photo: Chris Procter).

Table 2. Total number and status of GPS radio-collars deployed on Moose in five study areas in central BC from February 2012 – 30 April 2016.

Study Year	Deployed Collars	Mortalities	Failed Collars	Active Collars
2012	9	0	0	9
2012–2013	29	2	0	36
2013–2014	129	5	27	133
2014–2015	69	11	15	176
2015–2016	100	31	26	219
Totals	**336**	**49**	**68**	**219**

Fix-rate success for 10 multi-fix radio-collars in the Entiako study area from 1 January 2014–26 December 2015 was 96% (range 90–98%) and 80 multi-fix radio-collars in the Bonaparte study area from 4 March 2012–31 March 2016 was 96% (range 75–100%). Directly downloading of location data from 23 recovered collars enabled us to acquire an average of 12% more location fixes (range 0-30%), resulting in increased fix-rate success of these collars. We considered collars to have failed when they stopped collecting location data due to collar malfunction, low battery, or when they physically slipped from the Moose due to incorrect collar fit.

Figure 8. A radio-collared cow with her calf observed during a calf survey in the Prince George South study area in March 2016. The calf shows a moderate to heavy level of winter tick infestation (Photo: Michael Klaczek).

Table 3. Number and status of GPS radio-collars deployed on Moose in each study area in central BC from February 2012 – 30 April 2016.

Study Area	Study Year	Deployed Collars	Mortalities	Failed Collars	Active Collars
Bonaparte	2012	9	0	0	9
	2012–2013	29	2	0	36
	2013–2014	14	3	27	20
	2014–2015	30	2	7	41
	2015–2016	36	7	7	63
	Totals	**118**	**14**	**41**	**63**
Big Creek	2013–2014	40	0	0	40
	2014–2015	13	3	8	42
	2015–2016	5	6	2	39
	Totals	**58**	**9**	**10**	**39**
Entiako	2013–2014	44	0	0	44
	2014–2015	9	4	0	49
	2015–2016	17	9	17	40
	Totals	**70**	**13**	**17**	**40**
Prince George South	2013–2014	16	0	0	16
	2014–2015	17	2	0	31
	2015–2016	16	6	0	41
	Totals	**49**	**8**	**0**	**41**
John Prince	2013–2014	15	2	0	13
Research Forest	2014–2015	0	0	0	13
	2015–2016	26	3	0	36
	Totals	**41**	**5**	**0**	**36**

Table 4. Programmed fix rates for GPS radio-collars deployed on Moose in each study area in central BC from February 2012 – 30 April 2016.

Study Area	>2 Fixes/Day	2 Fixes/Day	1 Fix/Day
Bonaparte	82	36	0
Big Creek	0	5	53
Entiako	17	15	38
Prince George South	0	16	33
John Prince Research Forest	0	18	23
Totals	**99**	**90**	**147**

Table 5. Fix-rate success for Vectronic GPS radio-collars deployed in this study from collar deployment through 30 April 2016. Collars record one or two locations each day.

Study area	Number of Collars	Fix Schedule (Locations per Day)	Number of Collars per Fix Schedule	Fix Rate			
				Mean (%)	SE	Min (%)	Max (%)
Bonaparte	33	1	0	0	0	0	0
		2	33	92	0.6	84	97
Big Creek	39	1	34	83	1.8	43	96
		2	5	94	0.3	94	96
Entiako	40	1	28	70	2.2	46	87
		2	12	93	7.5	88	96
Prince George South	41	1	25	64	0.2	43	82
		2	16	85	2.2	68	98
John Prince Research Forest	36	1	18	61	3.9	32	90
		2	18	60	2.3	45	78

4.2 Capture and Handling

Of the 336 cow Moose captured to date, we assessed 332 for age via tooth wear patterns (Figure 9), with 81% (n = 268) classified as adults (4.5 – 7.5 years old), 16% (n = 53) as old (8.5 – 14.5 years old) and 3% (n = 11) as young (1.5 – 3.5 years old). We assessed body condition according to a standardized protocol for 292 of the animals of which 69% (n = 203) were in good body condition, 21% (n = 61) were in excellent body condition, 9% (n = 25) were in fair body condition, and only 1% (n = 3) of cows in poor body condition (Figure 10). Of the 293 cow Moose for whom calf status at capture was recorded, 68% (n = 198) were not accompanied by a calf, 32% (n = 93) had one calf and <1% (n = 2) had twins (Figure 11).

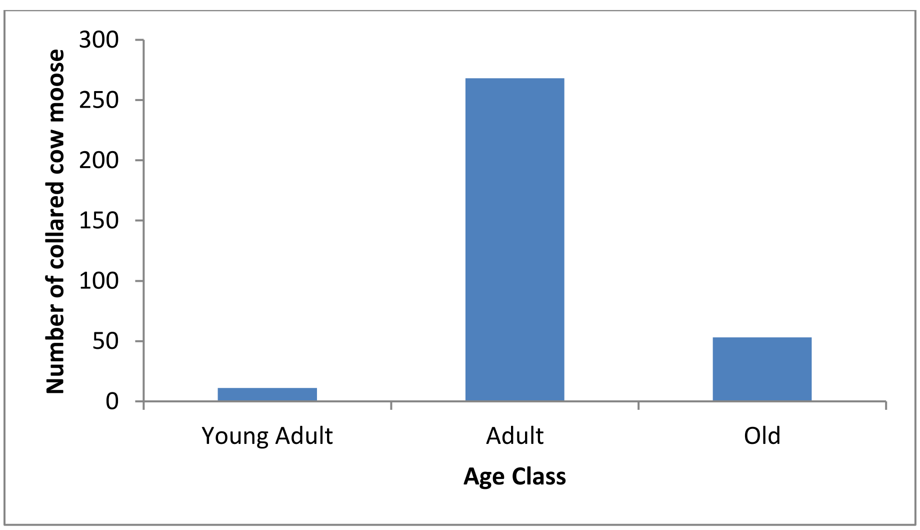


Figure 9. Age class summary of 332 cow Moose radio-collared in central BC from February 2012 – 30 April 2016 with ages estimated by tooth wear patterns. Young Adult Moose were estimated to be 1.5–3.5 years old, Adults as 4.5– 7.5 years old, and Old as 8.5–14.5 years old.

4.3 Biological Samples

Pregnancy determination is a key parameter for Moose health analysis. Laboratories used for the analyses confirmed that there was some degree of uncertainty using progesterone levels to diagnose pregnancy in cow Moose with lower levels of progesterone. Investigation into the interpretation of pregnancy results is ongoing in light of this uncertainty and due to variability in pregnancy diagnostic thresholds used by other jurisdictions, and calf survey results.

Serological screening of captured animals indicated minimal exposure to pathogens in the standard screening panel, and no significant

Figure 10. Summary of body condition scores of 292 cow Moose radio-collared in central BC from February 2012 – 30 April 2016. Condition scores were assessed using external physical traits modified from Franzmann et al 1977.

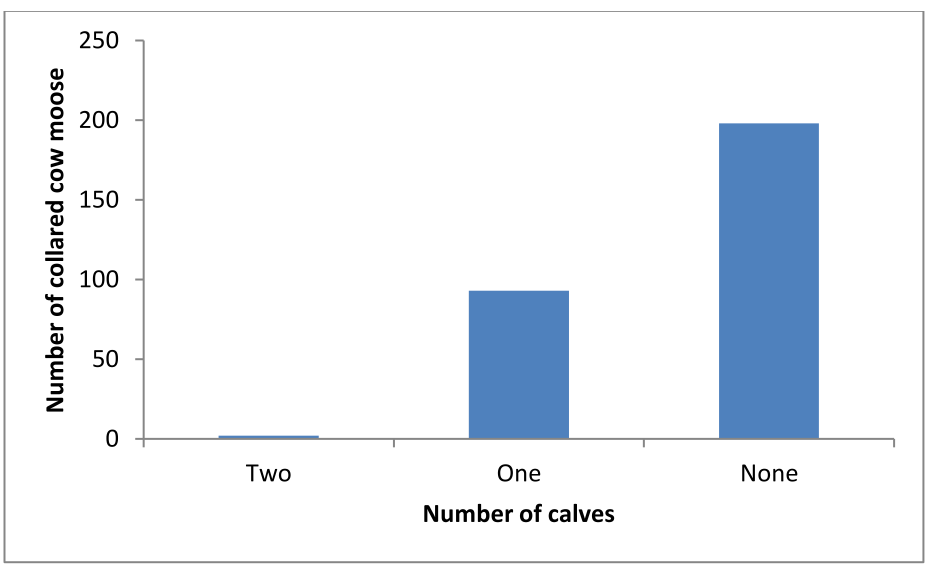


Figure 11. Calf status of 293 radio-collared cow Moose at time of capture in central BC from February 2012 – 30 April 2016.

Table 6. Number of mortalities and probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2016.

Study Area	Mortalities	Probable Proximate Cause of Death
Bonaparte	14	1 predation (1 wolf), 5 hunting (1 licensed, 4 unlicensed), 8 health-related (3 apparent starvation, 1 septicemia, 4 unknown health-related)
Big Creek	9	4 predation (3 wolf, 1 Cougar), 2 hunting (2 unlicensed), 2 health-related (1 apparent starvation, 1 septicemia), 1 natural accident
Entiako	13	9 predation (8 wolf, 1 bear), 4 unknown
Prince George South	8	3 predation (2 wolf, 1 Cougar), 1 hunting (1 unlicensed), 4 health-related (apparent starvation)
John Prince Research Forest	5	4 predation (4 wolf), 1 hunting (1 unlicensed)
Totals	**49**	**21 predation (18 wolf, 2 Cougar, 1 bear), 9 hunting (1 licensed, 8 unlicensed), 14 health-related (8 apparent starvation, 2 septicemia, 4 unknown health-related), 1 natural accident, 4 unknown**

internal parasite species or infection intensity. Winter ticks (*Dermacentor albipictus*) did cause a range of overt effects in Moose, such as significant hair loss and loss of body condition. No direct assessments of blood loss from ticks were done, and collected ticks have been archived for future investigation into their potential role as vectors for infectious diseases.

4.4 Mortalities of Radio-collared Moose

Forty-nine of the 336 radio-collared cow Moose died from February 2012 – 30 April 2016 (Table 6; Figure 13). Probable proximate causes of death (see Appendix C) were 43% from predation, 16% unlicensed hunting, 2% licensed hunting, 16% apparent starvation, 4% septicemia, 8% unknown health-related, 2% natural accident, and 8% unknown (Table 6; see Figures 12-16 for images from mortality investigations.

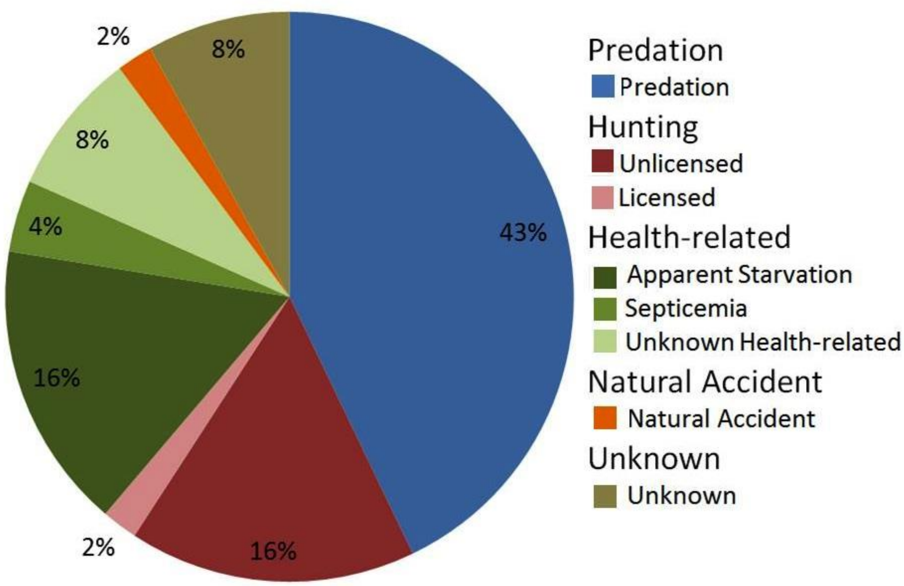


Figure 12. Probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2016.

Figure 13. Wildlife Biologist Pat Dielman conducting a mortality-site investigation on a radio-collared cow Moose killed by Cougar in the Big Creek study area, February 2016 (Photo: S. Sellars).

Figure 14. A mortality-site investigation within the Prince George South study area that occurred approximately two days after the cow Moose died, April 2016. The proximate cause of death was apparent starvation potentially advanced by winter tick infestation (Photo: Doug Heard).

Table 7. Survival rates of radio-collared cow Moose in central BC from February 2012 – 30 April 2016.

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

Table 8. Calf surveys to determine calf status of radio-collared cow Moose in central BC from February 2012 – 30 April 2016.

Study Area	# Calves/100 Cows in Late Winter (n=# collared cows, month of survey)		
	2014	2015	2016
Bonaparte	not surveyed	25/100 (n=40, Mar)	26/100 (n=68, Mar)
Big Creek	28/100 (n=41, Mar)	37/100 (n=43, Feb)	33/100 (n=43, Mar)
Entiako	not surveyed	not surveyed	14/100 (n=44, Mar)
Prince George South	not surveyed	39/100 (n=18, Mar)	27/100 (n=44, Mar)
John Prince Research Forest	not surveyed	8/100 (n=13, Feb)	17/100 (n=36, Mar)

Figure 15. Accidental death of radio-collared cow Moose in Big Creek study area. Cause of death was myopathy resulting from intense muscle activity struggling in deep mud, April 2016 (Photo: Becky Cadsand).

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.

4.5 Annual Survival Rates

From 2012 to 2016, the annual survival rate from all radio-collared cow Moose varied from 86–100% (Table 7). It should be noted that sample size was small in 2012, and therefore of limited reliability for this survival estimate.

4.6 Late Winter Calf Surveys

From 2014–2016, we conducted a total of 10 late winter (February and March) Moose calf surveys to determine survival rates of calves associated with the radio-collared cows. Results varied among study areas with calf/cow ratios ranging from 8–39 calves/100 cows (Table 8).

5. DISCUSSION

5.1 Data Collection – Biological Data

To date, we have monitored cow survival by deploying radio-collars on at total of 336 cow Moose in five study areas. At the time of capture, the majority of cow Moose were assessed to be in fair to excellent body condition (only 1% in poor condition) and predominately mid-aged adults (only 16% classed as old and 3% young). The calf ratio at capture (32 calves/100 cows) was similar to calf ratios found during comprehensive composition surveys in or near our study areas suggesting that our collared Moose sample is representative of the general population.

Capture methods and protocols used during this project are continually re-evaluated and refined over time by the project team to ensure that we are using the most humane and effective methods possible and capitalizing on the opportunity to collect meaningful biological samples while the animal is immobilized or restrained. The recent development of models and findings in wildlife health assessments of wild cervid species in BC

Figure 16. Wildlife Biologist Heidi Schindler conducting a mortality-site investigation of a wolf-killed cow Moose in the Entiako Study area, April 2016 (Photo: Conrad Thiessen).

and elsewhere has underlined a need to adjust and investigate more detailed measures of Moose health in the BC interior, including the impact of winter ticks and factors leading to poor body condition. The bacteria *Erysipelothrix rhusiopathiae* was identified in one of six research Moose samples analyzed to date. This has initiated collaborative work to further understand whether this organism is widespread and its role, if any, in wild BC cervid populations.

This recent emphasis on the importance of 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 collection of biological samples and documentation of information. Examples of this include the recent use and evaluation of BAM II as an alternative immobilization drug, and a recently established protocol to collect blood samples during mortality-site investigations to further inform the role of health factors as contributing to mortalities.

5.2 Data Collection – Radio-collar Data

Over the course of the project, we have used a variety of GPS radio-collar types and fix-rate schedules. It is important to evaluate radio-collar performance because 1) radio-collars are the primary tool used to monitor cow survival, so it is important to determine their efficacy and 2) it helps inform the future selection of collar types and programming methods. The lowest fix-rate success was observed for single-fix collars (one fix/day) and the highest rates of fix-rate success were observed in the collars programmed to acquire up to 16 fixes/day. Apart from increased fix-rate success, higher fix-rate collars provide detailed location data that can be used to examine behaviors linked to finer scale movements such as timing and rates of parturition (Poole et al. 2007) and assessing time of death when a delay occurs in sending mortality notices. Conversely, lower fix-rate collars have a significantly longer battery life (~ 5 years) relative to the higher fix-rate collars (~2-3 years); as such, while they may have lower fix-rate success, the period over which they collect data to assess survival is longer, which has been the primary objective of the research to date.

An important finding from 2015/16 was the improved performance of radio-collars with two fixes/day (average fix success rate of 85%) compared to single fix collars (average fix success rate of 69%). These two fix/day collars may therefore optimize the trade-off between data acquisition and collar battery longevity; however, because two fix/day collars were only deployed in the winter of 2015/16, continued monitoring is needed to reliably assess performance over a more representative period of time (M. Scheideman, University of Northern British Columbia, unpublished data). It is also important to note that the fix-rate success metrics reported are for data that has been remotely downloaded from satellite while collars are still on the animals. Direct download of recovered collars have provided an average of 12% more location fixes (range 0-30%) compared to what was remotely communicated to satellite from the same collar. These additional data are critical to future analyses and highlight the need to recover collars identified as having low fix-rate success via remote satellite download.

5.3 Survival of Collared Cows

The survival rates of radio-collared cow Moose range from 92 ± 5% in 2014/15 to 86 ± 5% in 2015/16. These survival rates are within the range expected for stable Moose populations (Bangs et al. 1989; Ballard et al. 1991; Bertram and Vivion 2002), and exceed the survival rates determined for adult cow Moose in areas of Northwest Territories (85%; Stenhouse et al. 1995) and northern Alberta (75–77%; Hauge and Keith 1981). The probable proximate cause of death of radio-collared Moose have been variable within and among study areas and include predation (wolves, bears, and Cougars), health-related issues (apparent starvation, septicemia), hunting, as well as natural accidents (getting mired in a wetland). Information and samples collected during mortality-site investigations helped inform the ultimate cause of death in some cases. For example, a cow Moose in the Big Creek study area died from septicemia, presumably initiated by a Grey Wolf attack four days prior. This Moose survived the attack but her wounds became severely infected. In this case, the proximate (or direct) cause of death was septicemia but the wolf attack played an initiating (or indirect) role in the ultimate cause of death. Further testing of samples collected from Moose during captures and mortalities may provide insight on pre-existing health conditions or other health indicators that may play a role in ultimate causes of death. At this time, there are an insufficient number of mortalities to draw reliable conclusions on the relative impacts of different probable causes of death on survival rates and Moose population growth.

The comprehensive survival analysis work at UNBC is scheduled to begin in May of 2017 rather than in spring of 2018, in part, due to increasing pressures around Moose management in BC (Kuzyk 2016). Broadly, this analysis will involve two approaches. It will characterize the survival of Moose (relative to collared Moose that die) with respect to a range of biotic, landscape, and anthropogenic features in order to identify those management actions that might best improve the survival of Moose within the study areas. In addition, we anticipate using a logistic regression and information theoretic approach (collared Moose that survive versus those that die) to determine if functional responses of Moose may be interacting with manageable anthropogenic factors influencing Moose survival. In these latter analyses, we will determine what temporal (e.g., previous days, weeks, months) and spatial scales best distinguish between Moose that survive and those that do not. Complementary to this comprehensive survival analyses, analysis of habitat selection of radio-collared Moose is currently underway at UNBC (Big Creek, Entiako, Prince George South study areas) and the University of Victoria (Bonaparte study area). John Prince Research Forest intends to investigate seasonal migrations of collared cows and fine-scale winter occupancy patterns.

5.4 Calf Surveys of Collared Cows

Seven of the 10 late winter calf surveys had calf/cow ratios at or above 25 calves/100 cows, which generally indicates stable Moose populations in areas with multiple predators (Bergerud and Elliot 1986). Six of 10 calf surveys had ratios of 27–39 calves/100 cows which are within the range of calf survival required to maintain a sustainable harvest of Moose populations (i.e., >25 calves/100 cows; FLNRO 2015). Calf survival varies annually even within stable populations for a variety of reasons including the severity of winter weather, predation levels, winter tick infestation levels, exposure to disease, appropriate nutrition, and habitat condition (Gaillard et al. 1998; Murray et al. 2006). Caution should be used when interpreting calf survey results in this study due to the relatively small number of cows monitored and short time frame for surveys from one to three winters.

6. FUTURE RESEARCH DIRECTION

Our research to date has provided a better understanding of factors affecting cow Moose survival. However, our work has also highlighted two important research gaps that should be examined in order to gain a more comprehensive understanding of Moose population change in central BC. Our recommendations for future work to address these research gaps are:

Continue Monitoring Cow Survival Indefinitely – This project is currently in its 4th year with ~240 radio-collared cow Moose active in five study areas. Results to date from tracking collared cows have provided valuable insights to the causes of Moose mortality including the importance of factors other than predation and hunting that affect Moose survival (i.e., health-related deaths including apparent starvation; see Figure 5, Table 6). Gaining a better understanding of health-related deaths and other measures of population health (Murray et al. 2006) warrant continued monitoring with an increased emphasis on potential population effects. Variation in ultimate causes of mortality among study areas highlights the differences in potential mechanisms of population regulation and appropriate management responses. We advocate funding of this core project be continued for a minimum of five years past its intended end date (1 April 2018 – 31 March 2023) but recommend continuing indefinitely. Academic institutions have been invaluable contributors to this research project to date, and we encourage continued collaboration with universities. Benefits of long-term monitoring of cow Moose include: 1) assessment of temporal variation in causes and rates of cow Moose mortality and relationships with environmental variation; 2) provision of information to monitor population trends and data inputs to improve the development of population models used to monitor Moose populations and determine sustainable harvest levels; and 3) provision of information essential to evaluating the effectiveness of future Moose population management decisions both within and outside the study areas. Continuation of the study may also provide opportunities to experimentally assess effectiveness of enhancement strategies.

Assess Moose Calf and Yearling Survival/Behavior – The importance of assessing calf survival has been highlighted in the Moose research design (Kuzyk and Heard 2014) and the 2015 progress report (Kuzyk et al. 2015), and is reflected in these recent 2015/16 preliminary results. The role of Moose calf and yearling survival affecting population growth in all our study areas remains unknown. In some study areas calf/cow ratios were at or below those required to maintain a stable population while in others, ratios reported were within ranges for Moose populations experiencing both wolf and bear predation (Gasaway et al. 1992). In some study areas, inventory data also suggests that calf/cow ratios were consistently lower now than rates typically observed 10-20 years ago, providing further evidence that calf survival may be an important component of Moose population change. Expanding the scope of the current Moose research project to include monitoring calf and yearling survival would enable a better understanding of causes and rates of mortality, factors that contribute to vulnerability, baseline health information on young Moose, and estimates of true juvenile recruitment (i.e., survival to breeding age). An improved understanding of these factors influencing Moose calves and yearlings will provide additional information to inform Moose population management decisions. Benefits of evaluating rates and causes of female Moose calf and yearling mortality include: 1) assessment of variation in mortality factors and survival rates for calves and yearlings; 2) estimates of true juvenile recruitment; and 3) introduction of known aged animals into the survival analyses as surviving yearlings could be recaptured and added to the research program as adult females. Future modeling efforts may also help understand the role of calf and yearling Moose survival in our study areas.

7. LITERATURE CITED

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

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

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

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

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

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

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

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

Gasaway W.C., R.D. Boertje, D.V. Grangaard, D.G. Kelleyhouse, R.O. Stephenson, and D.G. Larsen. 1992. The role of predation in limiting moose at low densities in Alaska and Yukon and implications for conservation. Wildl. Monogr. 120:3–59.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shackleton, D. 1999. Hoofed mammals of British Columbia. Royal B.C. Mus. Handbook. The Mammals of British Columbia, Vol. 3. Univ. B.C. Press, Vancouver, BC.

Sittler, K.L., and R.S. McNay. 2015. Peace-Williston Moose Limiting Factors Investigation: Progress Report December 2015 – March 2016. Wildlife Infometrics Inc. Rep. No. 524. Wildlife Infometrics Inc., Mackenzie, BC.

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

Appendix A. Tooth wear index from Passmore et al. (1955) used to estimate moose age for captured cow moose in central BC.

AGE CLASS ESTIMATE (Tooth wear)		
AGE CLASS	**AGE EST**	**DESCRIPTION OF TOOTH WEAR**
YOUNG ADULT	1.5	Permanent teeth in place. Cheek teeth are visible in lower jaw. Third premolar may still have 3 cusps.
	2.5	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.
	3.5	Lower jaw has now elongated. Last cusp of third molar no longer cradled in lower jaw. Dentine now wider than enamel.
ADULT	4.5 5.5 6.5 7.5	Wear on lingual crest and cupping of molars becomes increasingly pronounced.
AGED	8.5	Pit (infundibula) of 1st molar completely worn.
	9.5 10.5 11.5 12.5 13.5 14.5	Pit (infundibula) of 3rd premolar completely worn.

Appendix B. Body Condition Index modified for this project from Franzmann (1977) used to estimate body condition of 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 Franzmann score 6 are evident.
1	4	All three of the characteristics in Franzmann score 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 causes of proximate moose mortality in central BC.

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

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

BC MOOSE RESEARCH - MORTALITY INVESTIGATION FORM

Date:______________ Date of Mortality (signal):______________ Days elapsed since death: ________

Found dead ☐ or Euthanized ☐ Method of Euthanasia:____

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 (Tracks, Scat, Blood, Signs of Struggle, etc)

____

____

____

____

____

____

____

____

Snow Crust: ☐Heavy ☐ Light ☐Fluffy; Snow Depth (cm): _______ Sinking Depth (cm) ______; ☐no snow

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

Carcass Location	Carcass Condition	Carcass State	Body Condition	Skin / Hair Coat
☐ In Open	☐ Fresh	☐ Intact	☐ Excellent	☐ Normal
☐ Concealed	☐ Frozen	☐ Disarticulated	☐ Good	☐ Hide Inverted
☐ Buried	☐ Decomposed	☐ Scattered	☐ Fair	☐ Missing Hair
☐ ________	☐ __________	☐ Scavenged	☐ Poor	☐ External Parasites
		☐ __________	☐ Emaciated	☐ Abnormal Skin
			☐ Undetermined	☐ Lumps / Warts
				☐ ___________

Discharge / Blood	Diarrhea / Feces	Hoof Condition	Bones / Legs / Joints	Mouth / Teeth
☐ None	☐ None	☐ Normal Wear	☐ Normal	☐ Normal Wear
☐ Mouth	☐ Normal Pellets	☐ Worn	☐ Chewed	☐ Irregular / Worn
☐ Nose	☐ on Tail + Hind-legs	☐ Overgrown	☐ Fractured	☐ Broken
☐ Anus	☐ ___________	☐ __________	☐ Compound	☐ ___________
☐ ___________			☐ __________	

Calf/fetus present? Y / N, dead or alive?

Comments / Details / If animal was found alive, describe symptoms (recumbant, circling, vocalizing, aggessive, dull, etc.)

____

____

____

____

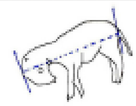
____

INTERNAL - Record all abnormalities, collect samples and take photos

	Normal	Abnormal	Comments
Lungs / Trachea	☐	☐	______________________
Heart	☐	☐	______________________
Muscle	☐	☐	______________________
Liver	☐	☐	______________________
Kidney	☐	☐	______________________
Spleen / Lymph nodes	☐	☐	______________________
Stomachs / 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): _____



Back Fat Depth (mm): __________

Comments/ Details: ____

____

____

CAUSE OF DEATH (check appropriate boxes)

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

Comments (include info on proximate and ultimate COD):

____

____

____

____

____

____

____

____

____

SAMPLES (check if collected)

SAMPLES	STORAGE	REASON for COLLECTION
☐ Long Bone	Freeze	For body condition index (bone marrow fat)
☐ Jaw	Freeze	For size and growth
☐ Teeth*	Freeze	For aging
☐ Head (if Intact)	Freeze	For CWD
☐ Kidney + Fat	Freeze	For body condition index (kidney fat)
☐ Liver (3 x 3 cm)	Freeze	For toxicology
☐ Kidney (3 x 3 cm)	Freeze	For contaminants
☐ Intestines	Freeze	For parasites
☐ Muscle	Formalin	For moose measles / parasites
☐ Muscle	Freeze	
☐ Hair	Dry	Stress testing
☐ Predator DNA swab	Dry	For predator ID
☐ Predator Hair	Dry	For predator ID
☐ Predator Scat	Freeze	For predator ID
☐ Fetus	Freeze	For culture
☐ Placenta (cotyledon)	Freeze	For culture and histology
☐ Repro Tract	Freeze	For culture and histology
☐ Blood	Blood tubes or filter paper	For serology

Ticks: ☐ None Obvious ☐ Few ☐ Moderate ☐ Heavy

Hair Loss: ☐ none ☐ mild (5-20%) ☐ mod. (20-40%) ☐ severe (40-80%) ☐ ghost (>80%)

☐ Photos Taken?

Send Samples to:
Helen Schwantje
2080 Labieux Road
Nanaimo, BC
V9T 6J9, 250-751-3219

*incisor preferred but can use molar if incisor not found