FACTORS AFFECTING MOOSE POPULATION DECLINES IN BRITISH COLUMBIA: UPDATED RESEARCH DESIGN

by

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EXECUTIVE SUMMARY

In response to declining Moose numbers in central British Columbia, the B.C. government initiated a research project in 2013 to determine the factors affecting Moose population change (Kuzyk and Heard 2014). The original research design was developed collaboratively with the Provincial Moose Management Team and benefitted from input, both in writing and in person, from the Provincial Hunting and Trapping Advisory Team. The British Columbia Wildlife Federation and British Columbia Guide Outfitters Association provided detailed comments on earlier versions of the original design. Throughout the project regional information sharing and engagement has occurred at various times and levels with First Nations and stakeholders. Currently, First Nations, other stakeholders and government support the B.C. Moose research project beyond the initial five years to continue providing B.C. specific information to guide Moose management actions. The purpose of this document is to provide our partners and the public with an update to the original research hypothesis (Kuzyk and Heard 2014). It acts as a framework to guide research direction for the provincial Moose research project for the next five years, through identification of seven new research topics. More detailed descriptions of research questions and methods will be developed by professors and graduate students from collaborating academic institutions.

Five study areas were chosen in central B.C. in order to evaluate a landscape change hypothesis proposed by Kuzyk and Heard (2014). The primary research objective of that project was to evaluate the landscape change hypothesis, which stated that Moose declines were in part attributable to a Mountain Pine Beetle (MPB) outbreak where habitat changes and increased salvage logging and road building resulted in greater vulnerability of Moose from hunters and predators. Preliminary results from February 2012 to April 2018 were presented in four annual reports: Kuzyk et al. (2015, 2016, 2017, 2018a).

Causes and rates of mortality for 400 cow Moose were assessed. Although rates varied annually and by study area, with some annual rates below 85% in one study area, survival rates overall were >85%, which is indicative of a stable population. Late winter survival rates of 60 8-month old Moose calves over two years varied from 45 to 75%. Information from population surveys and modelling suggested Moose populations declined in over 70% of their range in B.C., which was consistent with reports from First Nations and stakeholders. Preliminary results from this project, combined with survey/population modelling, suggest calf survival to one year of age may be the key reason for continued Moose population declines.

Due to the high concern over continued Moose population declines, the importance of monitoring cow Moose survival indefinitely has been reinforced for three main reasons: 1) cow Moose are the reproductive component of the population and their survival and calf production are critical to understanding population trends; 2) cow Moose survival and calf recruitment can be used to assess population trends, which is becoming increasingly important with warm winters that do not provide conditions required for aerial population surveys; and 3) we need to understand long term variation in cow Moose survival in relation to other environmental covariates. An unexpected finding was that health related mortalities (including apparent starvation) were the proximate cause of 19% of cow Moose mortalities. This was second to predation mortalities (53%) and more prevalent than harvest mortalities (16%). Health/starvation mortality causes were not recognized as key mortality factors initially in this study. Therefore, we recommend that monitoring cow Moose survival in these five study areas be maintained indefinitely as a long-term research and monitoring project. We recommend this research design be updated every five years to refine our understanding of factors that affect Moose population change, thereby guiding research and informing management recommendations to enhance Moose populations.

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1. INTRODUCTION

In 2013, the Province of British Columbia initiated a research project to determine the factors affecting Moose population change in central British Columbia (B.C.) by testing the landscape change hypothesis (Kuzyk and Heard 2014). This project was initiated because Moose numbers in central B.C. had declined since the early 2000s, causing concern with First Nations and stakeholders. Much of the decline happened concurrently with a Mountain Pine Beetle (MPB; *Dendroctonus ponderosae*) outbreak that killed a large proportion of mature pine trees and resulted in unprecedented salvage logging and road building (Alfaro et al. 2015). Initial review of survey and licensed harvest information found Moose populations in some areas of interior B.C. had declined by 50–70% since the early 2000s, while Moose populations in other areas of the province were stable or increasing (Kuzyk 2016). A recent analysis determined that Moose populations in >70% of their range in B.C. are declining (Kuzyk et al. 2018b). In response to these Moose declines, a 5-year (December 2013–March 2018) provincially-coordinated Moose research project was initiated by the B.C. 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).

The landscape change hypothesis proposed by Kuzyk and Heard (2014) assumed, *a priori*, that cow survival, relative to calf survival, has a greater proportional effect on population growth rates, but they acknowledged this assumption may not be correct (Gaillard et al. 1998; Eberhardt 2002). Bull survival was not considered to be a factor in population declines because bull:cow ratios were at or near objectives (30 bulls:100 cows) in all study areas. The first evaluation of the landscape change hypothesis was to determine cow survival rates. These rates were predicted to decline concurrent with increased salvage logging due to expected increases in harvest and predation mortality. GPS radio collars were placed on 460 individual Moose (400 cows and 60 8-month old calves) and their survival was monitored. Our results were inconsistent with the hypothesis that cow survival would decline as cow survival rates were within the range reported from other stable Moose populations (i.e., >85%) (Kuzyk et al. 2018a). The Bonaparte, Big Creek and John Prince study areas had cow survival >85% in all years, whereas Entiako was below 85% in most years and Prince George South below 85% in two of five years (Kuzyk et al. 2018a).

The second evaluation of the landscape change hypothesis was to determine the proximate cause of death and associated factors leading to mortality of cow Moose (Kuzyk and Heard 2014). It is important to understand the causative factors associated with the decline in Moose numbers in order to provide science-based management actions aimed at improving Moose survival. Of the collared cows that died, 53% died from predation (as proximate cause of death), with the majority of those killed by wolves. Predation by wolves occurred in all study areas. Bear and Cougar predation occurred in most study areas as well. The second most frequent proximate cause of death of cow Moose was from health-related issues, including mortality from apparent starvation (19%). Proximate cow Moose mortalities from harvest were 16%, which 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 harvesters.

Cow survival rates of >85% indicated stable or increasing populations; however, continued population declines occurred in most study areas. Therefore, determining the role of Moose calf survival in population declines has become more important. Initially, in 2013, late winter (March) calf surveys of collared cows were used to index calf survival and recruitment. Ten of the 15

Table 1. Moose management lever table from the Provincial Framework for Moose Management in British Columbia (B.C. FLNRO 2015).

#	Management Lever	Legal Authority to use Management Lever
1	Hunting Regulations	Authorized through *Wildlife Act*, supported by regulations and policy
2	First Nations Harvest	In the absence of a clear conservation concern, First Nations harvest will most likely be managed through agreements with First Nation governance bodies. Harvesting contrary to agreements may be enforced through the *Wildlife Act*.
3	Predator Management	Hunting and trapping of predators is authorized through *Wildlife Act*, although predator control to enhance ungulate hunting opportunities is not supported by current policy ("Control of Species Policy")[1]
4	Access Management	Access restrictions authorized through *Wildlife Act* supported by regulations and policy, also general recreation closures through the *Forest and Range Practices Act*
5	Habitat Enhancement and Protection	Numerous Acts involved, limited authority under *Wildlife Act*
6	Environmental Assessment and Mitigation	Provincial government staff review land-use applications and can influence mitigation measures to benefit Moose (e.g., Moose habitat supply through Timber Supply Reviews).

March calf surveys had calf/cow ratios at or above 25 calves/100 cows. These ratios generally indicate stable Moose populations if adult female survival rates are above 85% (Bergerud and Elliot 1986; British Columbia FLNRO 2015). Given continued population declines, we began direct investigation of Moose calf survival rates, timing of calf mortality (Bowyer et al. 1998), 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 8-month old Moose calves was much higher (78%) than in 2016/17 (45%). As a result, the recruitment rate in the Bonaparte study area was four times higher in 2017/18 relative to 2016/17, which had a big influence on population trends and growth; the rate of population change (i.e., lambda) was 0.93 in 2016/17 and 1.11 in 2017/18 (Kuzyk et al. 2018a). Variation and drivers of variation in calf survival are important when assessing causes of Moose population change.

Information from Moose population surveys and population modelling suggest Moose populations continue to decline in over 70% of their range in B.C. (Kuzyk et al. 2018b), which is consistent from reports from First Nations and stakeholders. Population modelling over a 20-year period (1996-2015) in 31 B.C. Game Management Zones (GMZs) determined calf:cow ratios at six months declined in 12 GMZs (39%), juvenile survival from 6–18 months declined in nine GMZs (29%), and cow survival declined in 10 GMZs (32%). No GMZ had an increase in calf:cow ratio, juvenile survival, or annual survival of cows (Kuzyk et al. 2018b). Preliminary interpretation of results from this project combined with survey/population modelling suggest calf survival to one year of age and poor nutritional condition of cows are involved in continued Moose population declines in most areas.

The purpose of the document is to provide our partners and the public with an update to the original research design (Kuzyk and Heard 2014) by including preliminary interpretations of the first five years of research (Kuzyk et al. 2018a), and to guide the next several years of research for this project. This document acts as a research framework by describing seven new areas of research, with detailed descriptions of research questions and methods to be developed collaboratively by professors and graduate students from academic institutions. Outcomes of this project will provide additional management actions building on management levers discussed in the Provincial Framework for Moose Management in British Columbia (B.C. FLNRO 2015) that guides Moose management in B.C. (Table 1).

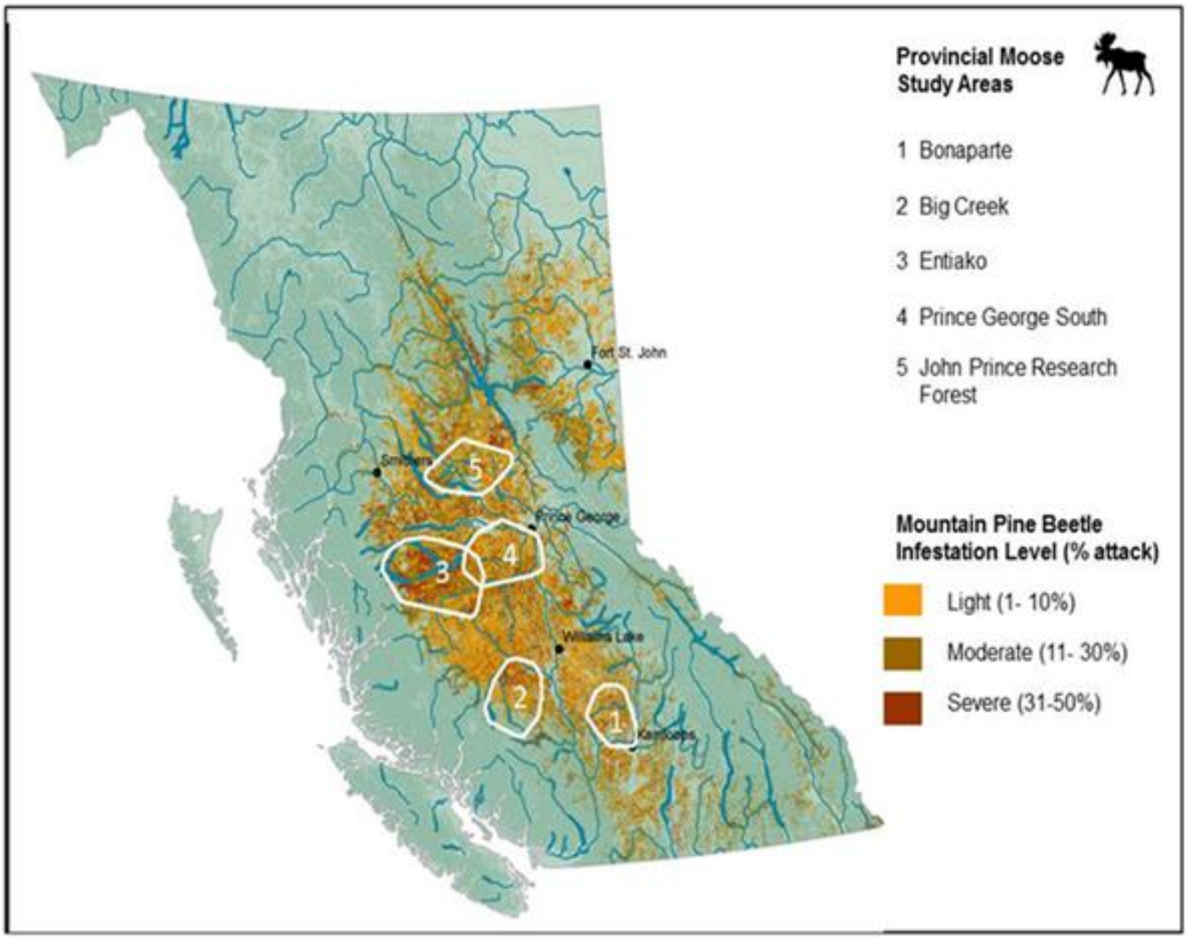

Figure 1. Moose research study areas in central British Columbia. Cow Moose survival monitored in the Bonaparte study area since February 2012 and the other four study areas since December 2013, overlaid on Mountain Pine Beetle Infestation spatial data layer (2016). The areas were selected to encompass 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 (from Kuzyk et al. 2018a).

Table 2. **Description of landscape features and large mammals in five Moose research study areas in central B.C., 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
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

Table 2. *(continued*)

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]
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): Restricted 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.

2. STUDY AREAS

The five study areas range from 6700 km^2 – >18000 km^2 (Table 1) and are described in detail in Kuzyk et al. (2018a). All study areas have differing amounts of forest affected by MPB and associated salvage logging and roads (Figure 1). Moose are the primary wild ungulate in all study areas except the Bonaparte, where Mule Deer (*Odocoileus hemionus*) are more abundant. All study areas contain multi-prey, multi-predator species assemblages, including Elk (*Cervus canadensis*), Mule Deer, White-tailed Deer (*O. virginianus*), Caribou (*Rangifer tarandus*), Grey Wolf (*Canis lupus*), Grizzly Bear (*Ursus arctos*), Black Bear (*U. americanus*) and Cougar (*Puma concolor*), all of which occur at varying densities and distributions (Shackleton 1999; Mowat et al. 2013; Kuzyk and Hatter 2014) (Table 1). 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). Licenced harvest for bulls occurred in all study areas having a range of season dates between September 1 and November 30. Bull harvest was regulated with general open seasons with or without antler restrictions, limited-entry seasons (i.e., hunters must draw an appropriate authorization) with no antler restrictions, or a combination of general open and limited entry seasons. Licensed harvest for cows and calves were mostly limited-entry hunts in three study areas between October 10 and November 10.

3. OBJECTIVES

This ongoing study will continue to investigate factors influencing Moose survival so that science-based recommendations can be developed to improve Moose populations in the province. Future research objectives include continued work towards original objectives and several new approaches to further investigate factors driving Moose population change.

The key objective of this study remains to evaluate the original landscape change hypothesis by identifying causes and rates of cow Moose mortality, and examining those spatial and temporal factors that may have contributed to increased vulnerability (Kuzyk and Heard 2014). A minimum of 30 GPS radio-collars on cow Moose should be maintained in the same five study areas (Kuzyk and Heard 2014) (Table 2 and 3, Figure 1). There are few existing data on cow survival in B.C., but previous research in other areas of Canada and Alaska where predation is considered to be the major factor influencing Moose populations suggests adult cow survival ranges between 75-95% (Hauge and Keith 1981; Mytton and Keith 1981; Gasaway et al. 1983; Larsen et al. 1989; Ballard et al. 1991; Gasaway et al. 1992; Bertram and Vivion 2002). Understanding variation in cow survival will provide insight into the ecological processes that determine Moose population growth rates and may help explain past and current population declines in some areas.

A new objective of this research is to investigate cow Moose response to experimental manipulations of forestry practices and landscape features thought to influence the quality of Moose habitat and support important life requisites. Given the scale of current research, limitations and variation of the quality of spatial data available within each study area and some limitations associated with GPS location data in some study areas (i.e., 1 or 2 fixes/day), fine-scale analysis of these attributes, and Moose response to these attributes, is not currently possible. Development of recommendations to guide forest development in Moose habitat remains a high priority need in the province.

Another major objective for the project is to determine the role of Moose calf survival in population change and the drivers of calf recruitment. We hypothesize that drivers of calf recruitment include nutritional condition and overall health of cow Moose prior to and during pregnancy. These also contribute to birth weight and lactation indices. We acknowledge that landscape change may influence calf production and survival in much the same fashion as initially proposed for cow Moose (i.e., Kuzyk and Heard 2014). Cause-specific rates of mortality of 8-month old calves is currently being assessed in the Bonaparte and Prince George South study areas (see section 5.3) using regional and other funding sources. These areas were selected based on a combination of factors including degree of population decline, reproductive parameters (i.e., pregnancy rates, parturition rates), health results, and logistical factors. Although insight has been gained in understanding the high variability and importance of 8-month-old calf survival, there remains a real need to determine factors influencing calving success and neo-natal calf survival, as these are also important factors contributing to overall recruitment rates (Patterson et al. 2013; Severud et al. 2015; Obermoller 2017). A multi-year (2017/18 – 2021/22) direct assessment of wolf-Moose interactions fills an identified research gap and is occurring in Prince George South and John Prince Research Forest study areas to inform management recommendations to enhance Moose populations. Through data obtained from collaring wolves and conducting cluster investigations, we can assess their habitat use as it relates to risk for Moose, prey selection and predation rates.

4. METHODS

Details of the field methods were originally presented in Kuzyk and Heard (2014) and methodologies have been updated and presented annually in Kuzyk et al. (2015, 2016, 2017, 2018a). Moose (cows and 8-month old calves) instrumented with GPS radio-collars gathering >6 spatial locations/day allows the majority of the new research approaches (see section 5) to be achieved. The most recent methods for radio-collaring cow and calf Moose and rapid-response mortality site investigations are presented in Kuzyk et al. (2018a). Captures were conducted in accordance with the British Columbia *Wildlife Act* under permit CB17-277227. GPS collars gathering one spatial location per hour and VHF radio-collars on wolves in the Prince George South and John Prince Research Forest study areas are being deployed on aerial winter captures and summer ground trapping (permit PG17-2782811).

5. RESEARCH APPROACH FOR FUTURE YEARS

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 B.C. interior (Kuzyk et al. 2018a). Our approach is to provide a framework of seven new areas of research realizing detailed descriptions of research questions and methods that will be developed collaboratively by the research team and academics. We have reconfirmed that important areas to focus on for the next several years 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 and measuring population change; 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 (Table 3). These research questions will be investigated to improve our understanding of factors influencing Moose population dynamics and facilitate the development of management recommendations. Consideration is given to how each research approach may provide information for the six Moose management levers (B.C. FLNRO 2015) to help benefit Moose populations in the province (Table 4).

Table 3. Research approach for Moose in future years in five study areas in B.C.

Study Area	Research Approach
Bonaparte (Region 3)	- Monitor cow survival indefinitely - True calf recruitment rates - Calf survival and landscape change - Calf survival and maternal body condition - Nutrition and health
Big Creek (Region 5)	- Monitor cow survival indefinitely - Nutrition and health
Entiako (Region 6)	- Monitor cow survival indefinitely - Nutrition and health
Prince George South (Region 7A)	- Monitor cow survival indefinitely - True calf recruitment rates - Calf survival and landscape change - Calf survival and maternal body condition - Nutrition and health - Wolf predation
John Prince Research Forest (Region 7A)	- Monitor cow survival indefinitely - Forest management trials - Nutrition and health - Wolf predation

Table 4. Research approaches related to informing available Moose management levers.

Management Lever	Research Approach that Informs Lever
Hunting Regulations	- Monitor cow survival indefinitely - True calf recruitment rates - Calf survival and maternal body condition - Nutrition and health
First Nations Harvest	- Monitor cow survival indefinitely - True calf recruitment rates - Calf survival and landscape change - Calf survival and maternal body condition
Predator Management	Monitor cow survival indefinitely - Calf survival and landscape change - Calf survival and maternal body condition - Wolf predation
Access Management	- Monitor cow survival indefinitely - Calf survival and landscape change - Calf survival and maternal body condition - Wolf predation
Habitat Enhancement and Protection	- Monitor cow survival indefinitely - Calf survival and landscape change - Calf survival and body condition of cow - Nutrition and health
Environmental Assessment and Mitigation	- Monitor cow survival indefinitely - True calf recruitment rates

5.1. Monitoring Cow Survival Indefinitely

We propose to monitor cow Moose survival indefinitely with GPS radio-collars gathering >6 spatial locations/day, which also enables the majority of the new research approaches to be achieved. We will do this by maintaining a minimum of 30 GPS collars on cow Moose in each of the five study areas indefinitely (Kuzyk and Heard 2014). Continued acquisition of these data allows for long-term monitoring of cow Moose, resulting in improved understanding of longer-term annual and seasonal variation in causes and rates of cow Moose mortality, and how it relates to variation observed in calf recruitment and Moose population dynamics and survival relative to environmental variation. Building long-term data sets of biological samples and various reproductive and health parameters allows evaluation of the effectiveness of management strategies to benefit Moose management, and provides data to monitor population trends, improve population models, and inform harvest management.

Current information on Moose population trends is critical for Moose management. Standard procedures for assessing Moose population trends are using stratified random block surveys that require complete snow cover (Gasaway et al. 1986; Heard et al. 2008) and temperatures < -10C (Quayle et al 2001; RISC 2002). Some surveys in recent years were cancelled due to warm winters and lack of snow. This challenge may be more pronounced with climate change. Radio-collars enable calculation of population rate of change (lambda) through use of survival rates of radio-collared cow Moose combined with late winter calf survival rates, gathered from radio-collared 8-month old calves and/or late winter calf surveys of radio-collared cows (Hatter and Bergerud 1991). The need to provide consistent information on Moose population trends emphasizes the importance of maintaining radio-collared cow Moose as part of a long-term research and monitoring project.

In addition to continuing these population assessments and collaring activities, we also propose exploring alternative methods to monitor Moose population trends. For example, in the John Prince Research Forest (JPRF) study area, the utility of camera traps to monitor Moose is being explored. Camera trap technology has advanced significantly over recent years (Burton et al. 2015) and new analysis approaches allow for greater inferences regarding population parameters, including density (Burgar et al. 2018). These new techniques will be compared to more traditional approaches to assess their validity (e.g.; Stratified Random Block surveys, lambda estimates from collar data). This allows for continual improvement and will enhance confidence in the results.

5.2. Forest Management Trials to Benefit Moose Populations

Science-based guidelines to inform forest development and habitat management to benefit Moose populations are needed. There is increased pressure from First Nations and stakeholders to implement forestry practices that benefit Moose populations. Guidelines or Best Management Practices are present 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 to inform and update guidelines for Moose habitat management. We will investigate Moose responses (at multiple spatial scales) to forest management factors (Scheideman 2018) such as varying 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., 6+ fixes/day) in addition to previous collar and survey 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, silviculture, and access control 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 over time can be a suitable alternative approach. The basic tenet behind resource selection theory is that animals are 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 patterns in an effort to quantify Moose responses to cumulative habitat change. An improved understanding of Moose/habitat relationships will allow for more informed management practices which should result in more resilient landscapes for Moose.

The 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 consist of important Moose habitat, and both parties are interested in this approach. In addition, these tenures have high-resolution habitat data derived from LiDAR inventories, making fine-scale resource selection models possible. In the next phase of the project, forest management activities will include enhanced retention of shrub communities, retention of advanced understorey conifer, reducing patch size to increase effective edge habitat, access control, and other activities identified as increasing Moose habitat suitability. The Bonaparte study area has another landscape manipulation underway where approximately 180 km of spur roads have been rehabilitated (i.e., total removal and impassable) in a large portion of the study area in 2017 and 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. We would prefer to use spatial information from high-fix rate GPS collars in all five study areas as that approach incorporates additional controls to assess treatment effects and increases the applicability, strength and rigor of analyses. 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 B.C. and elsewhere.

5.3. Monitoring True Calf Recruitment Rates and Measuring Population Change

The importance of assessing calf survival in relation to Moose population change has been highlighted in the initial Moose project research design (Kuzyk and Heard 2014) and the 2015, 2016, 2017 and 2018 progress reports (Kuzyk et al. 2015; Kuzyk et al. 2016; Kuzyk et al. 2017; Kuzyk et al. 2018a). Information from surveys (Klaczek et al. 2017; FLNRORD unpublished data) combined with population modeling (Kuzyk et al. 2018b) and results from the current research suggests Moose populations continue to decline despite cow survival rates capable of supporting stable to increasing populations in most study areas. This implies calf survival, and ultimately recruitment, is a main factor driving Moose population declines in B.C.; this was identified as a potential driver in the original research design (Kuzyk and Heard 2014).

Early evidence from monitoring survival of 60 8-month old 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 population of Moose in some years. The difference may have significant ramifications on Moose population trends. Therefore, continued monitoring of survival and recruitment of older Moose calves is warranted. We recommend maintaining a minimum of 20 8-month old calves in each of the Bonaparte and Prince George South study areas for at least five years to understand longer-term variation in this parameter and consequences for Moose population dynamics. This sample of 20 in each study area for five years (total n=200) will also enable the other new research approaches on calf survival to be achieved. We recognize that true recruitment is defined in multiple ways; however, we considered Moose calves to be recruited at age 1 (Bender 2006), as this is past the late winter/early spring mortality period typical of some ungulate populations and likely when juvenile and adult survival rates begin to align (Hickey 1955). To calculate true recruitment, we propose to correct mid-winter survey-based indices of recruitment (i.e., cow:calf ratios) with survival rates calculated to age 1 from radio-collared calves. We propose to continue monitoring 8-month calf survival and true recruitment rates to age 1 for the next several years with a minimum of 20–30 calves collared annually (see Boertje et al. 2007; Jones 2016) in two study areas (Bonaparte and Prince George South) due to financial and logistical constraints.

To provide context for survival estimates, an important objective of the project is to determine Moose population change over the same timeframe. This was done by comparing initial density estimates in each study area, completed when research began, to density estimates generated five years later (Kuzyk and Heard 2014). As of February 2019, all density surveys in all study areas have been completed and trends have been determined. Population trend estimates varied with methods used to calculate the trend (Serrouya et al. 2017). We propose to compare these density trend estimates to trend estimates generated through lambda calculations (Hatter and Bergerud 1991; Morris and Doak 2002) determined from this study using mid-winter survey-based indices of recruitment (i.e., calf/cow ratios), radio-collared cow survival rates, and true recruitment values determined from radio-collared 8-month old calves. This analysis will also help understand the magnitude of true recruitment estimates versus mid-winter estimates and their effects on population trend.

5.4. 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 5.5 below). We hypothesize that landscape change has increased mortality risk to calves by: 1) reducing security cover (e.g., decreased 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 have been monitoring 8-month old calves since 2016 and recently have begun to assess the effects of landscape change on calf survival by directly monitoring their survival, causes of mortality and locations of mortality.

Survival of new-born calves to 8-months of age is a key research gap in this project. To address this, we will use existing and new data from radio-collared cows for new analyses 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; McGraw et al. 2014; 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). There may be challenges with this approach as Obermoller (2017) was only 53% successful identifying mortality sites of calves up to three months of age. Monitoring these movements in near real-time may also allow ground checks to learn 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 an 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 100 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.

5.5. Assess Calf Survival in Relation to Body Condition of Cow Moose

This project has found evidence of 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 and emaciated body condition at time of capture and death. A more complete assessment of the nutritional 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, at least to some degree, 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 cows in better condition will be less likely to die from health-related causes, particularly apparent starvation.

It has been assumed by some that winter is the time of year that nutritional limitation occurs for wild ungulates in the northern hemisphere; however, recent research suggests reduced spring/summer/fall nutrition may negatively influence survival and reproduction (see Cook et. al. 2013 for a review). Recent research suggests spring/summer/fall nutrition, rather than winter, may be the more important predictor of ungulate survival and productivity due to its direct relationship with reproduction and subsequent 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 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 this 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 measure Moose body condition entering winter by measuring the maximum thickness of rump fat using ultrasonography (Stephenson et al. 1998; Cook et al. 2010).

We will focus body condition measurements on random new cows and existing collared cows to achieve a sample size of 30 on an annual basis. We will focus calf captures on those calves of cows captured randomly. Estimates of total body fat will be generated using equations developed by Stephenson et al. (1998). At the time of capture, we will also use ultrasonography to determine pregnancy and fetal rates for captured cows. Parturition rates will be determined by analyzing movement rates of collared cows through the parturition period and by conducting aerial searches for calves.

5.6. Role of Nutrition and Health in Influencing Moose Populations

The role of nutrition in driving Moose population dynamics in central B.C. is currently unknown, but preliminary results in the 2016, 2017 and 2018 progress reports (e.g., cows in poor to emaciated 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 (Thacker et al. 2019).

Forage quality and quantity may influence nutritional condition of ungulates (Cook et al. 2013). As a first step, new projects are underway that investigate diet content of Moose in all seasons in the JPRF and Prince George South (PG South) study areas. These results will inform new investigations related to forage nutrition quality (examining differences in forage quality between cutblocks and forested habitats) and health factors (Thacker et al. 2019) that may influence Moose populations. As discussed above, we are estimating body fat of collared cows in some study areas in the late fall/early winter to characterize summer and fall nutritional status and this work may lead to further investigation of factors influencing Moose nutrition. 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). Foraging patterns, predation, and habitat quality are inextricably linked and will also be explored in the context of different forest management scenarios (see Section 5.2 above).

We are actively assessing the factors affecting and methods to measure Moose herd health (Thacker et al. 2019). The development of a health baseline is important for understanding Moose health and survival (Murray et al. 2006). Future areas of investigation may include integrating current health monitoring with studies evaluating thermal stress, the quality and quantity of Moose forage, and winter tick (*Dermacentor albipictus*) effects on calf (Jones et al. 2017) and adult Moose survival (Samuel 2004, 2007) and health determinants. Continuing the current study and building robust data sets of biological samples and other information on individual Moose and populations contributes to the development of long-term health programs. The development of community and/or harvester-based Moose sampling programs and health assessments will be of assistance in obtaining samples from a wider area, and provides a means to actively engage external stakeholders.

Herbicide is used in silvicultural practices to kill and discourage competing deciduous growth in recently logged settings, in order to encourage crop tree growth and maximize timber production. 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. Herbicide use in study areas is low, ranging 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 with which treatments have been applied is variable. Ensuring adequate treatments occur, or have occurred in the past, in areas where we have Moose collared with appropriate radio collars remains a challenge to adequately assess our research questions. 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; Eschholz 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 whether Moose use areas sprayed with herbicide.

5.7. Role of Predation on Moose Populations

Predation on cow and 8-month old calf Moose is being monitored through identification of cause of death and species of predator in mortalities. A multi-year (2017/18–2021/22) direct assessment of wolf-Moose interactions is ongoing in PG South and JPRF. Through deployment of radio-collars on wolves, this project will inform management recommendations to enhance Moose populations by developing a Moose risk layer based on wolf habitat use. This layer will provide information on predations rates, prey species selection, pack size, and an increased sample size of Moose mortalities to assess age/condition of 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 such as 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 Trials. Having a more detailed understanding of the role of predation and predator species in Moose survival could help develop priorities for management recommendations benefiting Moose survival.

6. CONCLUSION

We have provided direction for seven avenues of research that will provide science-based information to inform Moose management decisions. New research questions will likely arise during the next several years of this project. Therefore, it is important that this research design be updated every five years and reviewed by stakeholders and academics so that research direction can remain aligned with management needs and current science.

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