Cumulative Effects Assessment Methods for Moose in British Columbia

Standards for British Columbia's Values Foundation

Prepared by

Provincial Moose Technical Working Group – Ministry of Environment and Forest, Lands and Natural Resource Operations

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1 Table of Contents

2 Introduction

Moose are a conspicuous and iconic part of British Columbia's fauna that have environmental, economic and social and cultural importance. Moose provide recreational opportunities to resident and non-resident hunters, and their harvest provides economic benefits through the sale of hunting licenses and associated expenditures. First Nations rely on moose for social, ceremonial, and sustenance purposes. The importance of this species is reflected by the objectives established for moose through legislation, regulation and policy.

Additionally, moose are a wide-ranging species which depend upon multiple, well-connected ecosystems with properly functioning ecosystem processes. As such, moose are susceptible to cumulative impacts on their habitat and their populations from activities and related access across the land-base. Data for moose are available to support a cumulative effects assessment and can be spatially identified and mapped. These factors support the selection of moose as a CEF value.

The purpose of this document is to provide the methods and an associated rationale for evaluating cumulative effects on Moose (*Alces americanus*), which is a value that has been identified for provincial assessment under British Columbia's (BC) Cumulative Effects Framework.

2.1 Moose distribution, ecology and status

Moose are generally abundant and distributed throughout most of B.C., with notable exceptions being Haida Gwaii, Vancouver Island, the Lower Mainland, and portions of the mainland coast. They are currently on the provincial Yellow List and are not considered at risk (CDC 2016).

Three subspecies are recognized in B.C.: Alaskan Moose (*Alces americanus gigas*) in the extreme northwest, Shiras' Moose (*Alces americanus shirasi*) in the East Kootenay, and Northwestern Moose (*Alces americanus andersoni*) throughout the remainder (Demarchi and Demarchi 2003). As a conspicuous and widespread ungulate, Moose are instantly recognizable and valued by society for their many intrinsic and extrinsic values. As a species that tolerates–and even benefits from–some human activities on the landscape, Moose-human interactions are common and complex.

2.2 Cumulative Effects Framework and Legal Context

In British Columbia's Cumulative Effects Framework (CEF), cumulative effects are defined as "changes to environmental, social, and economic values caused by the combined effect of past, present, and potential future activities and natural processes". The process for a cumulative effects assessment is predicated on a value assessment based on best-available scientific knowledge, information, and understanding. This science-based assessment relies on benchmarks to support the interpretation of the condition of the value. The desired outcome from this assessment is the long-term resilience or proper functioning of the value.

The value assessment supports the CEF's assessment of objectives set by government for the value, or for components of the value. Objectives are defined as the desired condition of a value (or a component or indicator associated with a value) as defined in legislation, policy, agreements with First Nations. Objectives can be broad, aspirational statements (approved or non-approved) or specific and measureable (approved).

Objectives are the desired condition of a value obtained from existing legislation, policy, land use plans, and other agreements that are described in a qualitative or quantitative manner. Cumulative effects are assessed relative to the objectives for the value on a regional basis.

Objectives for moose were derived from provincial legislation and regulations that provide both broad and specific direction in the form of objectives about sustaining moose populations. Some of these pieces of legislation include:

- *Forest and Range Practices Act* (FRPA) – Ungulate Winter Range designations
- *Oil and Gas Activities Act* (OGAA) – Ungulate Winter Range designations
- *Land Act* – Land-use plan direction and objectives specific to moose
- *Wildlife Act* – hunting regulations

Objectives for moose include both broad objectives that are over-arching descriptions of desired conditions which often lack clear definitions and metrics, as well as specific objectives that have metrics directly associated with them.

The Provincial Framework for Moose Management in British Columbia (FLNRO 2015) supports the goal of population management for moose "to ensure moose are maintained as integral components of natural ecosystems throughout their range, and maintain sustainable moose populations that meet the needs of First Nations, licensed hunters, and the guiding industry." The associated broad objectives for moose are to:

1. Ensure opportunities for consumptive use of moose are sustainable;
2. Maintain a diversity of hunting opportunities;
3. Follow provincial policies and procedures (e.g. provincial moose harvest management procedure) as guidance for regulatory options and management objectives.

The Cumulative Effects Moose Knowledge Summary provides a summary of legal and non-legal objectives for Moose or their habitat.

> Where specific objectives exist, they may be approved for use as *management triggers* in the assessment. Management triggers identify where government is approaching or exceeding a specific legal or policy objective. Management triggers delineate enhanced or intensive management classes, where management responses will be considered to either prevent the condition of the value from exceeding the objective, or to return the condition of the value to meeting the objective.

3 Protocol

3.1 Overview

The Moose assessment protocol is composed of a set of indicators that capture different aspects of Moose ecology and links to management actions. The protocol is intended to provide a provincial standard for assessing Moose, and to be repeatable and periodically updated.

Indicators are structured in a conceptual model that provides a testable, causal framework. Interrelationships between indicators and other factors are explicitly presented and the model generates testable hypotheses regarding current conditions and the effectiveness of management actions (Figure 1). The model is not intended to capture all factors, but focuses on those under management control and that are hypothesized to have a significant effect on the value. Factors linked by lines are expected to be correlated and the direction of arrows indicate causal assumptions.

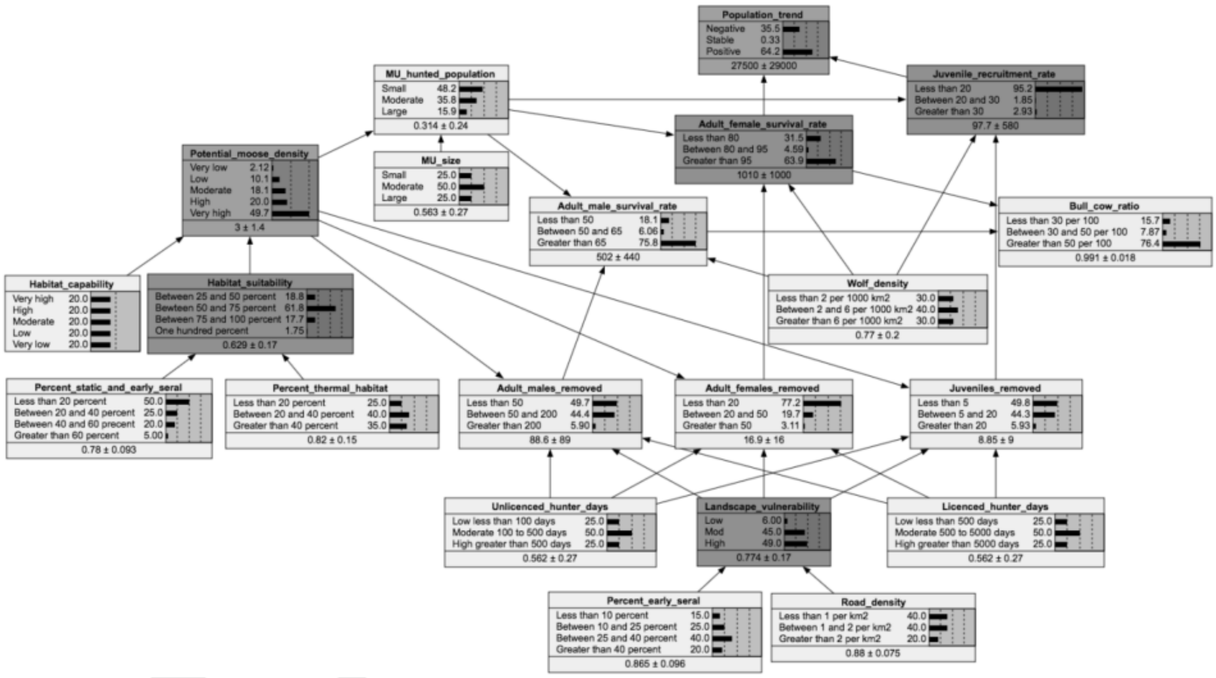

Figure 1. Conceptual model used to assess the Moose value. The model is organized around two *components* (green), 4 *indicators* (orange), and 9 *inputs* (yellow). Beige boxes indicate latent factors that are calculated from combinations of inputs. Lines indicate correlations expected among factors and the direction of arrows indicate causal assumptions.

The model is organized around two *components*: potential moose density and population trend, 4 *indicators* representing various aspects of Moose habitat and population characteristics, which are in turn influenced by 9 *inputs*. *Latent factors* are quantities that are calculated from combinations of inputs but are not usually observed directly, although in some case they can be.

Each factor is associated with:

1. *States*, which describe how the factor is stratified;
2. A conditional probability table, which describes how a factor is related to its *parents.* Tables are either populated directly, or are calculated from equations and associated coefficients.

Initial parameters are described in the following sections; however, states, coefficients and equations are based largely on expert opinion and will be revised to better calibrate the model as existing data are analyzed and as new data become available.

The model is designed such that the confidence in the value of indicators and components increases as input data become more available and precise. Therefore, data are not required for all inputs in order to generate an estimated condition; however, the more inputs that are provided, the greatest the confidence in the output.

Model indicators and components can be mapped at any scale, depending on the resolution of input variables. "Management unit" is used here generically to represent spatial areas to which the model is mapped.

4 Indicators and Components

4.1 Habitat Suitability

4.1.1 Scientific Context

Habitat suitability is a standard metric used in British Columbia to assess the condition of the land base and its ability to support a wildlife population (RIC 1999). Suitability is defined as "the ability of the habitat in its current condition to provide the life requisites of a species" (page 2; RIC 1999).

4.1.2 Indicator

Habitat_suitability is a function of two inputs:

*Habitat_suitability (Static_and_early_seral_habitat, Thermal_habitat) = Static_and_early_seral_habitat*Thermal_habitat*

Static_and_early_seral habitat measures the proportion of the land base providing suitable forage habitat, and *Thermal_habitat* provides cover for temperature regulation when ambient conditions are above -5 degrees in winter and 14 degrees in summer (Dussault et al. 2004). These inputs are described in more detail in Section 5.

4.2 Landscape Vulnerability

4.2.1 Scientific Context

A proposed hypothesis to explain the decline of Moose observed in some regions of BC is that Moose become more vulnerable to hunting when road density and the abundance of early seral habitat increases (Kuzyk et al. 2015). Roads can increase access for hunters and early seral habitat can reduce cover that visually screens Moose from hunters.

4.2.2 Indicator

Landscape_vulnerability accepts two inputs:

*Landscape_vulnerability (Road_density, Percent_early_seral) = Road_density*Percent_early_seral*

Output is a derived variable that is scaled from 0 to 1 and is used to estimate hunter success and the number animals removed from a management unit.

4.3 Adult Female Survival Rate

4.3.1 Scientific Context

Adult female survival rate is a standard metric of reproductive performance in Moose (Hatter and Bergerud 1991). It estimates the proportion of a population of adult females at time *t* that are expected to be alive at time *t + 1* (where time is generally measured in years).

4.3.2 Indicator

The principal drivers of *Adult_female_survival_rate* are assumed to be: the size of the population available to hunted (*MU_hunted_population),* the number of females removed from the population by hunting (*Adult_females_removed*) and *Wolf_density*:

*Adult_female_survival_rate (Adult_females_removed, Wolf_density, MU_hunted_population) = MU_hunted_population*Wolf_density*1/(Adult_females_removed/100)*

There are other factors (e.g., accidents, health, other predators) that affect this rate but are not considered in the model but will contribute to unexplained variance.

4.4 Juvenile Recruitment Rate

4.4.1 Scientific Context

Juvenile recruitment rate is another standard metric of reproductive performance in Moose (Hatter and Bergerud 1991) and is generally measured by the number of juveniles observed in late winter per 100 cows surveyed. It estimates the proportion of young moose that are “recruited” into the breeding population.

4.4.2 Indicator

The principal drivers of *juvenile_recruitment_rate* are assumed to be: the size of the population available to hunted (*MU_hunted_population),* the number of juveniles removed from the population by hunting (*Juveniles_removed*) and *Wolf_density*:

*Juvenile_recruitment_rate (Juveniles_removed, MU_hunted_population, Wolf_density) = MU_hunted_population*Wolf_density*1/(Juveniles_removed/50)*

There are other factors (e.g., accidents, health, other predators) that affect this rate but are not considered in the model but will contribute to unexplained variance.

4.5 Potential Moose Density (Component)

4.5.1 Scientific Context

Moose density is ultimately limited by the capability of the habitat within a management unit. Capability is defined as “the ability of the habitat, under the optimal natural (seral) conditions for a species to provide its life requisites, irrespective of the current condition of the habitat” (page 2; RIC 1999).

4.5.2 Indicator

Capability is discounted according to current suitability to derive *Potential_moose_density* according to the following table:

Inputs		**Conditional probabilities (moose/km²)**				
Habitat capability	**Habitat suitability**	**Very low (0-0.25)**	**Low (0.25-1)**	**Moderate (1-2)**	**High (2-3.5)**	**Very High (3.5-5)**
Very high	25-50%	0	0	50	50	0
Very high	50-75%	0	50	50	0	0
Very high	75-100%	50	50	0	0	0
Very high	100%	100	0	0	0	0
High	25-50%	0	0	0	50	50
High	50-75%	0	0	50	50	0
High	75-100%	0	50	50	0	0
High	100%	0	100	0	0	0
Moderate	25-50%	0	0	0	0	100
Moderate	50-75%	0	0	0	50	50
Moderate	75-100%	0	0	50	50	0
Moderate	100%	0	0	100	0	0
Low	25-50%	0	0	0	0	100
Low	50-75%	0	0	0	0	100
Low	75-100%	0	0	0	50	50
Low	100%	0	0	0	100	0
Very low	25-50%	0	0	0	0	100
Very low	50-75%	0	0	0	0	100
Very low	75-100%	0	0	0	0	100
Very low	100%	0	0	0	0	100

4.6 Population Trend (Component)

4.6.1 Scientific Context

Population trend of Moose by management unit is critically important for management purposes and is routinely calculated for monitored populations (Hatter and Bergerud 1991).

4.6.2 Indicator

Because adult survival rates are frequently available only for the female component of the population (because researchers rarely radio-collar males), the equation to calculate *lambda* (population growth rate) is restricted only to the female component of the population:

Population_trend (Adult_female_survival_rate, Juvenile_recruitment_rate) = Adult_female_survival_rate/(1-((Juvenile_recruitment_rate/2)/(100+(Juvenile_recruitment_rate/2))))

4.7 Factors Not Currently Modelled

There are growing concerns about Moose health and related implications on survival and reproduction; however, without additional research to isolate factors and to hypothesize causal effects and possible management responses, heath effects cannot be included in the model in a manner that's meaningful.

A suite of other predators and factors contribute to Moose mortality but these are difficult to both quantify and manage. As a result, for version 1 of the model these factors will contribute to unexplained variance.

5 Inputs and Latent Factors

5.1 Habitat Capability

5.1.1 Scientific Context

As stated above, habitat capability is defined as "the ability of the habitat, under the optimal natural (seral) conditions for a species to provide its life requisites, irrespective of the current condition of the habitat" (page 2; RIC 1999) and is the factor most commonly used to determine the ability of landscapes to support wildlife populations.

5.1.2 Input

The model accepts any existing capability rating. The states are currently configured to conform with RIC (1999) standards. The capability ratings are used with habitat suitability to estimate the potential moose density of a management unit.

5.2 Percent Static and Early Seral Habitat

5.2.1 Scientific Context

As large-bodied browsers, moose require abundant, shrubby vegetation, which is found most commonly in riparian and wetland areas, as well as in young, regenerating forests (Shackleton 2013).

In contrast to early seral habitat that occurs following fire or forest harvesting, "static" habitat commonly refers to disclimax riparian and wetland ecosystems that are minimally disturbed by forestry and fire.

5.2.2 Input

Percent_static_and_early_seral is the proportion of a management unit that consists of both static and early seral habitats that are assumed to provide adequate moose forage.

The Moose Technical Working Group estimated that optimal foraging conditions for Moose occur when >60% of the land base is composed of static habitat and forest stands <20 years old. Consequently, the following coefficients were assigned to different percentages of a management unit in static and early seral habitat:

Percentage of static and early seral habitat	<20%	20-40%	40-60%	>60%
Coefficient	0.7	0.8	0.9	1.0

5.3 Percent Thermal Habitat

5.3.1 Scientific Context

As large-bodies and dark-coloured mammals, thermal regulation is an important life requisite for moose and seeking suitable habitats for moderate ambient temperatures is an important driver of habitat use (Dussault et al. 2004).

5.3.2 Input

Percent_thermal_habitat is the proportion of a landscape unit in condition consistent with providing thermal cover. The Moose Technical Working Group estimated that optimal thermal conditions for Moose occur when >40% of the land base is composed of forest stands >15 m tall. Coefficients are assigned to different percentages based on the following table:

Percentage of suitable thermal cover	<20%	20-40%	>40%
Coefficient	0.6	0.8	1.0

5.4 Percent Early Seral Habitat

5.4.1 Scientific Context

Early seral habitat reduces visual screening that hunters may use to their advantage (Kuzyk et al. 2015). This input informs the landscape vulnerability index.

5.4.2 Input

Management units with different percentages of early seral habitat are assigned coefficients to estimate landscape vulnerability according to the following table:

Percentage of early seral habitat	<10%	10-25%	25-40%	>40%
Coefficient	0.7	0.8	0.9	1.0

5.5 Road Density

5.5.1 Scientific Context

Roads provide primary access for hunters they are one of the assumed correlates of hunter success and, therefore, population pressures on Moose (Rempel et al. 1997).

5.5.2 Input

Road_density is stratified into three states and assigned initial coefficients used in calculating landscape vulnerability:

Road density (km/km^2)	<1	1-2	>2
Coefficient	0.8	0.9	1.0

5.6 Licensed/unlicensed Hunter Days

5.6.1 Scientific Context

Hunter days by resident and non-resident hunters is the primary indicator of hunter effort used in BC. A sample of resident hunters is sampled annually and guide-outfitters report hunting activity by their clients. These data are stratified by Management Unit and tracked in the Summary Statistics Database.

Unlicensed hunting is a right of First Nations hunters and data are not routinely reported, but may be available for some areas if provided by communities.

5.6.2 Input

Hunter days are stratified into three broad categories of effort and are assigned coefficients of low (0.25), moderate (0.5) and high (1). The categories are scaled differently for licensed and unlicensed hunters based on their estimated proportional representation in the hunter population. The coefficients are used to estimate survival rates according to the equations reported in Section 4.

5.7 Wolf Density

5.7.1 Scientific Context

Wolves are the primary predator of Moose (Shackleton 2013) and pressure can be sufficient to affect population trends (Ballenberghe and Ballard 1993).

5.7.2 Input

Wolf_density is used to estimate survival and recruitment rates (along with the number of animals removed and the size of the hunted population), using equations presented in Section 4. Coefficients are assigned according to the following table:

Wolf density (km/km^2)	<2	2-6	>6
Coefficient	1	0.8	0.5

5.8 MU Size

5.8.1 Scientific Context

The hunting vulnerability and hunter-days component of the model predicts the number of animals removed by hunting, but to convert this to a rate requires consideration of the size of the management unit, because larger units will have larger populations of moose than smaller units and will have higher survival rates for a given number of moose removed.

5.8.2 Input

For simplicity the indicator for MU size is stratified into small, moderate and large and assigned the following coefficients:

MU size	Small	Moderate	Large
Coefficient	0.25	0.5	1

5.9 MU Hunted Population

5.9.1 Scientific Context

The potential population available to be hunted in a management unit is a function of the size of a management unit and its potential moose density.

5.9.2 Factor

MU_hunted_population is scaled from 0-1 and used to estimate survival rates, along with the number of animals removed by hunting and wolf density:

*MU_hunted_population (MU_size, Potential_moose_density) = MU_size*Potential_moose_density/5*

5.10 Adult Male Survival Rate

5.10.1 Scientific Context

Adult male survival rate is not required to estimate indicators and/or components, but because most hunting is focused on males it is included in the model for completeness and validation purposes.

5.10.2 Factor

Adult male survival rate is calculated in a manner analogous to adult females:

Adult_male_survival_rate (MU_hunted_population, Adult_males_removed, Wolf_density) = MU_hunted_population*Wolf_density*1/(Adult_males_removed/500)

5.11 Bull:cow Ratio

5.11.1 Scientific Context

Bull:cow ratios are a primary indictor used in harvest management (FLNRO 2015) but are controversial because reproductive implications of skewed sex ratios have not been clearly demonstrated (see review in FLNRO 2015, also Schwartz et al. 1992). As with adult male survival rates, bull:cow ratios are therefore not necessary to estimate indicators and/or components, but is included for other monitoring purposes.

5.11.2 Factor

Bull_cow_ratio accepts adult male and adult female survivorship rates as inputs and is estimated according the following table:

Inputs		**Conditional probabilities (bulls per 100 cows)**		
Adult female survival rate	**Adult male survival rate**	**<30**	**30-50**	**>50**
<0.8	<0.5	80	20	0
<0.8	0.5-0.65	0	80	20
<0.8	>0.65	0	0	100
0.8-0.95	<0.5	90	10	0
0.8-0.95	0.5-0.65	0	90	10
0.8-0.95	>0.65	0	0	100
>0.95	<0.5	100	0	0
>0.95	0.5-0.65	0	100	0
>0.95	>0.65	0	0	100

5.12 Adult males/females/juveniles removed

5.12.1 Scientific Context

Hunting removes predominantly adult males; however, adult females and calves are also hunted. The number of animals removed can be estimated by a function of the effort (as measured by hunter days), as well as the density of animals available to hunt.

5.12.2 Factor

Equations for all demographic components of the population are the same except for scaling factors applied to unlicensed hunting to recognize that these hunters are likely less selective and more successful than licensed hunters.

Adult_males_removed (Unlicenced_hunter_days, Landscape_vulnerability, Licenced_hunter_days, Potential_moose_density) = Potential_moose_density/5*Landscape_vulnerability*Licenced_hunter_days*Unlicenced_hunter_days*500

*Adult_females_removed (Landscape_vulnerability, Unlicenced_hunter_days, Licenced_hunter_days, Potential_moose_density) = Potential_moose_density/5*Landscape_vulnerability*Licenced_hunter_days*Unlicenced_hunter_days*100*

*Juveniles_removed (Potential_moose_density, Landscape_vulnerability, Licenced_hunter_days, Unlicenced_hunter_days) = Potential_moose_density/5*Landscape_vulnerability*Licenced_hunter_days*Unlicenced_hunter_days*50*

6 Next Steps

As noted in Section 3, factor states, coefficients and equations are approximations based largely on expert opinion and are provided to instantiate version 1 of the model. However, all of the relationships are theoretically testable and data exist to calibrate and refine the model. Improving model calibration based on analysis of existing data is a logical next step, once the model structure is stable based on feedback from broader consultation.

Concurrent with model calibration will be development of current condition maps. This will require decisions regarding baseline mapping for habitat capability.

7 Acknowledgements

This protocol and related background information is based on foundational work developed by Demarchi and Hentze (2015) and Dawson et al. (2015).

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MOOSE – AN IDENTIFIED VALUED ECOSYSTEM COMPONENT (VEC)

INTRODUCTION:

Assessing the cumulative effects of changes to moose populations over time allows for adaptive management of activities that influence moose numbers. Knowledge of which variables (indicators) most affect the Moose Population Trend allows management to concentrate on changing or mitigating those factors.

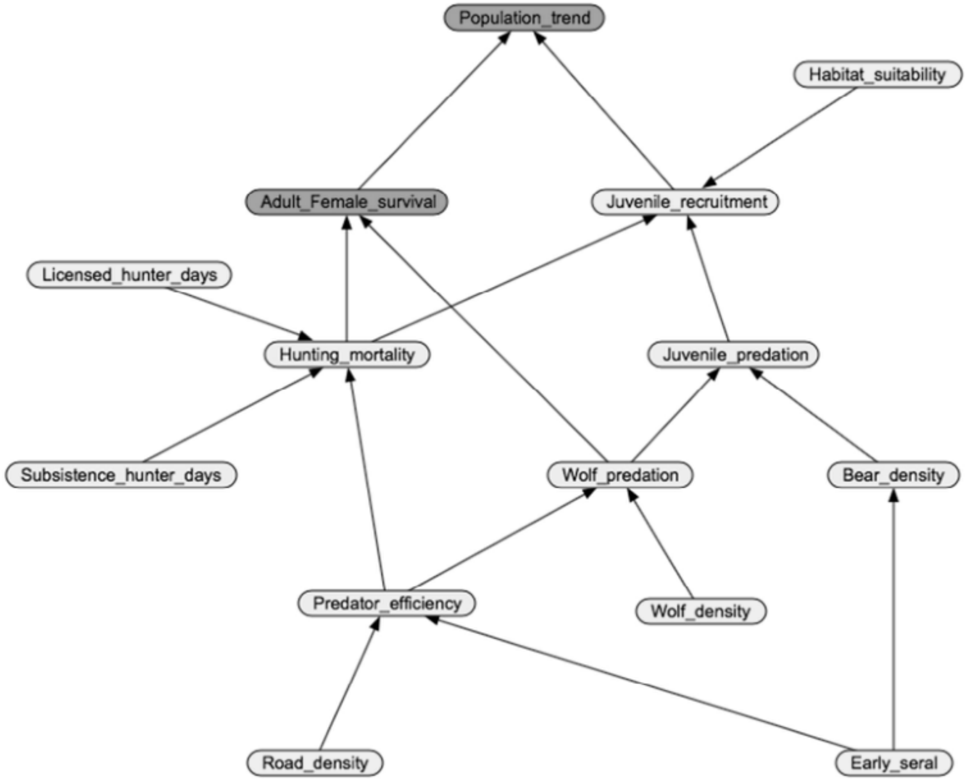
The primary anticipated use of results from this project is to help guide Cumulative Effects Assessments (CEA) for Moose in the Omineca ESI Demonstration Project area of BC.

In order to measure and assess changes in populations, indicators were selected that capture changes most influenced by natural or anthropogenic disturbances and that can be measured or estimated.

Two scales or 'filters' were applied to assess moose population trends:

- Coarse Filter: Omineca Region.
- Meso Filter: Management Units - focus on life-history and associated important habitat used by moose within a local population.

CONCEPTUAL MAP



- Green indicates the main Component/Output of Interest (Moose Population Trend);
- Yellow indicates inputs (indicators) derived from data collected in the Omineca Region and CSFN Traditional Territory;
- Beige indicates an intermediate variable that is calculated based on the other inputs into the model (i.e., Predator efficiency is determined by the amount of early seral and road density in a given MU); and
- Arrows indicate the assumed causal direction of effects among variables.

COLLABORATION – TEAM MOOSE

TEAM MOOSE:

The creation of the moose assessment model is the result of a collaborative approach of information exchange between individuals representing CSFN, provincial government (FLNRO and MOE), moose biologists, and other experts (Team Moose). Input regarding key indicators and variables was reviewed and draft results were presented and discussed with Team Moose as well as to the ESI Project Team for feedback.

Traditional/Local CSFN Knowledge was a key focus of discussion for the project team. The adjacent table was identified through the Tl'azt'en Nation and UNBC community-based research project and provided on behalf of CSFN for Team Moose to consider. The table includes critical local values (CLVs) and related thematic topics and monitoring measures.

The moose population assessment team provided descriptions and comments on whether-or-not each CLV was addressed in the model. A number of the related thematic topics fit well into the population trend model.

CRITICAL LOCAL VALUES, THEMATIC TOPICS, AND MONITORING MEASURES

Critical Local Values	Thematic Topics	Monitoring Measures	Moose Assessment Model
Maintain viable moose habitat	Habitat availability	Are swamp/riparian (static / natural) habitats increasing or decreasing?	Riparian habitat and wetland ecosystems are tracked at a broad scale. This topic is best addressed at a finer scale.
	Habitat use	Number of clearings used to hunt moose	Habitat use by moose and licenced hunters from Hunter Harvest Statistics are included in the model.
	Herbicide/pesticide	Moose habitat that is thought to be affected by pesticide spraying.	Not included in moose assessment model at this time. Field surveys are planned to examine this issue further.
	Mountain Pine Beetle	How forests killed by MPB have/have not affected moose behaviour	Not included in moose population trend assessment model at this time.
	Food sources	Description of willow habitat where moose are hunted	Habitat Model Input (ecosystem type)
Maintain viable moose population	Moose abundance	Number of moose seen in a particular area over a particular time span	Survey / count data is used as an indicator of moose abundance.
	Subsistence harvest	Satisfaction of amount of moose available for consumption per household/family per year	Not included in the population trend assessment model, but related variables are included.
	Age structure	Number of calves per cow observed on the land	Cow to Calf ratios were included in the assessment model.
	Sex ratio	Number of mature male moose hunted over a particular time span	Not included in the model, but related population dynamics are included
Maintain health and quality of moose	Fur, Behaviour, Body Size, Ticks, Colour of Meat, Scent of game, Fat, Health of organs	Mainly related to body condition.	Related indicator of health is the overall population trend, Calf:Cow ratios, recruitment and mortality rates.

SCALE OF ANALYSIS

RATIONALE:

Moose populations in BC are managed on the basis of Wildlife Management Units (MUs), which are aligned with the scale of assessment unit considered in the provincial Cumulative Effects Framework (CEF) protocol for moose.

The MU is considered to provide a biologically meaningful scale at which to assess moose population trends and relative risks. MUs are the smallest units for which Hunter Harvest Statistics are available.

Model input and output values were determined for all MUs within the Omineca Region as well as the ESI Study Area (orange boundary indicated in the adjacent figure) that represents the full extent of all CSFN Traditional Territories.

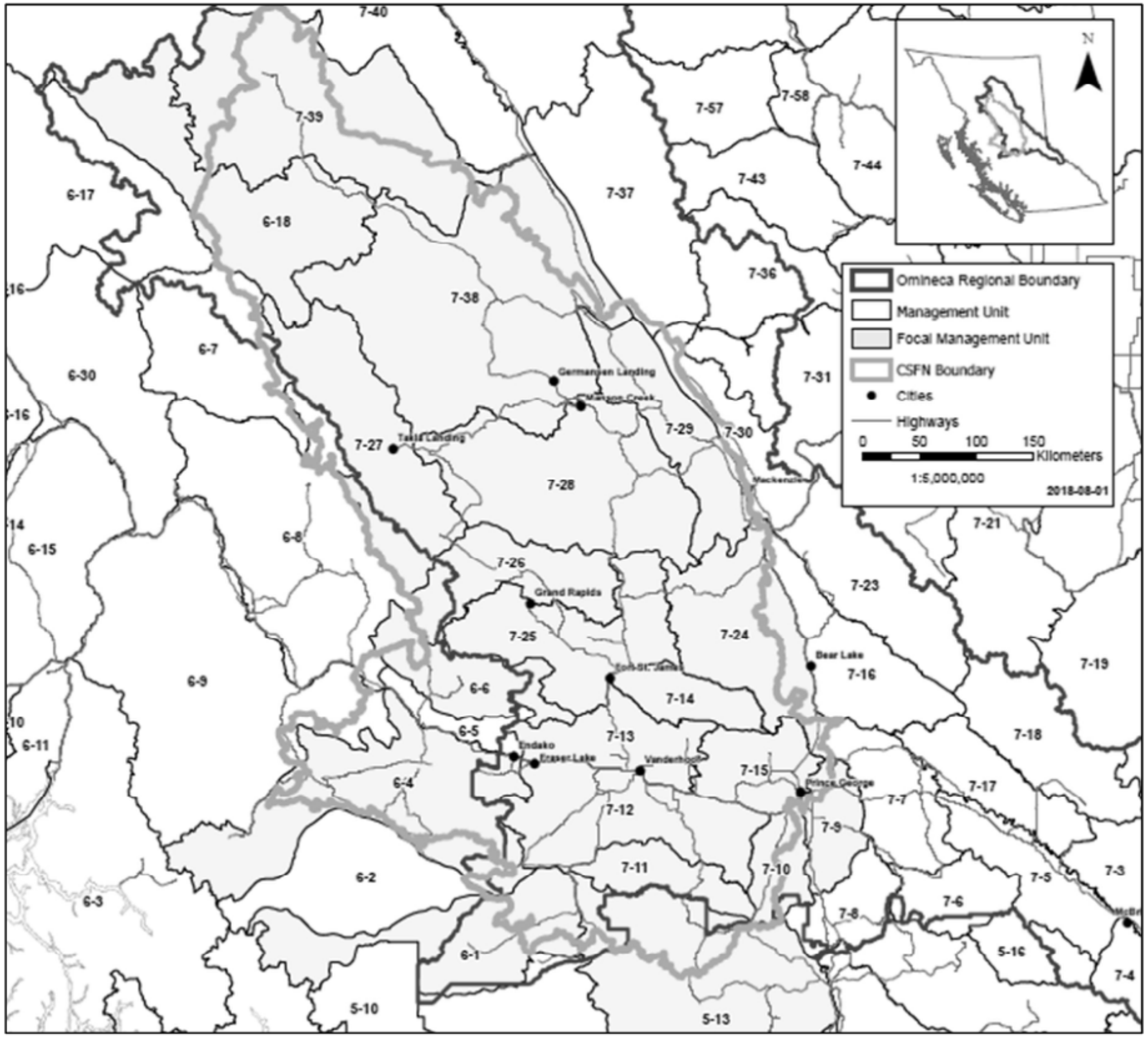
SCALE OF ANALYSIS:

Management Units

ASSESSMENT UNITS:

Key variables affecting habitat conditions and population performance – the primary factors considered to determine Moose population sustainability – were defined and assigned to each Management Unit (MU) for the Omineca Region (7a), and portions of the Skeena and Peace Regions (5 and 6) by species experts; covering a total of 40 MUs of which 20 are predominately contained within the ESI CSFN project area.

SCALE OF ANALYSIS FOR POPULATION TRENDS 2000 TO 2015 (MANAGEMENT UNITS)



JUVENILE RECRUITMENT – REGIONAL DATA INPUT

RATIONALE:

Juvenile recruitment rate is a standard metric of reproductive performance in moose populations and is generally measured by the number of juveniles observed in early winter (typically Dec-Jan) per 100 cows surveyed. It estimates the proportion of young moose that are "recruited" into the breeding population.

If recruitment of female juveniles into the breeding population exceeds deaths of adult females, the population will increase. If deaths exceed recruitment, it will decrease. If recruitment equal deaths, the population will be stable.

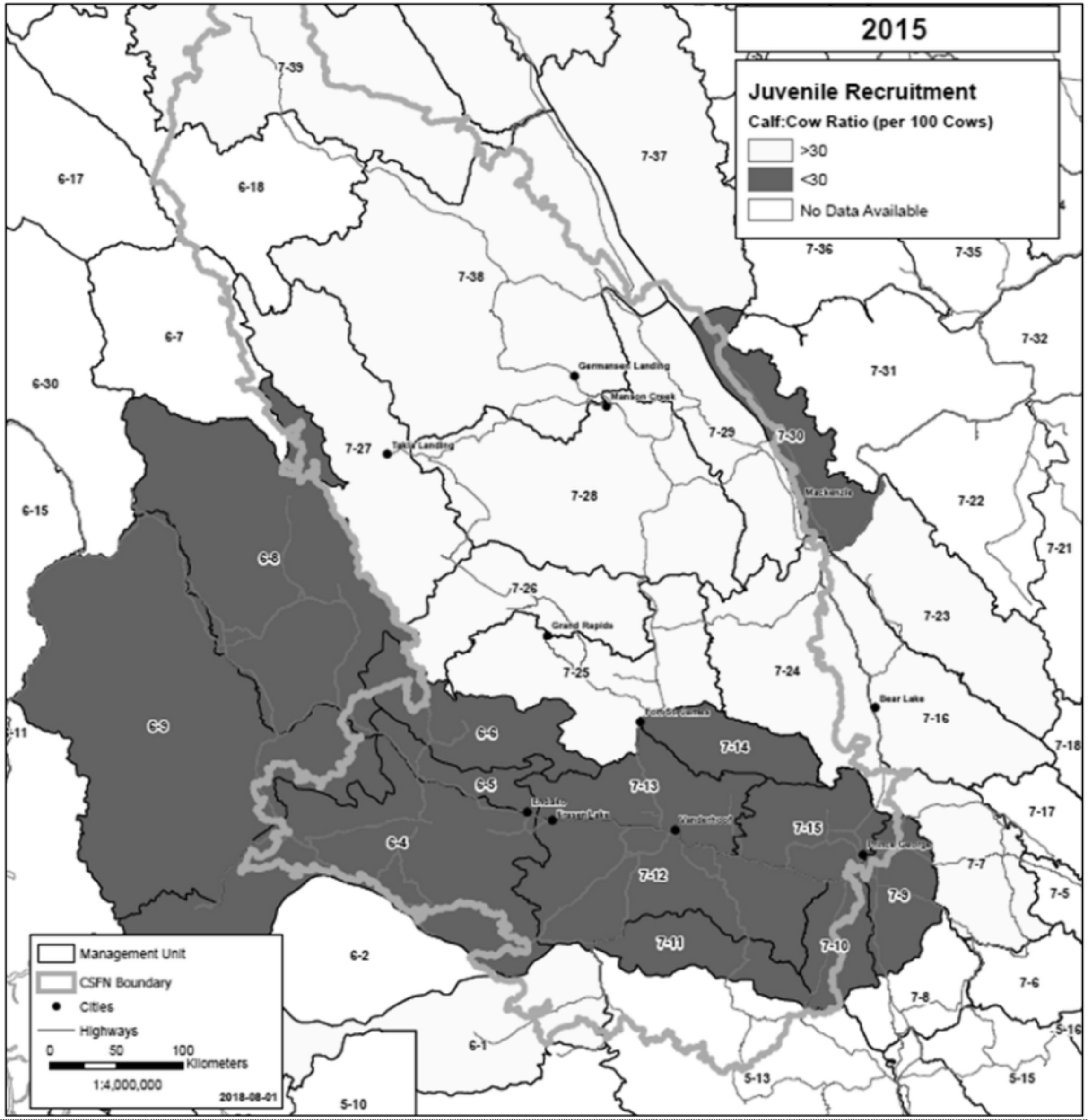
INDICATOR: JUVENILE RECRUITMENT

<30 calves per 100 cows
>30 calves per 100 cows

CURRENT CONDITIONS:

Of the 20 MUs predominately contained within the CSFN traditional territory, regional survey data indicates that 9 MUs had less than 30 calves per 100 cows for the period representing 2015.

CURRENT CONDITION:



EARLY SERAL – SIGHTABILITY OF MOOSE

RATIONALE:

The amount of early seral habitat (recently harvested forest that is now between 0-10 years) is thought to increase visibility of moose and could thus increase their susceptibility to hunting mortality. Early seral has increased significantly in the Omineca and CSFN traditional territory over the last 15 years in part due to forestry rotation rates, tree death due to mountain pine beetle, and pine beetle salvage efforts.

INDICATOR: EARLY SERAL

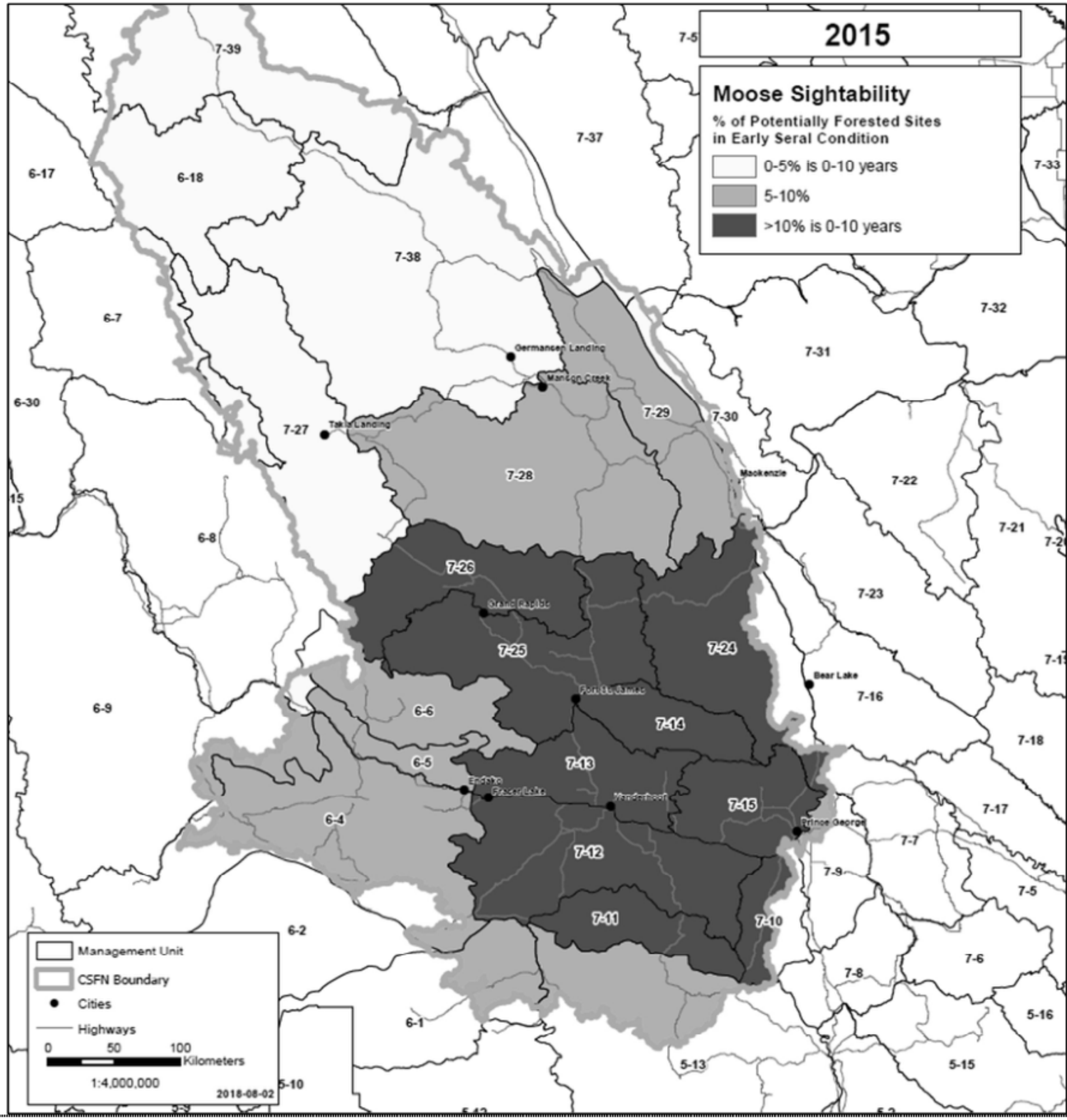
- <5% of potentially forested area in the management unit is under 10 years of age
- 5 to 10% is under 10 years of age
- > 10% of the potentially forested area is under 10 years of age since disturbance

ASSESSMENT RESULTS:

A broad ecosystem map product was produced for the Omineca region that was then extended westward into the Skeena region to provide full coverage of the ESI CSFN project area. Results for this input are displayed within the portion of the MU where ecosystem coverage was available within the project area to calculate % early seral.

Of the 20 MUs predominately contained within the CSFN traditional territory, 9 have >10% percent of the potentially forested area in early seral conditions (<10 years of age), 7 have 5-10% early seral, and the remaining have <5% early seral.

CURRENT CONDITION:



LICENCED HUNTER DAYS

RATIONALE:

The number of licenced hunters days spent in an area is assumed to correlate with the likelihood of moose removal from a given MU. The number of hunter days in a given MU may reflect moose numbers, accessibility (ease of access), and/or local hunting regulations. Data used to measure and assess this indicator was obtained from Hunter Harvest Survey statistics collected and tracked by MU by the province; and results (input data) are therefore displayed for the entire MU.

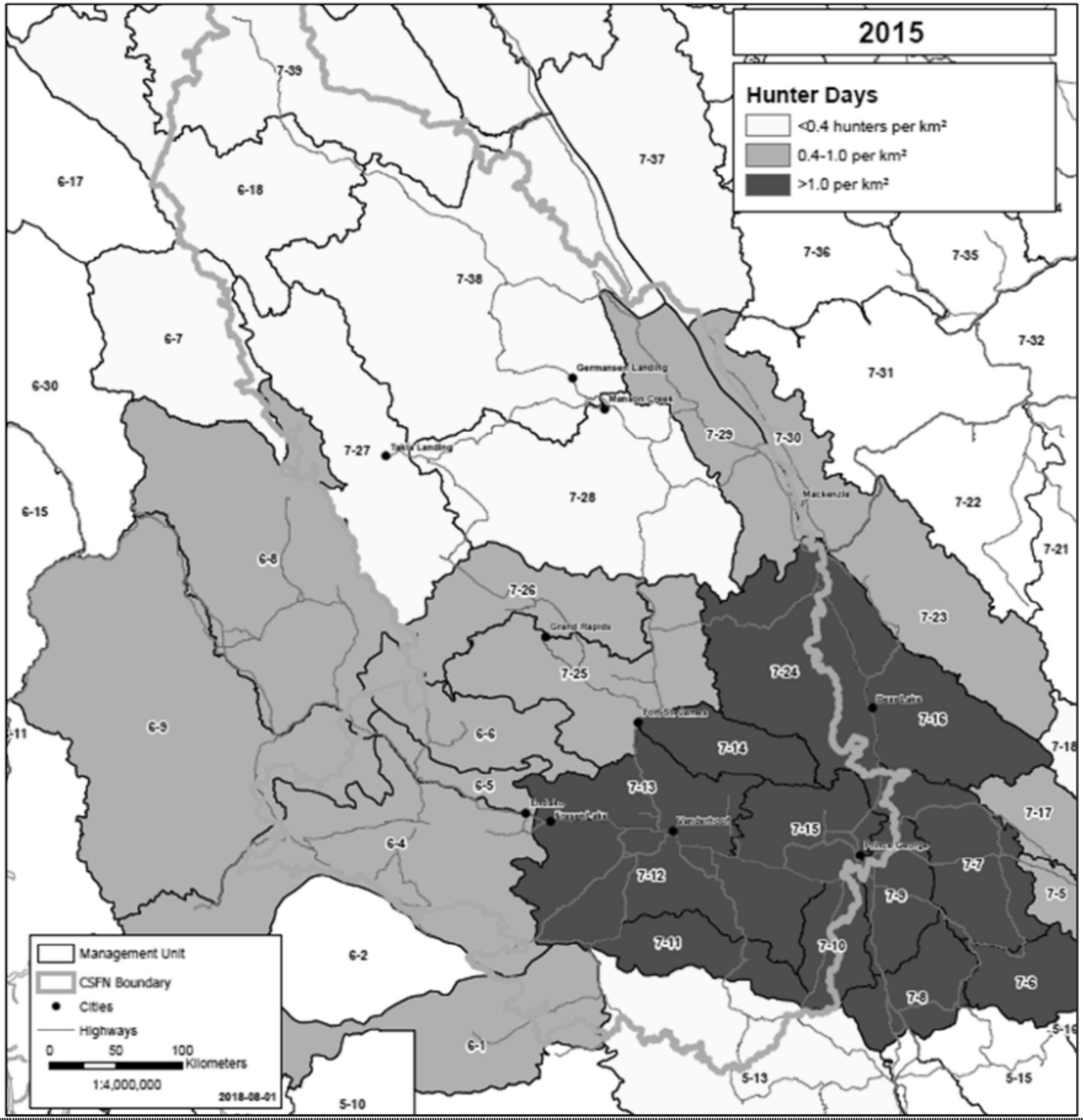
INDICATOR: LICENCED HUNTER DAYS

- <0.4 hunters per km^2
- 0.4 to 1.0 per km^2
- > 1.0 per km^2

ASSESSMENT RESULTS:

Of the 20 MUs predominately contained within the CSFN traditional territory, 7 were assessed as having >1.0 hunter days per km^2, 7 as 0.4-1.0 days per km^2, and 6 as having <0.4 hunter days per km^2.

CURRENT CONDITION:



ROAD DENSITY

RATIONALE:

The length of road within an MU is thought to increase susceptibility of moose to hunting because hunters can search larger areas where roads are abundant.

Higher road density is also likely to be directly associated with other forms of access; specifically use by predators such as wolves.

INDICATOR: ROAD DENSITY

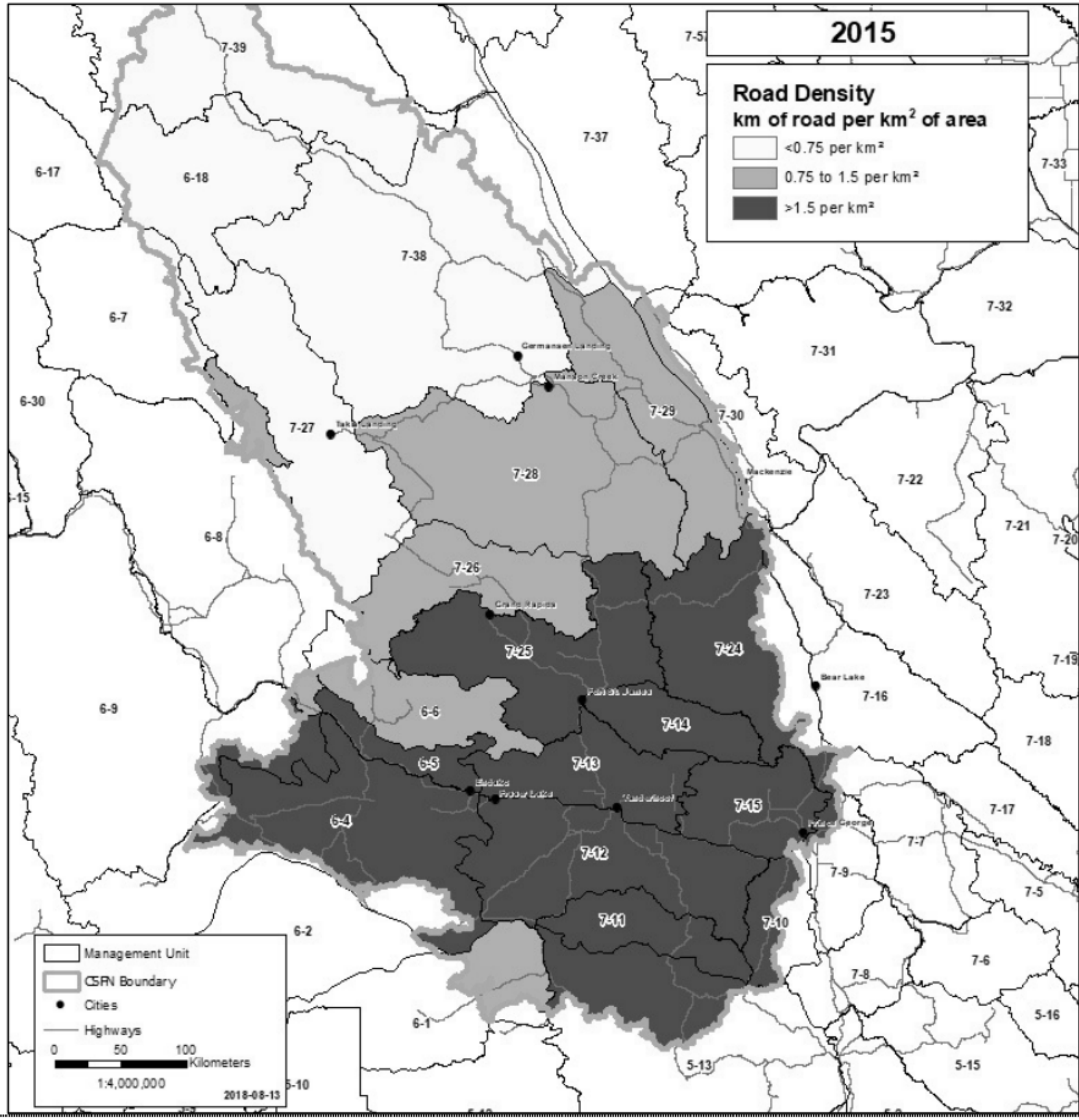
- <0.75 km of road per km^2 of area
- 0.75 to 1.5 km of road per km^2
- >1.5 km of road per km^2

ASSESSMENT RESULTS:

Road density was calculated only for the portion of the MU that fell within the CSFN area. For example, we only quantified road density within a small portion of MU 6-9 (shown in dark blue). Therefore, we did not extrapolate the results to the remainder of MU 6-9 (shown as "white" indicating no data or not assessed).

Of the 20 MUs predominately contained within the CSFN traditional territory, 11 were assessed as having >1.5 km or road per km^2, 5 as 0.75 to 1.5 per km^2, and the remainder as <0.75 km of road per km^2. The highest density of roads occurs in the southern half of the project area (as indicated by dark blue).

CURRENT CONDITION:



WOLF DENSITY

RATIONALE:

Wolves are the major natural predator of moose and can significantly influence their population size and structure. Higher wolf densities generally lead to higher predation rates on moose.

Wolf Density for each MU was based on the average licenced hunter results from the provincial Hunter Harvest Survey database with the addition of trapline records. The trapline records are actual reported trapping results and are not an estimate. Results are displayed for entire MUs; the extent of the data coverage.

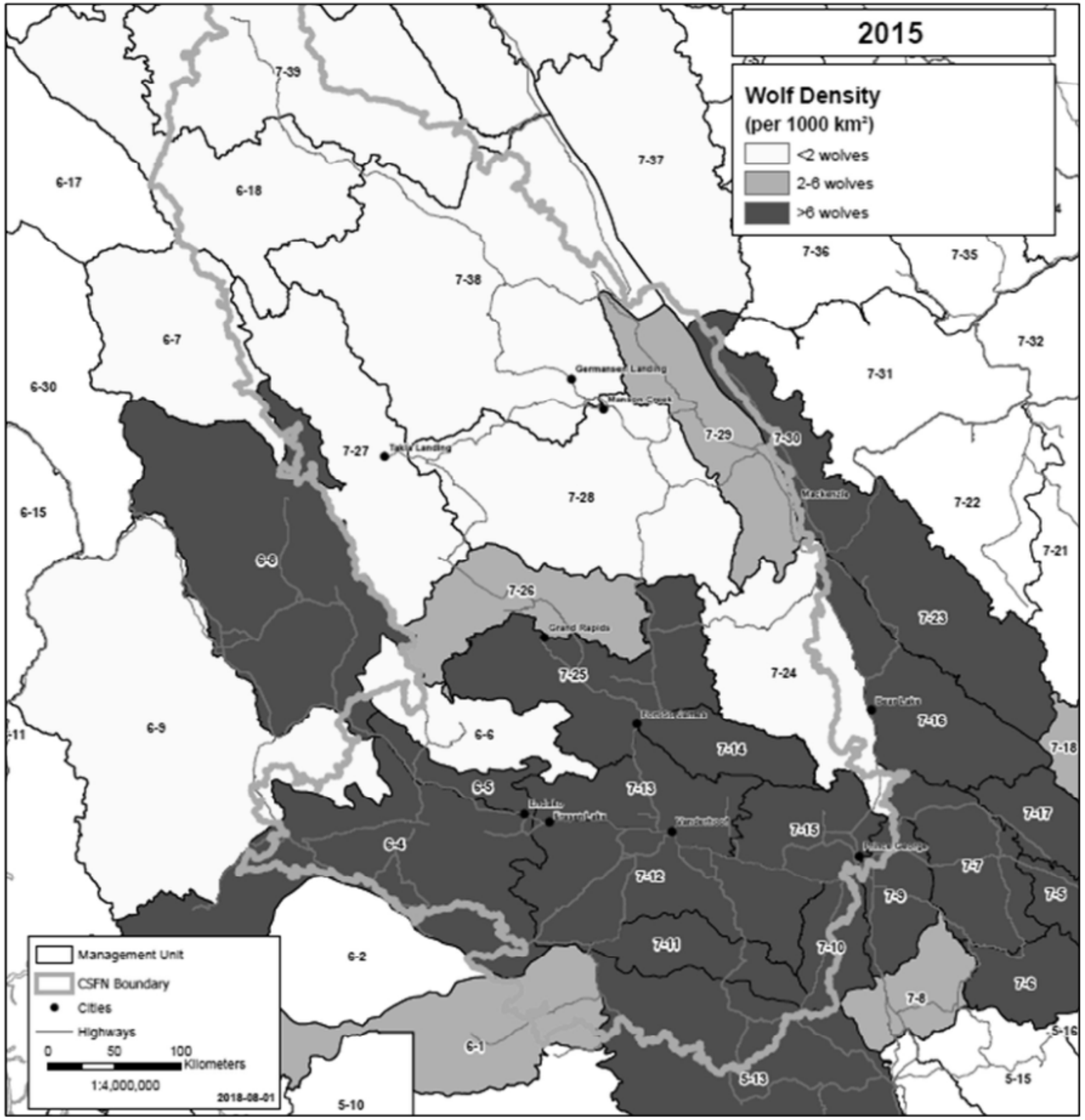
INDICATOR: WOLF DENSITY

- Estimate of < 2 wolves per 1,000 km^2
- Estimate of 2 to 6 wolves per 1,000 km^2
- Estimate of >6 per 1,000 km^2

ASSESSMENT RESULTS:

Of the 20 MUs predominately contained within the CSFN traditional territory, half were assessed as having >6 wolves per 1,000 km^2.

CURRENT CONDITION:



HABITAT SUITABILITY

RATIONALE:

Habitat suitability ratings (ranked Class 1 (High) to Class 5 (Very Low)), based on ecosystem types mapped at a broad level, were used to estimate potential moose densities (number of moose per km^2 of suitable habitat within the MU). Conditions representing 2000, 2008 and 2015 for winter habitat (forage and shelter) were included to provide input related to habitat availability and quality for each of the three time periods. It is assumed that MUs with higher proportions of suitable winter habitat would be advantageous to moose populations resulting in higher potential densities and higher juvenile recruitment.

Note: There were and still remain many questions related to habitat quality and effectiveness. Many of these questions were examined in a separate, related project via the creation of a Habitat Effectiveness Model (HEM).

INDICATOR: HABITAT SUITABILITY

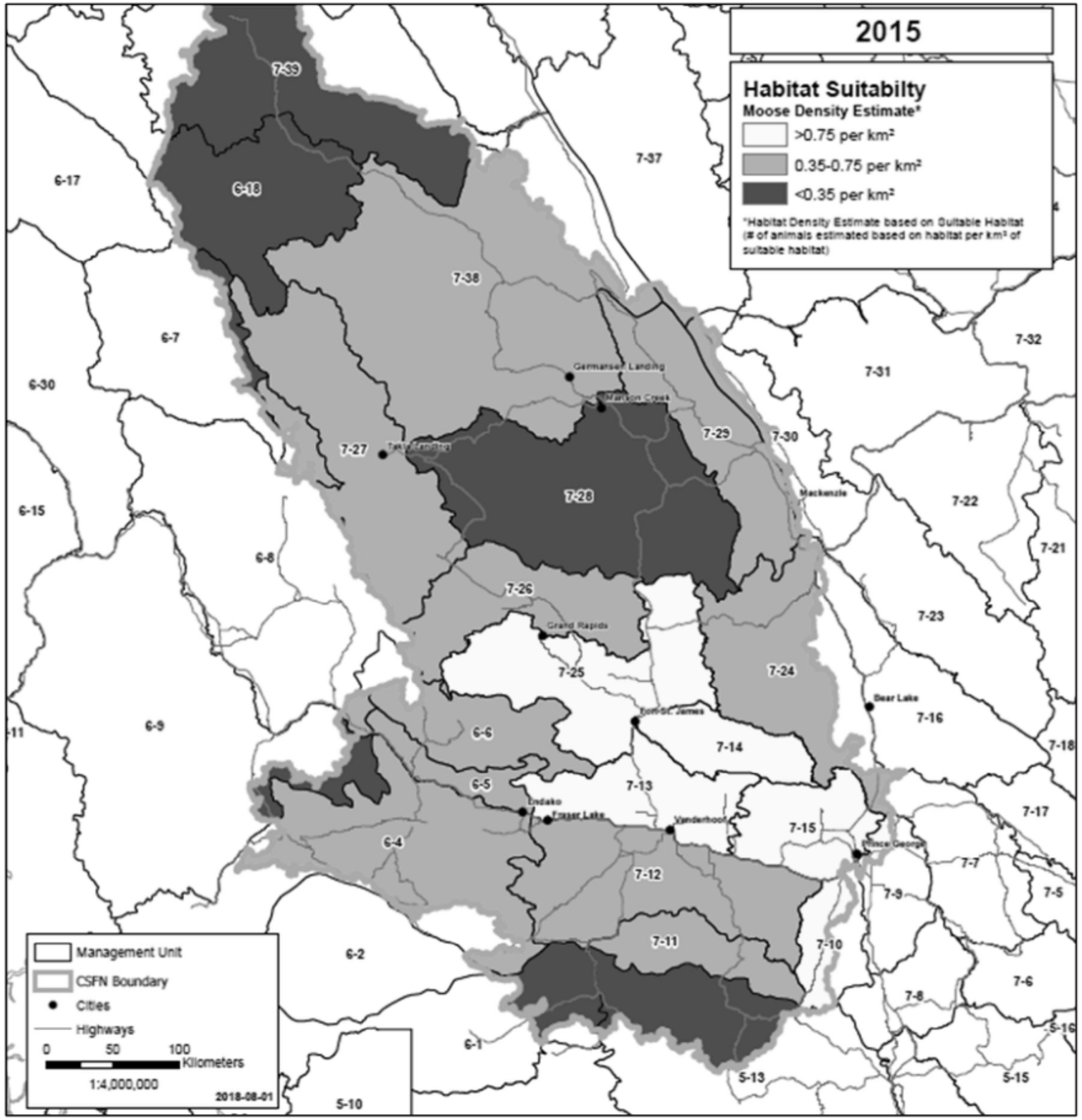
- <0.35 potential moose density/km^2 of suitable habitat
- 0.35-0.75 moose density/km^2
- >0.75 moose density/km^2

ASSESSMENT RESULTS:

Results are displayed for each MU based on the extent of the habitat suitability coverage within the CSFN project area.

Of the 20 main MUs that occur within the CSFN, 5 were assessed as <0.35 moose per km^2, 10 as 0.35 to 0.75 per km^2, and 5 as having the potential habitat suitability to support >0.75 moose per km^2.

HABITAT SUITABILITY AS AN INDICATOR OF POTENTIAL MOOSE DENSITIES:



INCORPORATION OF THE SRB DATA

RATIONALE:

Moose population size is estimated through Stratified Random Block (SRB) surveys conducted roughly every 5 years. Data from these surveys is extrapolated from the area surveyed to a larger area of suitable winter moose habitat. Survey data are critical to the modelling process because they provide information to calibrate model parameters.

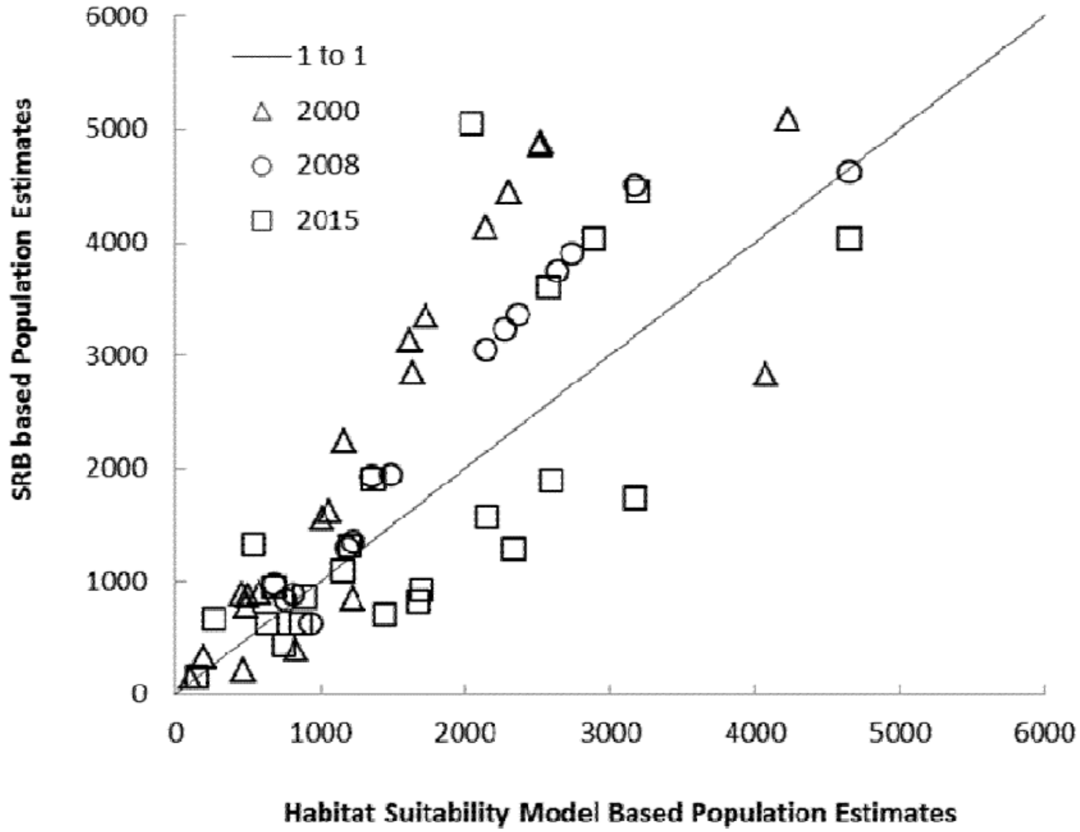
On completion of the draft model, the recommendation to incorporate SRB data was approved by Team Moose. This step was conducted with the intent to increase confidence in the population estimates contained within the population model (observed from SRB surveys vs. predicted via a habitat suitability model).

Extensive discussion took place with Team Moose to determine the best and most efficient way to collect and incorporate the SRB data.

ASSESSMENT RESULTS:

Survey results vary from year-to-year for a variety of reasons (e.g., survey conditions, stochastic impacts on survival and reproduction), and it is important that we not over-fit our models to the precise estimates derived from surveys. However, survey data should be used to test assumptions and calibrate parameters on an ongoing basis.

OBSERVED VS. PREDICTED:



In the above graph, SRB population estimates are regressed against habitat suitability-based estimates for each Management Unit during three survey years: 2000, 2008, and 2015.

The solid line represents a 1:1 correspondence. If the habitat suitability model were a perfect predictor of population size, and SRB surveys calculated population size without error, all of the points would line up along the solid line. Of course, there are many other factors affecting population estimates, and these factors manifest as variation along y-axis. For example, in years of low moose abundance, points should generally occur below the 1:1 line, and in years of high abundance, points should generally be above the line.

REGIONAL MODEL FOR POPULATION TREND

RATIONALE:

The Provincial Framework for Moose Management in BC supports the goal "to ensure moose are maintained as integral components of natural ecosystems throughout their range, and maintain sustainable moose populations that meet the needs of First Nations, licenced hunters, and the guiding industry." This indicator was based on moose surveys in the Omineca Region over the last 15-20 years.

The modelling process generates useful testable hypotheses that can be confirmed or refuted through additional data collection. As a result, the model can be updated iteratively as information improves to ensure that management decisions are always based on current information.

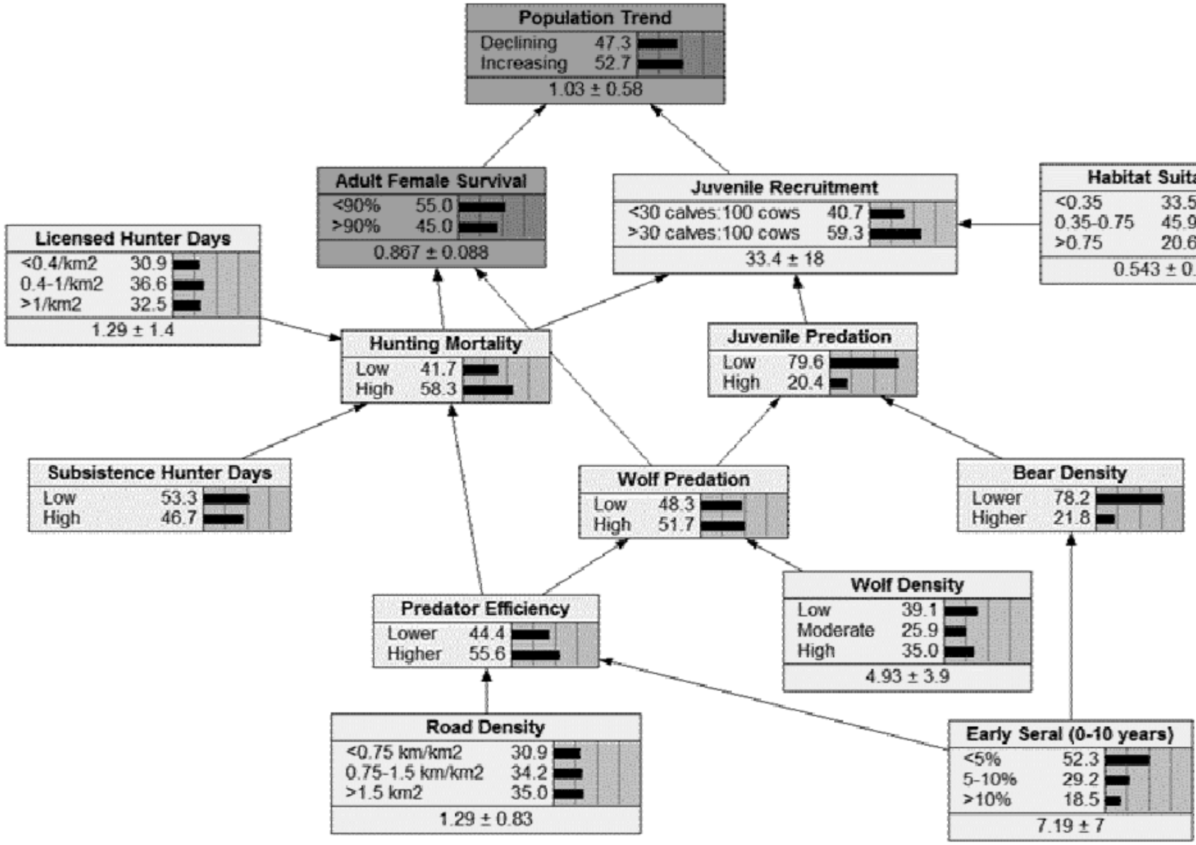
INDICATOR: POPULATION TREND

Increasing or Decreasing

ASSESSMENT RESULTS:

The Population Trend box (node) at the top represents the overall (regional) probability of a positive population trend as slightly more likely to be increasing (52.7% vs. 47.3%) based on roughly a 15 year trend.

REGIONAL MODEL V3.0:



Note: The above example of the model is based on data representing three time periods (2000, 2008, and 2015) from 40 management units for a total of 120 rows of input data (cases).

REGIONAL MODEL FOR POPULATION TREND

RATIONALE:

The likelihood of a positive population trend is an integrated measure of conditions for moose, based on available population and habitat data for a Management Unit.

INDICATOR: POPULATION TREND

Increasing or Decreasing

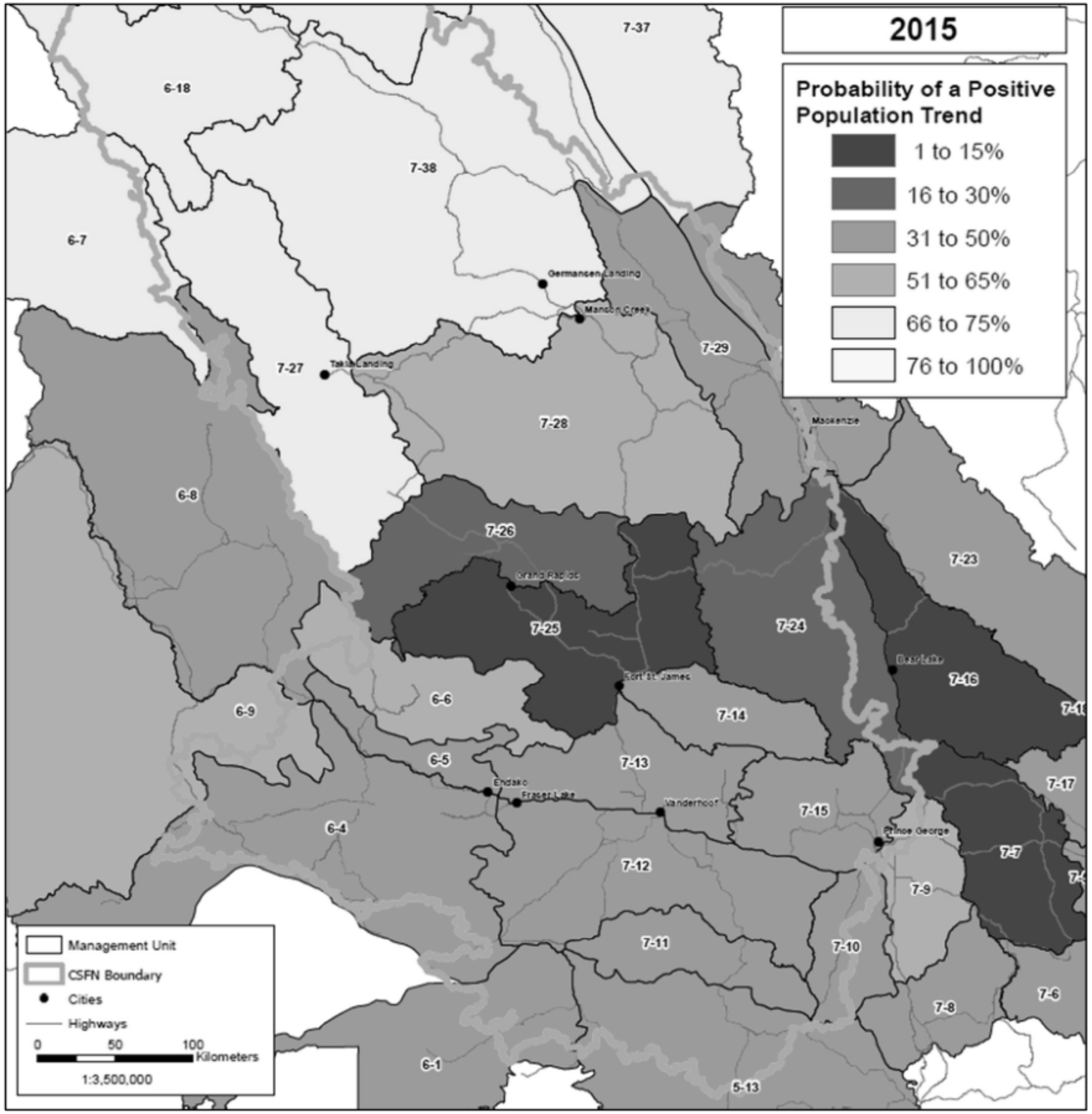
ASSESSMENT RESULTS:

The example figure depicts results of the model for population trend current (2015) conditions based on a six scale colour ramp. Based on the regional data, the model indicates that the majority of the southern part of the project area has a less than 50% probability of having a positive population trend.

In contrast, the northern MUs were indicated as more likely to have a positive population trend. In contrast, for the time period "2000" the model indicated that the majority of MUs had a greater than 50% chance of a positive population trend. Refer to the project report for further details and tables of results.

Extreme care should be exercised in applying these results at any different scale than the MU. Regional species experts should be consulted before making any interpretations for areas not specifically defined by MU boundaries.

EXAMPLE OF POTENTIAL CURRENT CONDITIONS:



KNOWLEDGE TRANSFER AND APPLICATIONS OF THE MODEL

RATIONALE:

Due to the complexity of probability models (the input, the software, and the output), Team Moose supported efforts to "deep dive" into the model. Two training workshops were conducted on how to run the model and interpret results were provided to Team Moose and other ESI project team members.

The population trend model was developed as a Bayesian Belief Network using the modelling shell Netica® (version 5.24; Norsys Software Corp., Vancouver, BC). http://www.norsys.com/download.html.

APPLICATIONS:

The model integrates available data to predict population trends and the likely causes of those trends. Applications include identifying where:

- Moose may be at highest risk;
- Predation risk is high and/or increasing;
- Habitat suitability is likely changing;
- Road density may be creating risks; and,
- Cow:Calf ratios are low.

The model assists in generation of testable hypotheses (e.g., predicts cow:calf ratios and adult female survival, which can then be corroborated through additional survey work or research) and can forecast the effects of management actions on moose population trends.

HOW TO RUN THE MODEL AND INTERPRET THE OUTPUT – TRAINING VIDEOS:

Video Segment	START	STOP	SEGMENT/TOPIC
Part 1 *Omineca BBN Model v3_Part 1.mp4* *301MB*	0	1:41	Overview of topics going to be covered
	1:41	7:09	Basic model descriptions, Bayesian Network Model concept
	0:7:09	0:11	Advantages of Bayesian Models
	0:11	0:13	Disadvantages of Bayesian Models
	0:13	1:02	Simple examples of building a models using Netica Application
Part 2 *Omineca BBN Model v3_Part 2.mp4* *635MB*	1:02	1:26	Unlearned to learned version moose model
	1:26	1:38	Model Sensitivity, sensitivity analysis in model
	1:38	1:56	Specific Situations, for wildlife management unit
	1:56	2:06	How to obtain outputs, and going through the output numbers
	2:06	2:09	Updating model with new data
	2:09	2:14	Required data for an effective/reliable model
	2:14	2:18	Model Revisions (how to update the model)
	2:18	2:26	Different model/modeling software shown
	2:26	2:31	Modeling Best Practices

NEXT STEPS:

- What is the best way to use the model going forward?
    - We can use the model to test the different management options. The model offers expected outcomes to management changes and answers the question "what is the likely effect of our management actions, applied independently or collectively?"
- Firmly determine how to include habitat effectiveness and adjacency in the model. Is habitat effectiveness sufficiently reflected in other nodes/inputs? Do more nodes/inputs need to be included to fully encompass habitat effectiveness (a proximity/distance-to-edge node could be included, for instance).
- Should we endeavor to construct an independent BBN for habitat effectiveness? A BBN model focused on Population Estimates/Densities would be a better "match" for focusing on how habitat effectiveness could influence moose numbers.

Cumulative Effects Framework: Assessment Protocol for Moose in British Columbia

Standards for British Columbia's Values Foundation

Prepared by

Provincial Moose Technical Working Group – Ministries of Environment and Forest, Lands and Natural Resource Operations

18 May 2017

Version 2.0 (Updated to incorporate internal and external engagement – enhanced to provide balance of habitat and population assessment components)

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Acknowledgements

This protocol is based on foundational work developed by Demarchi and Hertze (2015) and Dawson et al. (2015).

The Provincial Moose Technical Working Group (PMTWG) (Tony Button, Gerald Kuzyk, Mark McGirr, and Steve Wilson) of the Cumulative Effects Framework (CEF) initiative adopted a moose management assessment protocol in August 2016 (Version 1.0). The logic and parameters of the protocol were documented in a draft report *Cumulative Effects Assessment Methods for Moose in British Columbia* (August 26, 2016). The assessment approach was consistent with one developed for use in regional cumulative effects work in the Thompson-Okanagan.

Version 1.0 of the CEF assessment protocol for moose in British Columbia (B.C.) was circulated for internal review starting in October of 2016. An updated version of the documentation (February 21, 2017; Version 1.1) incorporated editorial review and feedback, and summarized limitations and issues noted from the internal engagement process. The updated document (Version 1.1) was circulated and a webinar was hosted by PMTWG on April 12, 2017 for additional internal engagement.

External engagement was initiated in March of 2017 via invitation to a webinar hosted by the PMTWG.

Updates and enhancements to this document are the direct result of feedback provided through internal and external engagement. A number of the enhancements to the protocol are related to Habitat and Risk Assessments adapted from work completed by Rick Dawson, Robin Hoffos, and Mark McGirr in *A Broad Scale Cumulative Impact Assessment Framework for the Cariboo-Chilcotin* (Dawson et al. 2015).

Citation:

Provincial Moose Technical Working Group (PMTWG). 2017. Cumulative Effects Assessment Protocol for Moose in British Columbia. Version 2.0 (May 2017). Prepared by the Provincial Moose Technical Working Group – Ministries of Environment and Forest, Lands and Natural Resource Operations – for the Value Foundation Steering Committee.

Executive Summary

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Moose are one of five high-value resources identified for provincial assessment under British Columbia's (B.C.) Cumulative Effects Framework (CEF). Moose are a high priority species for the Province, which has legal authority for its conservation and management. The importance of this species is reflected in the objectives established for moose through legislation, regulation, and policy.

Moose are a conspicuous and iconic part of British Columbia's fauna that have environmental, economic, social and cultural importance. First Nations rely on moose for social, ceremonial, and sustenance purposes. Moose also provide recreational opportunities to resident and non-resident hunters, and their harvest provides economic benefits through the sale of hunting licenses and associated expenditures.

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Moose are a wide-ranging species, and they depend upon multiple, well-connected and functioning habitat with properly functioning ecosystem processes. As such, moose are susceptible to cumulative impacts on their habitat and their populations from extensive land use activities and disturbances. As a species that can tolerate, and may even benefit from, some human activities on the landscape, moose-human interactions are common and complex.

The purpose of this document is to provide a standardised provincial method (protocol) for evaluating cumulative effects on moose across the province of B.C.; while also allowing a degree of flexibility within regions of the province. The protocol is intended to provide a transparent and repeatable provincial standard for assessing moose that can be periodically updated. The protocol consists of two assessment components: 1) habitat, and 2) population. Results from habitat and population assessment components provide a systematic and comprehensive approach to describing, rating, and estimating risk.

Assessment of the habitat component is organized around habitat capability, habitat suitability, and habitat effectiveness. Results of the habitat assessment are integrated directly into the population assessment.

Assessment of the population component provides an indication of whether moose in a Wildlife Management Unit (~~referred to as Management Units (MU) in this protocol~~WMU) are increasing, stable, or decreasing; based on indicators representing various aspects of moose population structure and dynamics.

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Results of the habitat and population assessments provide estimates of risk that focus on ecological importance, hazards, and current mitigation.

~~This protocol provides a standardised provincial method of assessment for evaluating cumulative effects on moose across the province of B.C.; while also allowing a degree of flexibility within regions of the province.~~ While there has been general agreement that the assessment protocol captures appropriate variables and relationships, feedback through internal and external review highlighted opportunities for improvement.

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Use of this information should anticipate some changes in the substance and formatting of the assessment protocol in the future. It is expected that results from regional assessments will potentially clarify, standardize and improve the assessment protocol.

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List of Acronyms

BBN	Bayesian Belief Network
B.C.	British Columbia
BEI	Broad Ecosystem Inventory
CDC	Conservation Data Centre
CE	Cumulative Effects
CEF	Cumulative Effects Framework
CPT	Conditional Probability Table
FLNRO	Ministry of Forests, Lands and Natural Resource Operations
FRPA	*Forest and Range Practices Act*
HHS	Hunter Harvest Statistics
LEH	Limited Entry Hunting
~~MU (~~WMU~~)~~	Management Unit (also referred to as Wildlife Management Unit)
OGAA	*Oil and Gas Activities Act*
VRI	Vegetation Resource Inventory

1 Introduction

Moose (*Alces americanus*) are a conspicuous and iconic part of British Columbia's (B.C.) fauna that have environmental, economic, social and cultural importance. First Nations rely on moose for social, ceremonial, and sustenance purposes. Moose also provide recreational opportunities to resident and non-resident hunters, and their harvest provides economic benefits through the sale of hunting licenses and associated expenditures. The importance of this species is reflected in the objectives established for moose through legislation, regulation and policy.

Moose are a wide-ranging species, and they depend upon multiple, well-connected and functioning habitat with properly functioning ecosystem processes. As such, moose are susceptible to cumulative impacts on their habitat and their populations from extensive land use activities and disturbances. As a species that can tolerate, and may even benefit from, some human activities on the landscape, moose-human interactions are common and complex.

Additionally, the harvest demand for moose is high and typically exceeds the available yield. Thus, moose are a high priority species for the Province, which has legal authority for its management and conservation. Moose management strives to balance the use, rights, and traditions of First Nations,; the hunting opportunities for resident hunters,; and the hunting opportunities for non-resident hunters through the guide outfitting industry, with conservation requirements and objectives of the species.

Based on the numerous factors outlined above, moose have been identified as a high-value resource for provincial assessment under British Columbia's Cumulative Effects Framework (CEF). The purpose of this document is to provide methods for evaluating cumulative effects on moose across the province of B.C. This protocol is intended to provide a transparent, repeatable provincial standard for assessing moose that can be periodically updated.

1.1 Current Distribution and Status

Moose are generally abundant and distributed widely throughout most of B.C., with notable exceptions being Haida Gwaii, Vancouver Island, the Lower Mainland, and portions of the mainland coast. In B.C., moose are managed at the species level, and are currently on the provincial Yellow List and are not considered at risk (CDC 2017). s.13

1.2 Cumulative Effects Framework and Legal Context

In ~~British Columbia's~~B.C.'s CEF, cumulative effects are defined as "changes to environmental, social, and economic values caused by the combined effect of past, present, and potential future activities and natural processes". In addition to moose, other values currently being assessed under the CEF include: Grizzly Bear, Forest Biodiversity, Old Forest, and Aquatic Ecosystems~~s~~.

Cumulative effects assessments (CEAs) are completed on identified environmental, social, and economic values using the best-available scientific knowledge, information, and understanding. This science-based assessment relies on the identification of benchmarks[1] to appraise the condition of the value. The desired outcome from this assessment is to provide information that can be used by decision makers to maintain the value objectives.

Objectives are the desired condition of a value obtained from existing legislation, policy, land use plans, and other agreements that are described in a qualitative or quantitative manner. Cumulative effects are assessed relative to the objectives for the value on a regional basis. Objectives for moose are derived from provincial legislation and regulations that outline both broad and specific direction for sustaining moose populations.

Some pieces of legislation that inform objectives for moose include:

- *Forest and Range Practices Act* (FRPA) – Ungulate Winter Range designations
- *Oil and Gas Activities Act* (OGAA) – Ungulate Winter Range designations
- *Land Act* – Land-use plan direction and objectives specific to moose
- *Wildlife Act* – hunting regulations

The Provincial Framework for Moose Management in British Columbia (FLNRO 2015) supports the goal "to ensure moose are maintained as integral components of natural ecosystems throughout their range, and maintain sustainable moose populations that meet the needs of First Nations, licenced hunters, and the guiding industry." The associated broad objectives are to:

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1. Ensure opportunities for consumptive use of moose are sustainable;
2. Maintain a diversity of hunting opportunities; and
3. Follow provincial policies and procedures (e.g. provincial moose harvest management procedure) as guidance for regulatory options and management objectives.

The broad objective for this moose assessment summarizes a number of provincial broad and specific objectives for moose included in various legislation, regulations and policy, and is stated as follows:

> *"Maintain self-sustaining populations of moose throughout their current range and provide opportunities for consumptive and non-consumptive use."*

Where specific objectives exist, they may be approved for use as management review triggers in the assessment. Management review triggers identify where government is approaching or exceeding a specific legal or policy objective. Management review triggers delineate enhanced or intensive management review classes, where the review of management responses will be considered to either prevent the condition of the value from exceeding the objective, or to return the condition of the value to meeting the objective.

[1] Benchmarks are proposed reference points that support interpretation of the condition of an indicator or component. Benchmarks are based on our scientific understanding of a system, and may or may not be defined in policy or legislation.

1.3 Overview of Assessment Protocol

The moose assessment protocol comprises components, indicators, factors, functions and processes that capture different aspects of moose ecology. Two ecological components and their associated indicators are assessed: 1) habitat, and 2) population.

Inputs and outputs (results) from assessment of these two components are used to provide measurements and ratings of ecological importance and hazard. When examined in combination with current mitigation an estimate of risk to the moose value is determined. Figure 1 provides a conceptual diagram for the moose value assessment protocol.

The habitat, population, and risk assessments are not intended to capture all potential factors, functions, and indicators but, rather, focus on ones hypothesized to have a significant effect on moose. Key factors, functions, and indicators selected for assessment include ones that are:

i. under management control, and/or
ii. associated with existing regulations, policy or guidance, and/or
iii. measurable with available data sets (or confidently quantifiable using expert opinion), and/or,
iv. believed to comprise the most parsimonious set of variables.

The systems affecting moose, as currently conceptualized, are based on expert knowledge from moose biologists and researchers throughout B.C., and a review of existing information presented as a supporting document to the protocol; *Moose Value Knowledge and Legislation Summaries*.

1.3.1 Scale of Analysis

The population assessment is designed to reflect increasing confidence in the values assigned to specific indicators and/or components as more precise input data become available. Although initial data are not required for every input to generate an estimated condition, assessment confidence increases as data quantity and quality increase.

The scale of analysis (the assessment unit) is important to consider; review feedback and discussions regarding this topic during internal engagement were extensive. If very large areas are used, the results will be the average for a very large area, which will often mask important variation within the unit.

Indicators and components can be mapped at any scale, depending on the resolution of the input variables, but are generalized to the ~~Wildlife Management Unit~~WMU scale (~~referred to as Management Units (MU) in this protocol~~). MUs are the spatial areas used to manage moose harvest and these align with the harvest data and management options inputted into the population assessment.

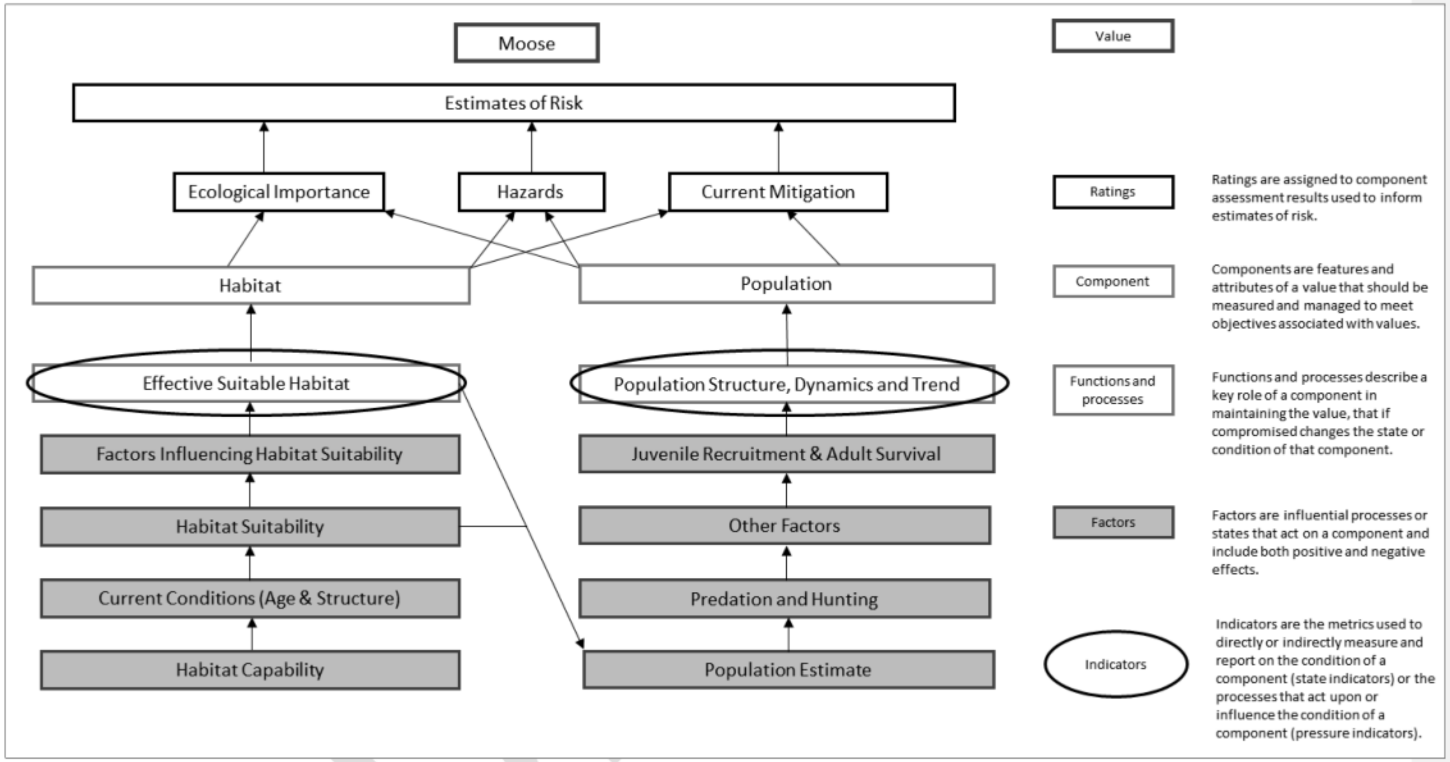

Figure 1. Conceptual diagram for the moose value assessment protocol.

Adult Female Survival Rate, Juvenile Recruitment Rate, and Population Trend should only be applied and used at a WMU level. Harvest data derived products should not be developed or used at a finer scale than the WMU. Harvest data is gathered and estimated at the WMU scale and can be applied across one or more Management Units. Population assessment indicators that use harvest related inputs must be summarized at the Management Unit or coarser scale.

Habitat is mapped and managed at a variety of scales in order that it can be scaled up and summarized at a WMU level to accommodate an integrated habitat-population model. Habitat assessment units are sub-units of Landscape Units based largely on watershed boundaries.

2 Habitat Assessment

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Concepts important to understanding the selection of habitat indicators include key life requisites for moose, and associated habitat capability, suitability, and effectiveness (how the habitat is affected by human disturbance). Capability indicates the potential number of moose when habitat is in optimal condition for moose. Suitability indicates the potential number of moose in its current condition (before adjusting for non-habitat factors; e.g. predation, inter/intra species dynamics). Habitat effectiveness incorporates the effects of human access and disturbance on amount and quality of available habitat.

2.1 Key Life Requisites

Food, cover, reproduction, and mobility are all basic requirements for moose. Although these needs are all important, and may change according to season, the assessment focuses on the life requisites that are considered most limiting to the population (referred to as key life requisites).

Winter forage and shelter habitat are key life requisites used because they are important limiting habitats for moose populations. Moose will also use some of the same habitats in spring, summer and fall, but they will range much more widely in those seasons allowing them to spread out to access more forage that was not available in the winter and to more effectively avoid predation.

2.1.1 Dynamic and Static Forage

Two types of forage habitat are identified:

- **Dynamic** forage habitat is created by disturbances such as fire or harvesting which put forested sites back to an earlier, shrubby successional stage that lasts for a relatively short period of time at a specific location and then may be created in another location by further disturbance.
- **Static** forage habitat does not move around the landscape and includes habitats such as wetlands, riparian areas and self-sustaining deciduous forests.

These two types of moose forage habitat have different management implications because of their different degrees of permanence on the landscape. Maps and assessment information that separate the two types therefore provide useful information for resource managers.

Forest cover for hiding, thermal protection, and snow interception (shelter) are important components of moose winter habitat. The requirements and relative importance of these three functions of cover vary across the province, between and within regions depending on factors such as snow depth and winter temperature.

2.2 Habitat Capability and Suitability

Wildlife habitat capability and suitability describe the potential quality and current state of wildlife habitat in a given area. Capable habitat includes all the area that has potential value for moose winter habitat. Suitable habitat represents the current state of the habitat and is a subset of capable habitat.

Definitions for capability and suitability from the Ministry of Environment publication *British Columbia Wildlife Rating Standards*[2] are:

"***Capability** is defined as the ability of the habitat, under the optimal natural (seral) conditions for a species to provide its life requisites, irrespective of the current condition of the habitat.* It is an estimate of the highest potential value of a particular habitat for a particular species and is useful in providing predictive scenarios for various habitat management options. The provincial Broad Ecosystem Inventory (BEI) maps for moose capability were used for the habitat capability. The highest capability rating for each BEI polygon was used as the input.

***Suitability** is defined as the ability of the habitat in its current condition to provide the life requisites of a species.* It is an estimate of how well current habitat conditions provide the specified life requisite(s) of the species being considered. The suitability of the land is frequently less than the capability because of unfavourable seral conditions.

Reductions to suitable habitat from human access and disturbance result in effective habitat (Figure 2).

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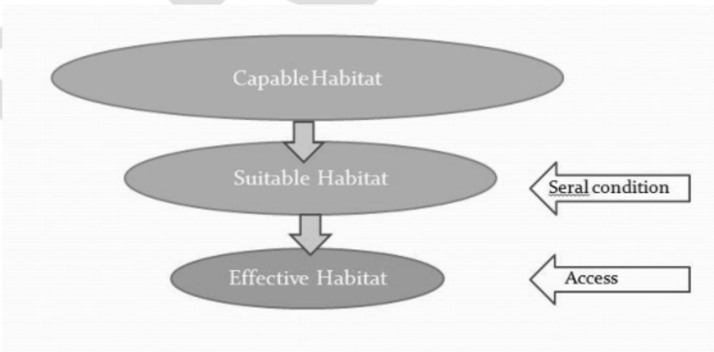

Figure 2. The relationship of capable, suitable, and effective habitat.

[2] https://www.for.gov.bc.ca/hts/risc/pubs/teecolo/whrs/assets/whrs.pdf

Figure 3 is a conceptual diagram of factors, functions and processes affecting the moose habitat component, and associated indicators. The habitat indicators are summarized in Table 1 and described in the following subsections.

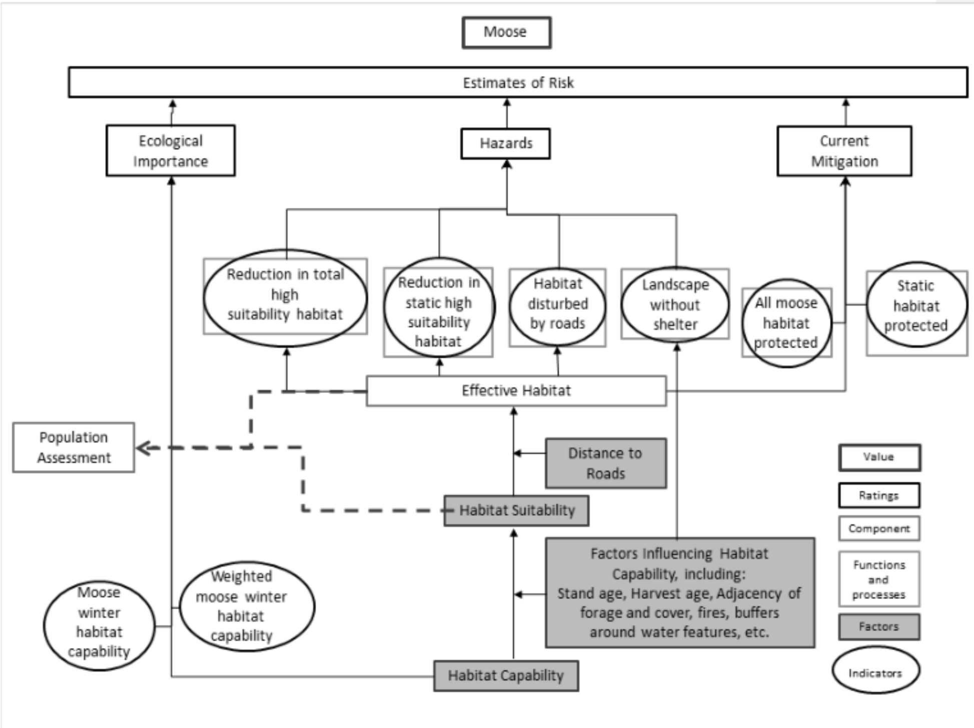

Figure 3. Overview of the key factors, functions, and processes for the moose value habitat assessment.

2.3 Habitat Indicators

Careful selection and design of habitat indicators is critical to produce meaningful assessments. Criteria used for selection of indicators included the following:

- Clear and meaningful relationship between each indicator and key habitat requirements for moose, and key attributes for coarse filter values;
- Readily measureable and understandable;
- As simple as and as few as possible while still providing a meaningful assessment; and
- Hazard indicators that relate to expected types of impacts resulting from human activities and natural disturbance.

Table 1. Summary of indicators in the moose habitat assessment. s.13

Category	Indicators	Description of Measurement	Comments
Habitat Baseline	Moose winter habitat	Percent of the assessment unit classified as capability class 1-5. Class 1-5 includes all winter habitat from very high to very low capability.	Based on provincial Broad Ecosystem Inventory (BEI) moose winter habitat capability mapping. The weightings for the second indicator are based on the relative habitat quality estimates built into the provincial wildlife habitat capability ratings.
	Weighted habitat capability	Weighted % of the total moose winter habitat classified as low, moderate and high capability: 100/75 X ((class 1-2 area X 0.75)+(Class 3 area X 0.37)+ (class 4-5 area X 0.125)) The number is multiplied by 100/75 to standardize the maximum score to be 100.	
Habitat reduced by development	Reduction in total high suitability habitat	Percent reduction in total high suitability moose winter habitat between undeveloped and current landscape.	Indicates the reduction in total modelled high suitability moose winter habitat as a result of forest harvesting to date.
	Reduction in Static high suitability habitat	Percent reduction in static, high suitability moose winter habitat between undeveloped and current landscape.	Indicates the reduction in static modelled high suitability moose winter habitat as a result of forest harvesting to date.
Capable area lacking Adequate cover	Landscape without adequate shelter	Percent of capability 1-5 habitat that does not meet shelter criteria. Evaluated in all 10 km^2 cells in capable habitat.	
Road Disturbance	% Road disturbance of high suitability habitat	Percentage of the high suitability moose habitat in all capability classes that is within 1000m of a paved or gravel road.	This indicator assesses habitat disturbance resulting from paved and gravel roads as defined in the Digital Road Atlas. It does not include the many small roads and 'in block" roads referred to as "undefined".

2.3.1 Habitat Baseline

Current high suitability moose winter habitat area is compared with the same area in a simulated "Undeveloped Landscape" which is used as a baseline. This undeveloped landscape is created by replacing logged areas with conifer stands capable of providing moose shelter habitat (>60years old). The assessment determines the area of "Total High Suitability Moose Winter Habitat" in the undeveloped landscape and compares it with the current landscape to indicate change in available habitat.

Using this undeveloped landscape as a reference point for the analysis is a simple approach to assessing landscape change which does not incorporate the potential landscape composition effects of natural disturbance. However, after examination of the options, this approach was selected because it provides a way of documenting how much habitat change has happened up to the present and because it does so spatially.

For moose, this spatially explicit analysis recognized the need to have current forest cover adjacent or close to important feeding areas. It also allowed habitat suitability (current patterns of winter habitat) to be assessed in relation to habitat capability. In addition, this assessment provides a baseline for evaluation of moose forage areas created by forest harvesting and wildfire.

An alternative method would compare non-spatial habitat proportions in the current landscape to habitat proportions in a simulated naturally disturbed landscape. While this approach would better reflect natural disturbance effects, it would lack the important spatial specificity related to adjacency of cover and forage.

The use of a simple reference landscape allows for meaningful, spatially explicit assessments. The possible errors resulting from the use of this method due to the omission of natural disturbance are acknowledged. Therefore the raw numbers for habitat reduction indicators are an approximate measure of divergence between a consistent reference landscape and current conditions. This comparison is intended to provide a meaningful indication of relative habitat conditions across the province.

2.3.2 Landscape Shelter Indicator

Each moose winter home range requires both forage and adequate shelter to provide effective habitat. A potential home range area with lots of forage habitat will only function as fully effective habitat if it also has adequate shelter. Landscapes with a very high level of disturbance can sometimes have much forage habitat but not enough shelter. The landscape shelter indicator assesses the adequacy of cover for moose over all potential home range units in the assessment unit. As well as estimating the proportion of potential home ranges with adequate cover, it is also an index of the distribution of the amount and distribution of cover required for moose to travel across the unit.

This indicator is different than the other indicators in that it is assessed across all capable habitat rather than just over the best habitat. It essentially measures if, or the extent to which, moose winter habitat values across the whole assessment unit have been compromised by very high levels of disturbance even if this disturbance has provided large areas of forage habitat.

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The landscape shelter indicator is designed to estimate the proportion of the capable habitat area within each assessment unit that has an adequate amount and suitable distribution of thermal/snow interception cover to provide useful habitat for moose in winter.

2.3.3 Static Habitat

As large-bodied browsers, moose require abundant, shrubby vegetation, which is found most commonly in riparian and wetland areas, as well as in young, regenerating forests (Shackleton 2013).

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Two types of forage habitat are identified:

1) "Dynamic" early seral forage habitat is created by disturbances such as fire or forest harvesting which put forested sites back to an earlier, shrubby successional stage that lasts for a relatively short period of time at a specific location and then may be created in another location by further disturbance.

2) "Static" forage habitat does not move around the landscape and includes habitats such as wetlands, riparian areas and self-sustaining deciduous forests. Static habitat is also considered important for life requisites such as calving.

Static habitat was defined as areas classified as wetlands or >50% riparian habitat using land cover data. Seral forest-related inputs were based on Vegetation Resources Inventory (VRI) data.

2.3.4 Roads

The effectiveness of moose habitat is reduced by having well-used roads located within one kilometre of important habitat. The assessment methods recognizes this by calculating the proportion of "disturbed" moose habitat within the high suitability areas.

Disturbed Moose Winter Habitat (ha) = High Suitability Moose Winter Habitat that is within 1 kilometre of a gravel or paved road or the footprint of a major development such as a mine.

2.3.5 High Suitability Winter Habitat

The assessment first defines potential habitat for winter feeding and winter thermal/snow interception cover. It then applies a proximity constraint between the potential feed and cover habitats types to ensure that the habitat can be effectively used. The result is "Effective Winter Feeding Habitat" and "Effective Winter Shelter Habitat". The sum of these two is defined as the "Effective High Suitability Moose Winter Habitat". This approach is designed to define the high suitability habitat, but does not identify all habitat used by moose throughout the winter. Moose can make significant use of sub-optimal habitat for various reasons such as reducing predation risk.

Since high suitability habitat is defined the same way in every assessment unit, this approach allows for valid and consistent broad scale assessment and comparisons between assessment units. However, care must be taken when using maps of habitat for planning at scales finer than the habitat assessment unit since GIS data is rarely perfect. In addition, not all details of habitat across the province and within regions are incorporated yet.

2.4 Integration With Population

Results of the habitat assessment are integrated into the population assessment via providing a population estimate based on the abundance and quality of moose habitat. In addition, habitat data related to early seral and road density are integrated into factors related to predation, and the indicator related to vulnerability to hunting in the population assessment.

3 Population Assessment

Of all the wild ungulates in B.C., moose are among the most productive because: (i) adults can breed every year, (ii) twinning is not uncommon, and (iii) calf survival can be high where predation is modest. The combination of these factors makes moose particularly responsive to management actions geared to increasing moose production. It is important to note that although a species may be capable of a rapid population increase, environmental (e.g. predation) and human-caused factors can override the species' intrinsic tendency toward high rates of survival and reproduction, thereby causing a population decline.

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Identifying the factors that limit or regulate moose numbers is complex. A population at any given time and place reflects the composite effect of all limiting and regulating influences; rarely is it possible to measure the effect of any single factor or to rank that factor's importance relative to other factors (Connolly 1981). Despite these challenges, successful moose management requires that those factors that limit moose populations be understood if they are to be manipulated with the goal of managing moose (Van Ballenberghe and Ballard 1998).

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Although population dynamics can be very complex, at its simplest level population size is simply the mathematical result of births (natality) and deaths (mortality). If births exceed deaths the population will increase. If deaths exceed births, it will decrease. If births equal deaths, the population will be stable.

Natality refers to the addition of new animals to a population via the birth. Moose mortality occurs via a number of pathways that alone, or in combination with others, can lead to a population decline. Important causes of moose mortality in B.C. include: hunter harvest (legal and illegal), predation by large carnivores (i.e., wolves, bears, cougars), and accidents (e.g., rail kill, roadkill, drowning).

The population assessment comprises factors, functions and processes, and indicators that capture different aspects of moose population dynamics and structure. Figure 4 provides an overview of the key indicators, factors, functions, and processes for the moose value population assessment.

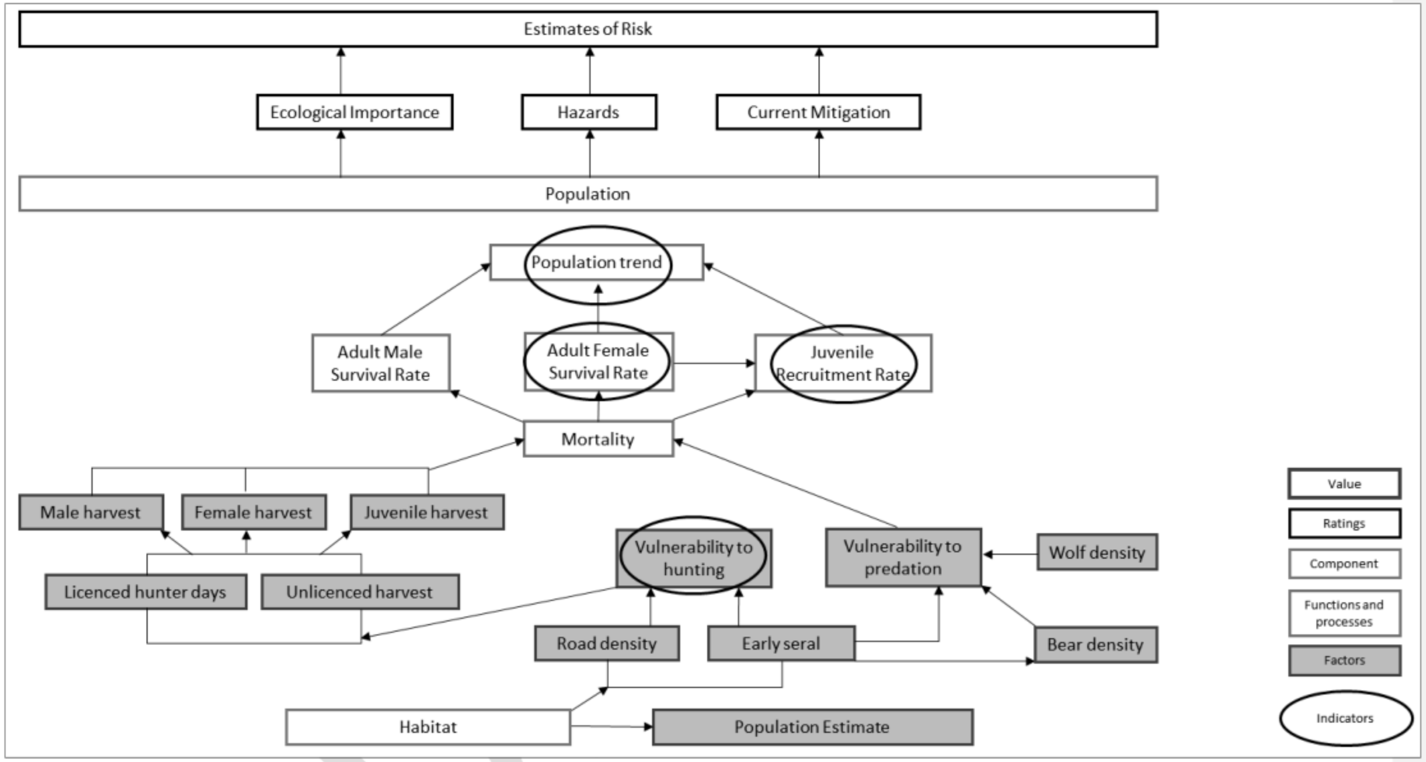

Figure 4. Overview of the key indicators, factors, functions and processes for the moose value population assessment.

The primary indicator of the population assessment is population trend, which provides an indication of whether moose in a given WMU are increasing, stable, or decreasing. Moose population trend and related indicators are structured in a Bayesian Belief Network (BBN)[3] model that provides a testable, causal approach to evaluate the relationships among indicators and their effects on population trend. The assessment explicitly presents interrelationships among indicators and inputs. The assessment process generates useful testable hypotheses, but does not explicitly test their validity.

Indicators, inputs, and latent factors included in the population assessment model are summarized in Table 2, and described in the following sub-sections.

Table 2. Summary of indicators, inputs, and latent factors included in the moose population assessment.

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Name	Measurements
Primary Indicator	
Population Trend	Negative, Stable, Positive
Secondary Indicators	
Hunting Vulnerability	Low, Moderate, High (based on % early seral and road density)
Adult Female Survival Rate	<85%, 85-95%, >95%
Juvenile Recruitment Rate	Less than 30%, 30-40%, >40%
Inputs	
Licenced Hunter Days	Low (<500 days), Moderate (500-5000), High (>5000 days)
Unlicenced Hunter Days	Low (<100 days), Moderate (100-500), High (>500 days)
Road Density	<1 per km^2, 1-2 per km^2, >2 per km^2
Wolf Density	Less than 2 per 1000 km^2, 2-6 per 1000 km^2, >6 per 1000 km^2
Population Estimate	<1500, 1500-4000, >4000
Other Juvenile Mortality	Low, Moderate, High
Other Adult Male Mortality	Low, Moderate, High
Other Adult Female Mortality	Low, Moderate, High
% Early Seral	<5%, 5-10%, >10%
Latent Factors	
Adult Male Harvest	<50, 50-100, >100
Adult Female Harvest	0, <10, >10
Juvenile Harvest	0, <5, >5
Adult Male Survival Rate	<50%, 50-65%, >65%
Predation (Wolves, Bears, and other)	Low, Moderate, High

[3] The population assessment was developed as a Bayesian Belief Network (BBN) using Netica 3.24 (Norsys Software Corp., Vancouver, BC).

3.1 Indicators

State indicators are metrics used to directly measure and report on the condition of a component, while pressure indicators measure and report on processes that act upon or influence the condition of a component. The primary state indicator of the habitat component is Population Trend. Secondary state indicators are: Hunting Vulnerability, Adult Female Survival Rate, and Juvenile Recruitment Rate.

3.1.1 Population Trend

Adult survival rates are frequently available for only the female component of the population. Researchers rarely radio-collar males, because their contribution to population trajectories is minor compared to females and calves and thus the utility in monitoring males is lower. Because population growth rates depend on female reproductive success, the equation to calculate *lambda* (population growth rate) is restricted only to the female component of the population. The output for population trend is either stable (lambda value of 0.98-1.02), declining (lambda value of <0.98), or increasing (lambda value of >1.02).

3.1.2 Vulnerability to Hunting

A proposed hypothesis to explain the decline of moose observed in some regions of B.C. is that moose become more vulnerable to hunting and predators when road density and the abundance of early seral habitat <20 years old increases (Kuzyk and Heard 2014). Roads can facilitate travel for hunters and predators, and early seral habitat can reduce cover that visually screens moose from hunters and predators.

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Hunting vulnerability is a derived variable that is scaled from 0 to 1 and is used to estimate hunter success and the number of animals removed from a Management Unit.

3.1.3 Adult Female Survival Rate

Adult female survival rate is a standard metric of reproductive performance in moose populations (Hatter and Bergerud 1991). It estimates the proportion of a population of adult females at time *t* that are expected to be alive at time *t + 1* (where time is generally measured in years). The principal drivers of adult female survival rate are assumed to be: the size of the population available to hunted, the number of females removed from the population by hunting and wolf density.

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There are other factors (e.g., accidents, health, other predators) that affect this rate that are not considered in the model but will contribute to unexplained variance.

3.1.4 Juvenile Recruitment Rate

Juvenile recruitment rate is another standard metric of reproductive performance in moose populations (Hatter and Bergerud 1991) and is generally measured by the number of juveniles observed in early winter (typically Dec-Jan) per 100 cows surveyed. It estimates the proportion of young moose that are "recruited" into the breeding population.

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The principal drivers of juvenile recruitment rate are assumed to be: the size of the population available to hunted, the number of juveniles removed from the population by hunting and wolf density. There are other factors (e.g., accidents and health) that affect this rate but are not considered in the model but will contribute to unexplained variance. Other sources of predation, specifically bears (Kuzyk et al. 2016), are included in this version of the population model.

3.2 Inputs

All test input data were assembled with input values assigned by WMU~~Management Unit~~ and then processed through the Netica model as a case file.

3.2.1 Estimated Population (Habitat Input)

The estimated population is an input produced from the habitat assessment that feeds directly into the population assessment. An estimate of potential moose density is based on the abundance and quality of moose habitat. Maximum moose density is limited by the capability of the habitat within a Management Unit.

Population estimates produced by the habitat assessment have the potential to be adjusted based on current research results, and known population densities from regions (i.e., stratified random block (SRB) surveys).

3.2.2 Road Density

Roads provide primary access for hunters and predators and they are one of the assumed correlates of hunter success and, therefore, may create a population pressures on moose (Rempel et al. 1997). However, licenced hunting should not be a population pressure on par with predation as licenced hunting is regulated.

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Road length was summed within the area of capable moose habitat by ~~Management Unit~~WMU and then divided by the area of capable moose habitat in each ~~Management Unit~~WMU to derive road density estimates (km of road per km^2). Road density is stratified into three states to calculate hunting vulnerability: <1, 1-2, and >2 km of road per km^2

3.2.3 Early Seral

In this context the Percent Early Seral input is seen as a negative variable when it is combined with the Road Density input to produce the Hunting Vulnerability indicator.

Early seral habitat reduces visual screening that hunters may use to their advantage (Kuzyk and Heard 2014). This input informs the vulnerability to hunting (sightability) index. ~~Management Units~~WMUs with different percentages of early seral habitat (<5%, 5-10%, and >10%), along with road density, are assigned coefficients to estimate hunting vulnerability.

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3.2.4 Licenced and Unlicenced Hunter Days

Hunter days by resident and non-resident hunters (Licenced Hunters) is the primary indicator of hunter effort used in B.C.. Resident hunters are sampled annually via a voluntary, randomly assigned questionnaire; and guide-outfitters are required to report all hunting activity by their clients. These data are often referred to as the Hunter Harvest Statistics (HHS) database.

Unlicenced hunting is a right of First Nations hunters and data are not routinely reported, but may be available for some areas if provided by communities.

Licenced hunter days were averaged for each ~~wildlife Management Unit~~WMU from FLRNO big game harvest statistics for 2010-2015. Days were summed for resident and non-resident hunters. These data are derived from questionnaires returned by a sample of resident hunters and from guide-outfitter reporting. No data were available to inform unlicenced hunter days.

Hunter days are stratified into three broad categories of effort and are assigned coefficients of low (0.25), moderate (0.5) and high (1). The categories are scaled differently for licenced and unlicenced hunters based on their estimated proportional representation in the hunter population.

3.2.5 Wolf Density

Wolves are the primary predator of moose and they can regulate moose population growth (Ballenberghe and Ballard 1993). Wolf density was derived from the *Management Plan for the Grey Wolf in British Columbia* (FLNRO 2014). Density estimates by wildlife Management Unit were assigned from the Ecosection-based management plan map at the centre of each Management Unit polygon.

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Wolf density is used to estimate survival and recruitment rates (along with the number of animals removed and the size of the hunted population). It is acknowledged that relatively poor survey history of wolves exists over much of the province. In combination with how quickly wolf populations can change over time makes wolf density a difficult metric to estimate with any degree of accuracy.

3.3 Latent Factors

Latent factors are not directly quantified but are calculated from combinations of inputs and indicators. Latent factors included in the CE population assessment for the moose value are: Adult male harvest, Adult female harvest, Juveniles harvest, Adult male survival rate, and predation.

3.3.1 Adult Male, Female, and Juvenile Harvest

Licenced hunting removes predominantly adult males. Adult females constitute approximately 2% of the harvest and calves approximately 0.1%. The number of animals removed can be estimated by a function of the effort (as measured by hunter days), as well as the number of animals available to hunt. Equations for all demographic components of the population are the same except for scaling factors applied to unlicenced hunting.

3.3.2 Adult Male Survival Rate

Adult male survival rate is not required to estimate indicators and/or components, but because most hunting is focused on males it is included in the model for completeness and validation purposes. Adult male survival rate is calculated in a manner analogous to adult females.

3.3.3 Predation

Predation from wolves and bears are accounted for in the population assessment as a latent factor. This factor is determined indirectly via estimated predator density and expert knowledge on predator populations in a given WMU, as well as the hypothesized influence of current conditions (habitat) on predator densities. Wolves and bears are the primary predators of focus in the assessment.

3.4 Other Considerations

3.4.1 Health

There are growing concerns about moose health as an indicator (including nutrition-related concerns related to habitat) and related implications on survival and reproduction (Kuzyk et al. 2016). The singular and cumulative roles that disease (organisms such as liver flukes and ticks can stress individual animals which can then contribute to premature death) might play in causing or contributing to moose mortality are probably important, but are largely unknown. There continues to be ongoing research to isolate factors and to hypothesize causal effects and possible management responses. Therefore, health effects cannot be included in the BBN model of the population assessment in a manner that is meaningful at this time.

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3.4.2 Climate Change

Requests to see climate change as an indicator in the assessment protocol were raised in the engagement sessions. Current work by the Climate Change (CC) and Integrated Planning Branch of FLNRO provides a draft approach of how climate change could be considered for the moose value (Daust and Price 2017). Their work describes an approach for incorporating the effects of climate change into BC's cumulative effects framework through adding pressure indicators within the CEF assessment protocols, using climate vulnerability assessments in current condition analyses and using climate scenario modeling in future condition analysis. The document presents a general discussion of the impact of climate change on each priority CEF value, including moose. As work is completed on the CC assessment protocols, they could be considered in future iterations of the moose assessment protocol.

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4 Risk Assessment

Outputs from the assessment of the habitat and population components provide ratings for estimates of risk related to:

- Ecological Importance,
- Hazards, and
- Current Mitigation.

4.1 Ecological Importance

Ecological Importance evaluates the ecological importance of each assessment unit. This rating can also be thought of as the level of ecological consequence if the value is impacted. Ecological importance is equivalent to the consequence of impact used in traditional risk analysis. Higher importance ratings reflect a greater consequence of any impacts. Factors evaluated and rated for ecological importance in the habitat assessment include: moose winter habitat, and weighted habitat capability. Future iterations of the protocol will likely identify additional factors of ecological importance for moose to include in the risk assessment.

4.2 Hazards

Hazard ratings assess the degree to which inherent sensitivity and development impacts have reduced available habitat or reduced the effectiveness of the habitat. They provide a measure of the probability of impact and/or the degree of impact. Hazard ratings are key as they flag current environmental conditions.

In the habitat assessment, hazard ratings are developed to measure changes in the amount of high suitability habitat (i.e., both dynamic and static types) and change in just the static high suitability habitat as a result of development.

The ecological importance and current mitigation component information can help provide a deeper understanding of the management significance of any hazards. For example, two areas may have identical high hazard ratings, but one has high ecological importance while other has low ecological importance. Management Units with high hazard, high ecological importance, and high population trend concern (declining trend) would warrant greater consideration.

4.3 Current Mitigation

Current mitigation indicators assess the level of risk reduction currently provided by legally designated no forest harvest and modified forest harvest areas. Two of the measures associated with current mitigation condisered in the protocol include:

- Percent of habitat protected (The percentage of the high suitability moose habitat in all capability classes that is overlapped by no forest harvest land use designations). Protected areas included in the analysis are Parks, protected areas, goal 2 protected areas, Permanent OGMAs, and riparian reserves (no forestry harvest designations).
- Percent of static habitat protected (The percentage of the static high suitability habitat that is overlapped by no forest harvest land use designations).

In future iterations of the protocol, there will likely be additional mitigation measures to include in the risk assessment.

4.4 Risk Ratings

The level of associated risk is based on a 5-scale rating system of Very Low, Low, Moderate, High, and Very High. The ratings are necessarily qualitative, but based on quantitative information from the literature and/or expert opinion. The ratings are meant to flag potential issues requiring management attention. As such, they are not designed to make decisions but rather to identify areas and issues where additional consideration is required.

The following points summarize considerations to be made in developing ratings:

- Available knowledge concerning habitat relationships;
- Established or commonly used threshold values;
- Natural benchmarks based on the estimated attributes of naturally disturbed landscapes;
- Expert judgment related to habitat relationships, system sensitivity and ecological processes;
- Range and frequency distribution in provincial or regional data;
- Level of precision and/or certainty of the input assessment data; and
- Expert assumptions about the "shape" of the relationship between the range of indicator values to risk, e.g. linear vs. bell shaped vs. some other shape.

Advantages of this type of rating approach include transparency,; uniformity of output and ease of modification based on expert input. Because ofDue to the standardization of outputs, users can quickly comprehend the results of a variety of assessments. Outputs can be checked and validated using a variety of actions including: comparison with local animal abundance and distribution data, comparison with other peer reviewed models, and checks for reasonableness by topic experts, especially those familiar with moose habitat relationships in British ColumbiaB.C. Experts with local knowledge can validate assessment results by comparing results with their expectation for areas for which they have intimate knowledge. They can also compare assessment results across the province and within regions with expectations of patterns of results.

Associated with the ratings are benchmarks. Benchmarks are proposed reference points that support interpretation of the condition of an indicator or component. Benchmarks are based on our scientific understanding of a system, and may or may not be defined in policy or legislation. Appropriate benchmarks are determined for ecological importance, hazard, and current mitigation.

4.5 Composite Ratings

The ratings provided for ecological importance, hazard, and current mitigation are each composite ratings derived from multiple indicators. The steps in calculating the ratings are:

- Apply the classification ranges to determine the rating for each indicator.
- Apply indicator weightings.
- Average the individual indicator ratings that make up each component. Round composite ratings to the nearest whole number.

4.6 Management Ratings

The range of values measured for each indicator is classified into three levels for management consideration to facilitate interpretation of assessment results. These indicator ratings are then considered as composite ratings for ecological importance, hazards, and current mitigation. Table 3 provides a general interpretation from the ratings.

Table 3. Management Ratings.

Management Rating		
Very Low/Low	**Moderate**	**High/Very High**
Little or no further consideration required.	Consideration required. For hazard component or indicators: May require additional information and/or management actions designed to maintain current status.	Very careful consideration required. For hazard component or indicators: Likely requires additional information to clarify situation. May required management actions to reduce environmental impacts.

Development of management ratings associated with the range of values for each indicator is a challenging but important step in the assessment approach.

5 Assumptions and Limitations

While there has been general agreement that the assessment protocol model captures appropriate variables and relationships, feedback through internal and external review highlighted opportunities for improvement.

5.1 Habitat Assessment

The following is a summary of assumptions and limitations related to the habitat assessment component:

- Reliability of several aspects of the habitat assessment is limited by the accuracy, currency and polygon size limitations of forest inventory data and by the quality of the data in the digital road atlas.
- Ratings for the landscape shelter indicator have not been peer reviewed.
- The relationship between various levels of stand mortality and its effectiveness for moose security and thermal cover is not known with any precision. Thermal and security cover values in high mortality pine stands would be reduced in relation to totally green stands, but would be significantly higher than in clearcut areas.
- The "reduced habitat" hazard indicator uses a very simple reference condition which does not explicitly reflect historic natural disturbance processes. However this indicator has been retained because it provides a valuable, spatially explicit assessment of current habitat. ~~B~~Due to~~ecause of~~ the nature of the reference condition, the indicator does not completely reflect the difference between the current landscape and a naturally disturbed landscape condition. However, since the same methodology is applied the relative differences in indicator values can be rated to meaningfully estimate relative habitat change across the province, and between and within regions.
- Current classification of digital road data is very coarse and classifies all roads into only three classes: paved, gravel, and undefined. The undefined class includes many roads to and through cut blocks that are relatively large and well-travelled which

would ideally be included as roads that that reduce habitat effectiveness for moose. Because of the coarseness of the road classification, these roads had to be excluded from the moose analyses when ideally they would have been included. Future, more refined road classifications may allow for a more refined treatment of roads with variable disturbance distances depending on road classifications that would reflect industrial and hunter traffic.

5.2 Population Assessment

Although the population assessment output aligned in general with expectations provincially (e.g., relative population differences and general trends), the following limitations were raised:

- Stratification of factors into states, coefficients and equations are based largely on expert opinion and have not yet been tested with available data. The expert opinion provided was through workshops with Thompson-Okanagan staff and does not represent province-wide knowledge. Additionally, while the initial assessment was completed, results were not reviewed with experts to assess correlations with regional expectations other than in the Thompson-Okanagan.
- Trends were sensitive to the population estimates, which are based on assumed densities, by habitat suitability class. If higher population estimates are used, estimated trends improve significantly in many areas.
- Related to the above., rRegional data could provide better population estimates based on survey data and fine-scale habitat suitability mapping, rather than on the BEI coverage currently used.
- Lack of data for unlicenced hunting is an outstanding issue and in the model it is not separated from the licenced harvest.
- There is a reliance on overly coarse stratification of some categories applied in the assessment (e.g., 3 classes for population size).
- Gaps remain in the specific demographic parameters of all age and sex classes of moose in the province. For example, while survival of adults, especially bulls, may be more confidently known, there is a lack of information on moose calf survival rates and behaviour from 6–12 months of age (Van Ballenberghe and Ballard 1998). s.13
- Related to the recommendations of McNay et al. (2013), the influence of nutritional constraints and the effects of habitat on the nutritional condition of moose (especially cows) have been noted as knowledge gaps (Kuzyk and Heard 2014). s.13

5.3 Risk Assessment

Validation of the risk assessment results by value experts and data such as census and radio-telemetry data is important to ongoing credibility and usefulness of the assessment protocol. Transparency and credibility are also enhanced by clear discussions of the strengths and limitations of the assessment for moose. It is important to remember that the main purpose of the arisk ssessment is to flag potential management concerns, which should then be more fully explored rather than to make definitive judgments.

6 Considerations and Next Steps

This protocol provides a standardised provincial method of assessment for evaluating cumulative effects on moose across the province of B.C.; while also allowing a degree of flexibility within regions of the province. Use of this information should anticipate some changes in the substance and formatting of the assessment protocol in the future. It is expected that results from regional assessments will potentially clarify, standardize and improve the assessment protocol

Factors, functions, and processes included in the habitat and population assessments are approximations based on best available data, expert opinion, and a thorough literature review. The relationships are testable where data exist to calibrate and refine the assessment inputs. Improving assessment calibration based on analysis of existing data is a logical next step. Concurrent with model calibration will be development of current condition maps. This may require further decisions regarding baseline mapping for habitat capability, suitability, and effectiveness.

6.1 What can the broad scale assessment results be used for?

Some possible uses include:

- Flagging specific issues and geographic areas requiring more management attention, more detailed analysis and assessment, or additional inventories and/or research.
- Input into environmental impact assessments.
- Providing a common source of information to all stakeholders to stimulate and focus discussion.
- Prioritizing which geographic areas may benefit from additional information and/or evaluation prior to development decisions.
- Input to proponents to help them better assess their business case and better design projects to meet environmental concerns.
- Input to decision-makers to support authorization decisions and inform mitigation and monitoring requirements.
- TUnder FRPA: to provide context information to professionals developing or approving Forest Stewardship Plans and Site Plans, under FRPA.

6.2 Site Level Considerations

This section is included to give decision-makers additional guidance and information at a finer scale of detail than the broad scale assessment provides. This type of information can lead to more informed discussions of the risk and more effective proposals for potential mitigation.

Moose winter moose feeding habitat is sensitive to the following types of changes in habitat:

- reduction Reduction in shrub productivity in winter feeding areas;
- lLoss of shrub habitat or adjacent forested thermal cover due to land use changes;

- Fforest harvesting of the thermal cover near to the productive shrub habitats;
- Ddevelopment of roads within 1000 m of moose winter habitat areas;
- Uincreased vehicle use of roads within 1000 m moose winter habitat areas; and
- Ssnow ploughing of roads within 1000 m of moose winter habitat areas.

Important site level habitat characteristics
Mapped information resulting from this assessment protocol could be used to roughly identify the relative site level importance and sensitivity to development of specific locations in the landscape as shown below.

Highest Importance

↓

Lowest Importance

- Areas with concentrations of static winter feeding habitat and adjacent shelter habitat especially where they overlap with high and moderate winter capability habitat.
- Concentrations of high suitability moose winter habitat overlapping high and moderate winter capability.
- Any other areas mapped as high winter capability.
- Any large concentrations of moose winter habitat in other capability areas.
- Areas mapped as moderate capability that are not overlapped with areas of modelled moose winter habitat.
- Areas mapped as low capability that are not overlapped with areas of moose winter habitat.
- Areas with nil capability.

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7 ~~Literature Cited~~References

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

2018 Progress Report: February 2012–April 2018

by

G. Kuzyk, S. Marshall, C. Procter, H. Schindler,
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BRITISH COLUMBIA

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

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EXECUTIVE SUMMARY

In 2013, the BC government initiated a research project to determine the factors affecting Moose population change in central BC by testing the landscape change hypothesis proposed by Kuzyk and Heard (2014). This report provides some preliminary results and some interpretation of the data collected from February 2012 to April 2018. This technical report was preceded by three annual reports: Kuzyk et al. (2015, 2016, 2017). This project was initiated because Moose numbers in central British Columbia (BC) had declined since the early 2000s, causing concern with First Nations and stakeholders. Much of the decline happened concurrently with a Mountain Pine Beetle outbreak that killed a large proportion of mature pine trees and resulted in increased salvage logging and road building. In response to the Moose decline, a 5-year provincially-coordinated Moose research project was initiated by the B.C. Ministry of Forests, Lands and Natural Resource Operations (FLNRO) [as of 2017, the Ministry name changed to Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD)]. In February 2012, a Moose study with similar objectives began on the Bonaparte Plateau and was integrated with this project. The primary research objective of this project is to evaluate a landscape change hypothesis, which states that Moose declines coincided with a mountain pine beetle (MPB) outbreak where habitat changes and increased salvage logging and road building resulted in greater vulnerability to Moose from hunters, predators, nutritional constraints, age/health and environmental conditions. It assumes Moose survival will increase when: a) forest cutblocks regenerate to the point where vegetation obstructs the view of predators and hunters; b) resource roads created for logging are rendered impassable; and c) Moose become more uniformly dispersed on the landscape. We evaluated that hypothesis by identifying causes and rates of cow Moose mortality, and examining factors that contributed to their vulnerability. To assess the causes and rates of calf mortality, an important research gap previously identified at the outset of this project, Moose calves were collared in Bonaparte and Prince George South in the winters of 2016/17 and 2017/18. This progress report provides data and a preliminary interpretation of the results from 28 February 2012 to 30 April 2018 from five study areas in central BC: Bonaparte; Big Creek; Entiako; Prince George South; and the John Prince Research Forest.

Since this project was initiated in 2012, we fitted GPS radio collars on a total of 460 individual Moose: 400 cows and 60 8-month old calves. There were 14 cow Moose that were recaptured to replace collars (total GPS radio collars = 414). Since 2016/17, we have collared sixty 8-month old calf Moose in the Bonaparte (n = 40) and Prince George South (n = 20) study areas. Three configurations of GPS radio collars were used: those programmed for one fix/day (n = 147), 2 fixes/day (n = 109), and >2 fixes/day (n = 158). As of 30 April 2018, 194 GPS collars were active on cow Moose, 110 censored (i.e., dropped at end of battery life, stopped collecting data or slipped from Moose), and 97 were associated with Moose that died.

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

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

animal assessment at capture or through marrow fat collection during mortality site investigations, as available. Six-year average pregnancy rates observed in this study ranged from 64–94%, with the lowest observed in the Bonaparte (64%) and Prince George South (75%) study areas. Average rates in the remaining study areas were 84–94%. Parturition (determined by analyzing cow movement rates) and pregnancy rates vary from each other in the same year but one metric is not consistently higher than the other. Bone-marrow-fat analysis from cow Moose mortalities (n = 63) showed 55% in good body condition (>70% marrow fat), 25% with acute malnutrition (<20% marrow fat), and 21% in poor body condition (20–70% marrow fat). The majority of mortalities involving cows with acute malnutrition and poor body condition occurred between March and June while mortalities in the remainder of the years typically involved cows in good body condition. Serological screening and ancillary testing did not demonstrate substantial exposure to pathogens (i.e., pathogens that would likely have increased a Moose's likelihood of death); however, some cows were emaciated at death with no apparent additional cause(s) of death determined to date.

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

Analyses on habitat selection patterns of radio-collared Moose for three years were completed in July 2018 at the University of Northern British Columbia (UNBC), and are currently underway at the University of Victoria and the John Prince Research Forest. A comprehensive survival analysis to provide inferences on factors contributing to increased risk of mortality in cow Moose across study areas began in summer of 2017 at UNBC. Final survival analysis is being completed at UNBC.

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

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1. INTRODUCTION

Moose populations in some areas of interior British Columbia (BC) have declined by 50–70% since the early 2000s, while Moose populations in other areas of the province were stable or increasing (Kuzyk 2016; Kuzyk et al. in press). The Moose declines within central BC coincided with a mountain pine beetle (*Dendroctonus ponderosae*; MPB) outbreak and associated increased levels of mortality of pine trees>30years old, salvage logging of beetle-killed timber and road building (Alfaro et al. 2015). These landscape changes may have influenced the distribution and abundance of Moose, hunters and predators (Janz 2006; Ritchie 2008). In 2013, in response to these Moose declines, a 5-year (December 2013–March 2018) provincially-coordinated Moose research project was initiated by the BC Ministry of Forests, Lands, and Natural Resource Operations (now Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and its partners (Kuzyk and Heard 2014). A Moose study with similar objectives began in February 2012 on the Bonaparte Plateau north of Kamloops and was integrated as one of the five study areas in this project (Figure 1, Table 1). We also collaborated with other Moose studies in BC (i.e., Sittler 2018) and other jurisdictions.

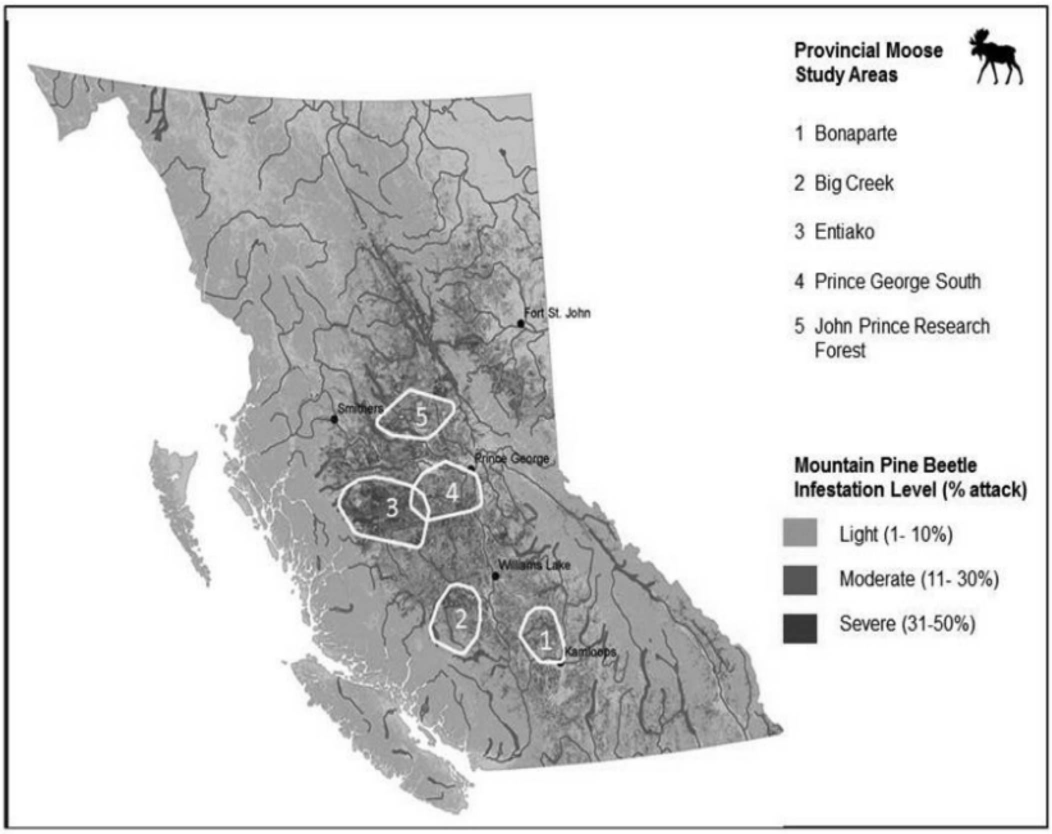

Figure 1. Moose research study areas in central British Columbia, where cow Moose survival has been monitored in the Bonaparte study area since February 2012 and in the other four study areas since December 2013, overlaid on Mountain Pine Beetle Infestation spatial data layer (2016). The areas were selected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

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

Study Area/ Region/ Management Unit/ Landform	Landscape Feature Prevalence[1]		BEC Zones[4]	Moose Density at Project Start ± 90% CI (winter year)[5]	Moose Density at Project End ± 90% CI (winter year)[5]	Potential Predators and Relative Abundance[6]	Wild Ungulates and Relative abundance[6]	Domestic/ Feral Ungulates and Relative Abundance[6]
Bonaparte 6800 km^2 Region 3 (Thompson), 3-29, 3-30B, Interior Plateau	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted Herbicide by Area Cut[2]: 0.03% Herbicide by THLB[3]: 0.02%	Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Pervasive Mining: Restricted	IDF: 33% SBPS: 23% MS: 22% ESSF: 8% SBS: 7% BG/PP: 7%	296 ± 18/ 1000 km^2 (2012/13)	254 ± 41/ 1000 km^2 (2017/18)	Wolves: M Black Bears: M/H Cougars: M/H Grizzly Bears: N	Mule Deer: H White-tailed Deer: M Elk: L Caribou: N	Cattle: H Domestic Sheep: L Feral Horses: N
Big Creek 9800 km^2 Region 5 (Cariboo), 5-04, Interior Plateau/Coast Mountains	MPB: Large/Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Small Herbicide by Area Cut[2]: 0.00% Herbicide by THLB[3]: 0.00%	Provincial Park: Restricted Agriculture: Restricted Crown Cattle Range: Large Mining: Negligible	SBPS: 48% IDF: 36% MS: 12% ESSF: 3% AT: <1% BG: <1%	170 ± 39/ 1000 km^2 (2011/12)	220 ± 38/ 1000km^2 (2016/17)	Wolves: M Black Bears: M Cougars: L/M Grizzly Bears: M	Mule Deer: L/M White-tailed Deer: L Elk: N Caribou: N	Cattle: H Domestic Sheep: L Feral Horses: H

Study Area/ Region/ Management Unit/ Landform	Landscape Feature Prevalence[1]		BEC Zones[4]	Moose Density at Project Start ± 90% CI (winter year)[5]	Moose Density at Project End ± 90% CI (winter year)[5]	Potential Predators and Relative Abundance[6]	Wild Ungulates and Relative abundance[6]	Domestic/ Feral Ungulates and Relative Abundance[6]
Entiako 18,000 km^2 Region 6 (Skeena), 6-01, 6-02, Interior Plateau/Coast Mountains	MPB: Pervasive Logging: Small Roads: Small Wildfire (<30yrs): Small Herbicide by Area Cut[2]: 0.71% Herbicide by THLB[3]: 0.24%	Provincial Park: Large Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 48% ESSF: 32% SBPS: 12% AT: 4% MH: 2% CWH: 1% MS: <1%	267 ± 45/ 1000 km^2 (2013)	Survey planned for Jan 2019	Wolves: M/H Black Bears: M/H Cougars: L Grizzly Bears: M	Mule Deer: L White-tailed Deer: N Elk: L Caribou: L/M	Cattle: L Domestic Sheep: N Feral Horses: N
Prince George South 11,000 km^2 Region 7A (Omineca), 7-10 to 7-12, Interior Plateau	MPB: Pervasive Logging: Pervasive Roads: Pervasive Wildfire (<30yrs): Restricted Herbicide by Area Cut[2]: 7.38% Herbicide by THLB[3]: 4.47%	Provincial Park: Restricted Agriculture: Small Crown Cattle Range: Large Mining: Negligible	SBS: 93% ESSF: 7%	630 ± 102/ 1000 km^2 (2011/12)	400 ± 78/ 1000 km^2 (2016/17)	Wolves: M Black Bears: M/H Cougars: L Grizzly Bears: L	Mule Deer: L White-tailed Deer: L Elk: L Caribou: N	Cattle: L Domestic Sheep: N Feral Horses: N
John Prince Research Forest 9600 km^2 Region 7A (Omineca), 7-14, 7-25, Interior Plateau	MPB: Large Logging: Large Roads: Pervasive Wildfire (<30yrs): Negligible Herbicide by Area Cut[2]: 0.26% Herbicide by THLB[3]: 0.13%	Provincial Park: Restricted Agriculture: Negligible Crown Cattle Range: Negligible Mining: Negligible	SBS: 95% ESSF: 5%	770 ± 93/ 1000 km^2 (2016/17)	490 ± 84/ 1000 km^2 (2016/17)	Wolves: M Black Bears: H Cougars: N Grizzly Bears: M	Mule Deer: L White-tailed Deer: L Elk: L Caribou: N	Cattle: N Domestic Sheep: N Feral Horses: N

[1]Estimated proportion of landscape affected: Pervasive = 71–100%, Large = 31–70%, Small = 11–30%, Restricted = 1–10%, Negligible = <1%. Note that the amount of pine varies between study areas.
[2]Proportion of area harvested within each study area to which herbicide has been applied. Earliest date of herbicide application was in 1986.
[3]Proportion of timber harvest land base to which herbicide has been applied. Earliest date of herbicide application was in 1986.
[4]Biogeoclimatic Ecosystem Classification (BEC): Interior Douglas Fir (IDF), Sub-Boreal Pine and Spruce (SBPS), Montane Spruce (MS), Engelmann Spruce Sub-alpine Fir (ESSF), Montane Spruce (MS), Sub-boreal Spruce (SBS), Bunchgrass (BG), Ponderosa Pine (PP), Alpine Tundra (AT), Mountain Hemlock (MH), and Coastal Western Hemlock (CWH).
[5]Reported Moose densities are from Stratified Random Block (SRB) surveys (RISC 2002) conducted in the study areas.
[6]Relative abundance/density: H = high, M = moderate, L = Low, N = nil or negligible.

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

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

Our research approach was to monitor survival of at least 30 GPS radio-collared cow Moose in each of five study areas (*n* = 150 annually) for five years (i.e., December 2013 to March 2018). We planned to determine mortality rates, causes and contributing factors in comparison to the predictions of the landscape change hypothesis with respect to horizontal screening cover roads, and spatial distribution of moose.

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

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

2. STUDY AREA

This study area description is similar to that provided in Kuzyk et al. (2017). In general, there was little annual variation in biotic or abiotic features within study areas. In 2017, wildfires burned a small portion of the Bonaparte study area and 15% of the Big Creek study area overlapped the Hanceville-Riske Creek fire perimeter boundary. In addition, fire burned ~1331 km^2 of the Entiako study area in 2014 (7%), when the Chelaslie Fire burned ~1331 km^2. This research project was conducted on the Interior Plateau of British Columbia, Canada, in five study areas: Bonaparte; Big Creek; Entiako; Prince George South; and John Prince Research Forest (Figure 1). Most of the plateau lies between 1200–1500 m above sea level and was characterized by rolling terrain with a mosaic of seral stages, conifer forest and wetland areas. The climate is generally continental, with warm, dry summers and cold winters with complete snow coverage. Dominant ecological zones of the interior include Sub-Boreal Spruce (SBS) and Engelmann-Spruce Subalpine Fir (ESSF) in the north, and Sub-Boreal Pine-Spruce (SBPS) and Interior Douglas-Fir (IDF) in the south (Meidinger and Pojar 1991). The study areas, delineated using the cumulative distribution of radio-collared Moose locations in each of the study areas, ranged from 6700 km^2 – >18000 km^2 (Table 1). Logging was the primary resource land use (Figure 2) with an increase in salvage logging after the large-scale MPB outbreak occurring during the early 2000s (Alfaro et al. 2015). The proportion of cutblock area sprayed with herbicide to promote regrowth of harvestable tree species in each study area ranged from 0% (Big Creek) to 7% (Prince George South) with the majority of herbicide application occurring after the year 2000. Natural variation in the dominant forest types, severity of the MPB attack (both within and among study areas), and differences in the extent of reserve areas that did not allow logging, resulted in differences in the degree of pine tree mortality, associated salvage logging and access among study areas (Figure 1, Table 1). Access for recreational use, such as hunting, all-terrain vehicle (ATV) use, and hiking, was primarily through resource roads created for logging. Free-ranging cattle (*Bos taurus*) are common in the Bonaparte and Big Creek, and to a lesser extent in Prince George South and Entiako study areas, and feral horses (*Equus caballus*) also occur in the Big Creek study area.

In addition to Moose, the Interior Plateau supports other large mammals; Elk (*Cervus canadensis*), Mule Deer (*Odocoileus hemionus*), White-tailed Deer (*O. virginianus*), Caribou (*Rangifer tarandus*), Grey Wolf (*Canis lupus*), Grizzly Bear (*Ursus arctos*), Black Bear (*U. americanus*) and Cougars (*Puma concolor*), all of which occur at varying densities and distributions (Shackleton 1999; Mowat et al. 2013; Kuzyk and Hatter 2014). Accordingly, all study areas contain multi-prey, multi-predator species assemblages (Table 1). Moose, however, were the primary wild ungulate in all study areas except Mule Deer are probably the most abundant ungulate in the Bonaparte. At the initiation of the study, Moose densities ranged from 170–770 Moose/1000 km^2 among study

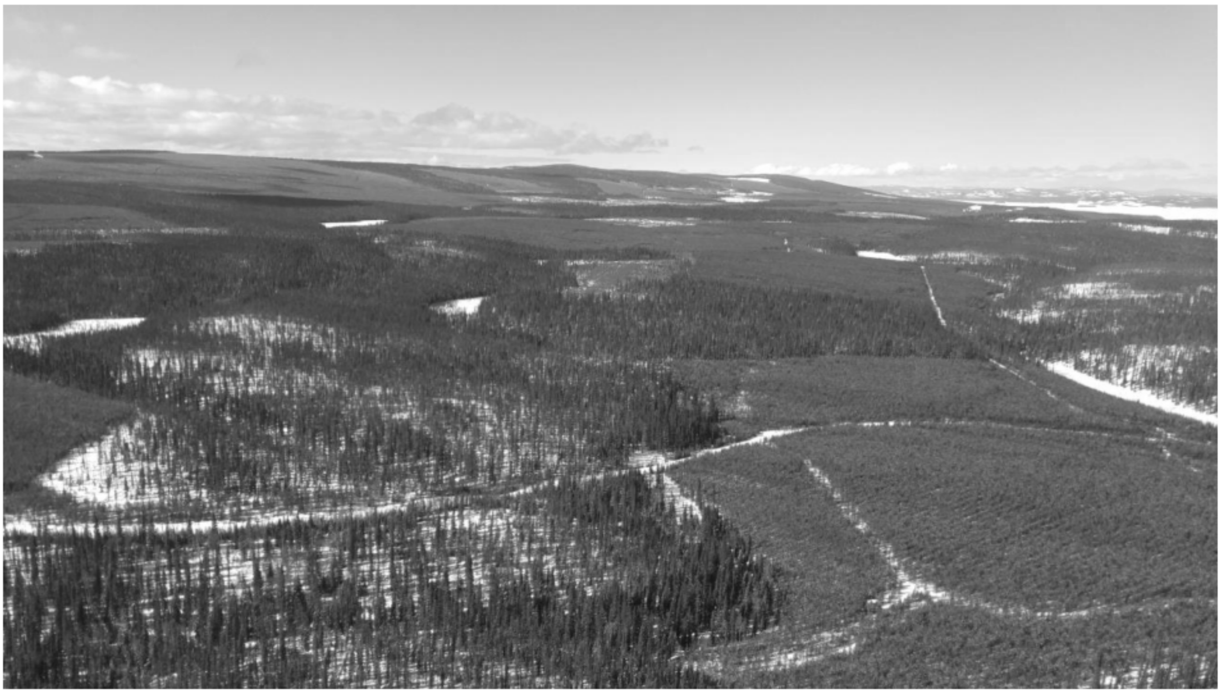

Figure 2. Aerial view of the Entiako study area, March 2018 (Photo: Heidi Schindler).

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

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

3. METHODS

Details of the field methods were originally presented in Kuzyk and Heard (2014) and certain methodologies have been updated and presented in Kuzyk et al. (2015, 2016, 2017). Methods are generally the same as those presented in Kuzyk et al. (2017) as they have become standardized over the course of the project. Captures were conducted in accordance with the British Columbia *Wildlife Act* under permit CB17-277227. Winter of 2016/17 was the first season to include calves in the study, and twenty 8-month old calf Moose were radio-collared. Generally, we captured cow and calf Moose between December and March, using either aerial net gunning and physical restraint or chemical immobilization by aerial darting. Aerial darts were remotely delivered with either a Pneudart or Daninject darting system. Of the cows captured via aerial darting, we immobilized 143 animals with a combination of carfentanil citrate (3 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) and xylazine hydrochloride (100 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) and 108 Moose with BAM II (Chiron Compounding Pharmacy Inc, Guelph, ON), a premixed combination of butorphanol (27.3 mg/mL), azaperone (9.1 mg/mL) and medetomidine (10.9 mg/mL). BAM II was also used to immobilize 8-month old Moose and was delivered in 2–4 cc darts. Upon completion of handling, naltrexone hydrochloride (at 50 mg/mL) for carfentanil, or naltrexone hydrochloride with atipamezole hydrochloride (at 25 mg/mL) for BAM II immobilizations were used to reverse at doses corresponding to immobilizing dose.

We examined and sampled captured Moose according to a standard protocol that included assessing for: 1) age class using tooth eruption, staining and wear as an index (Passmore et al. 1955; Appendix A); 2) body condition, using an index simplified from Franzmann (1977; Appendix B); 3) external parasite presence and prevalence; and 4) presence of calves. From each Moose, we drew 20–35 mL of blood using an 18 gauge x 1.5-inch needle for pregnancy and serological testing. Testing focused on exposure to pathogens considered of high priority for impacts on survival and reproduction of wild ungulate populations, utilizing the experience of other research programs, including the BC Boreal Caribou Health Program. Serum was screened for antibodies for Johne's disease, *Neospora*, Bovine Viral Diarrhea virus, and Parainfluenza 3 virus. Serum from a subset of cow Moose was submitted for testing for exposure to *Erysipelothrix rhusipathiae* and *Toxoplasma.* Serum from a subset of cow Moose captured in 2014/15 and from all cow Moose captured in 2015/16 and 2016/17 was analyzed for both progesterone and pregnancy specific protein B levels (PSPB). These dual pregnancy status indicators were used to further investigate the interpretation of pregnancy status. In 2017/18, pregnancy status was assessed via PSPB only. Blood samples were also assessed for trace mineral levels (manganese, iron, cobalt, copper, zinc, selenium, and molybdenum).

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

We fitted each cow Moose with a GPS radio collar programmed to obtain either one or two positional fixes daily (Vectronic Aerospace VERTEX Survey Globalstar radio collars, Berlin) or >2 locations per day (Advanced Telemetry Systems G2110E radio collars, Isanti, MN or Vectronic Aerospace VERTEX Survey Iridium radio collars, Berlin) (see Figures 3 through 9 for images illustrating captured Moose handling and sampling methods). We chose to use radio collars with one or two positional fixes daily at the outset of the project to facilitate survival monitoring for up to five years. We started deploying radio collars capable of collecting >2 fixes daily when funds were available to begin addressing other objectives, including calving rates and fine scale habitat use, as well as to improve fix rate success. Moose calves were fitted with expandable collars that collected six fixes per day (Vectronic Aerospace VERTEX Survey Iridium radio collars, Berlin). Calf collars expanded from an initial size of 50 cm–80 cm (average neck circumference of an adult female Moose) using protected expandable material. Calves will need to be recaptured after two years to either remove the collar or replace it with an adult-sized collar. Cotton spacers designed to rot-off within one year were put on collars deployed on bull calves because they could rapidly exceed the maximum expansion capable with these collars.

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

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

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

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

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

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

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

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

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

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

Annual survival rates were calculated for cow Moose from 28 February 2012–30 April 2018. We calculated survival rates by pooling survival of individual Moose across all study areas and for each study area. Survival analysis and mortality summaries included only cow Moose that lived >3 weeks post-capture to avoid the potential bias or effects of capture-related stresses and physiological changes on survival (Keech et al. 2011). Survival rates were monitored weekly and summarized by biological year (1 May–30 April) using a Kaplan-Meier estimator (Pollock et al. 1989). The biological year started on 1 May to coincide with the time immediately prior to the average time of parturition for Moose in northern (Gillingham and Parker 2008) and southern British Columbia (Poole et al. 2007). All cow Moose were assumed to be representative of the population behaviour and have equal risk of mortality (i.e., no cow Moose were assumed to be predisposed to predation due to giving birth or the presence of a calf).

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

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

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

4. RESULTS

4.1 GPS Radio Collars

From February 2012–30 April 2018, we captured and radio-collared 400 cow Moose of which 14 were recaptured to replace collars with dead batteries or close to anticipated battery end life (Tables 2 and 3). There were 281 cows captured by aerial darting and 133 captured by aerial net gunning. Twenty calf Moose (12 female, 8 male) were captured and fitted with GPS radio collars in the Bonaparte study area in January and February 2017. In January and February 2018, 20 calf Moose (6 female, 14 male) were collared in Bonaparte and 20 calf Moose (11 female, 9 male) in Prince George South study areas.

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

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

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

*Includes recaptures where the original collar was replaced by a new collar
**number of individual cows collared
***Derived by modifying the number of collars active at the end of the previous year by the number of new collars deployed and lost through mortalities or censoring

Table 3. Number and status of all GPS radio collars (n = 414) deployed on Moose (n = 400 i.e., 14 recollars) in each study area in central BC from February 2012–30 April 2018.

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

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

*Includes recaptures where the original collar was replaced by a new collar
**Total number of independent cows collared
***Derived by modifying the number of collars active at the end of the previous year by the number of new collars deployed and lost through mortalities or censoring

Table 4. Programmed fix schedule for GPS radio collars (n = 414) deployed on cow Moose (n = 400 i.e., 14 recollars) in each study area in central BC from February 2012–30 April 2018.

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

4.2 Capture and Handling

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

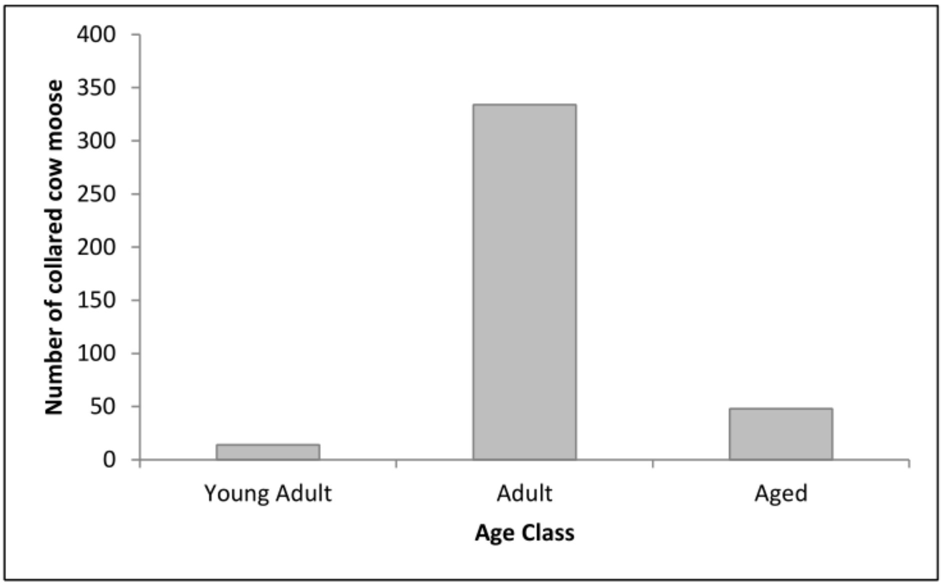

Figure 10. Age class summary of 396 cow Moose radio-collared in central BC from February 2012–30 April 2018 with ages estimated by tooth wear patterns. Young Adult Moose were estimated to be 1.5–3.5 years old, Adults as 4.5–7.5 years old, and Aged as >8.5 years old.

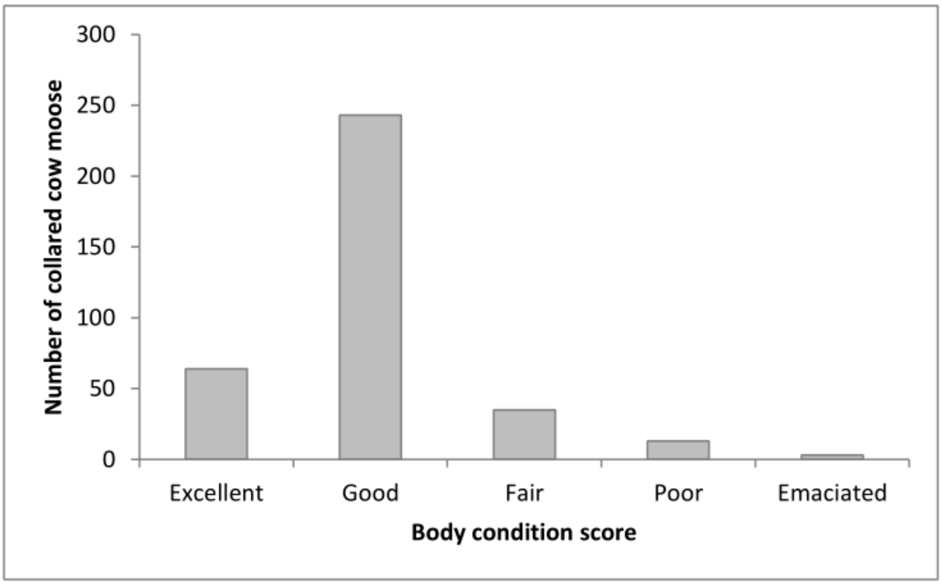

Figure 11. Body condition scores of 358 cow Moose radio-collared in central BC from February 2012–30 April 2018. Condition scores were assessed using external physical traits modified from Franzmann (1977).

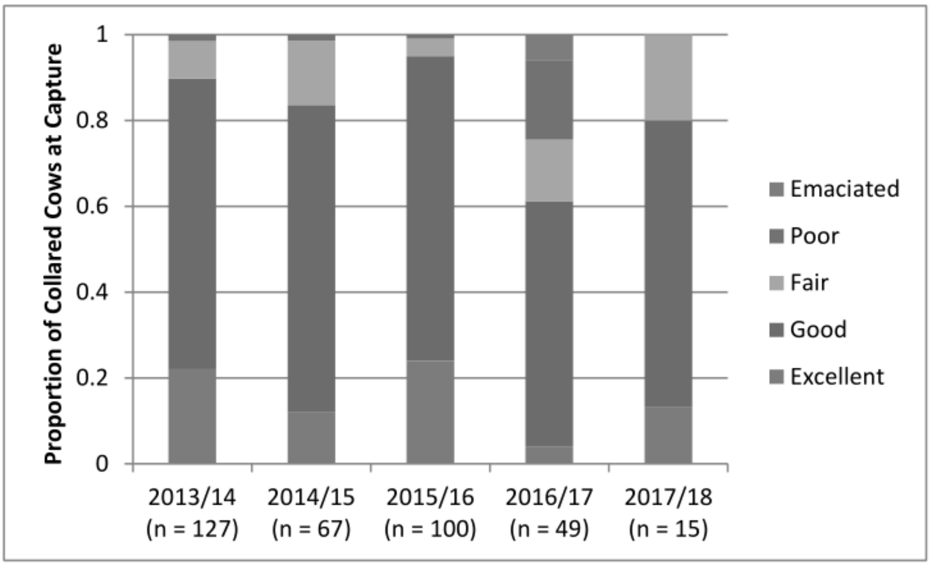

Figure 12. Annual body condition scores of 358 cow Moose radio-collared in central BC from February 2012-30 April 2018. Condition scores were assessed using external physical traits modified from Franzmann (1977).

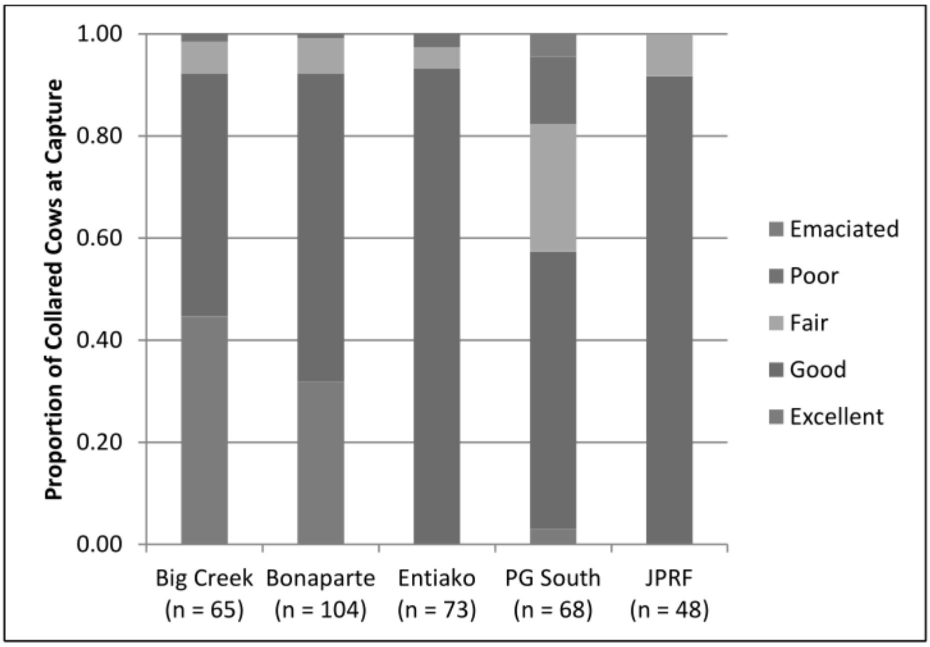

Figure 13. Study area specific body condition at time of capture scores of 358 cow Moose radio-collared in central BC from February 2012-30 April 2018. Condition scores were assessed using external physical traits modified from Franzmann (1977).

4.3 Biological Samples

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

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

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

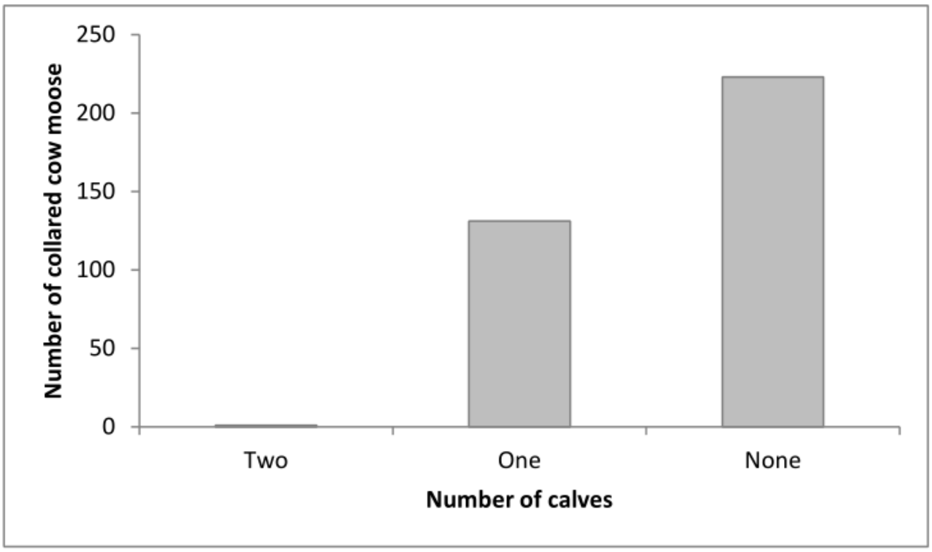

Figure 14. Calf status of 355 radio-collared cow Moose at time of capture in central BC from February 2012–30 April 2018.

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

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

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

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

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

4.4 Annual Survival Rates

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

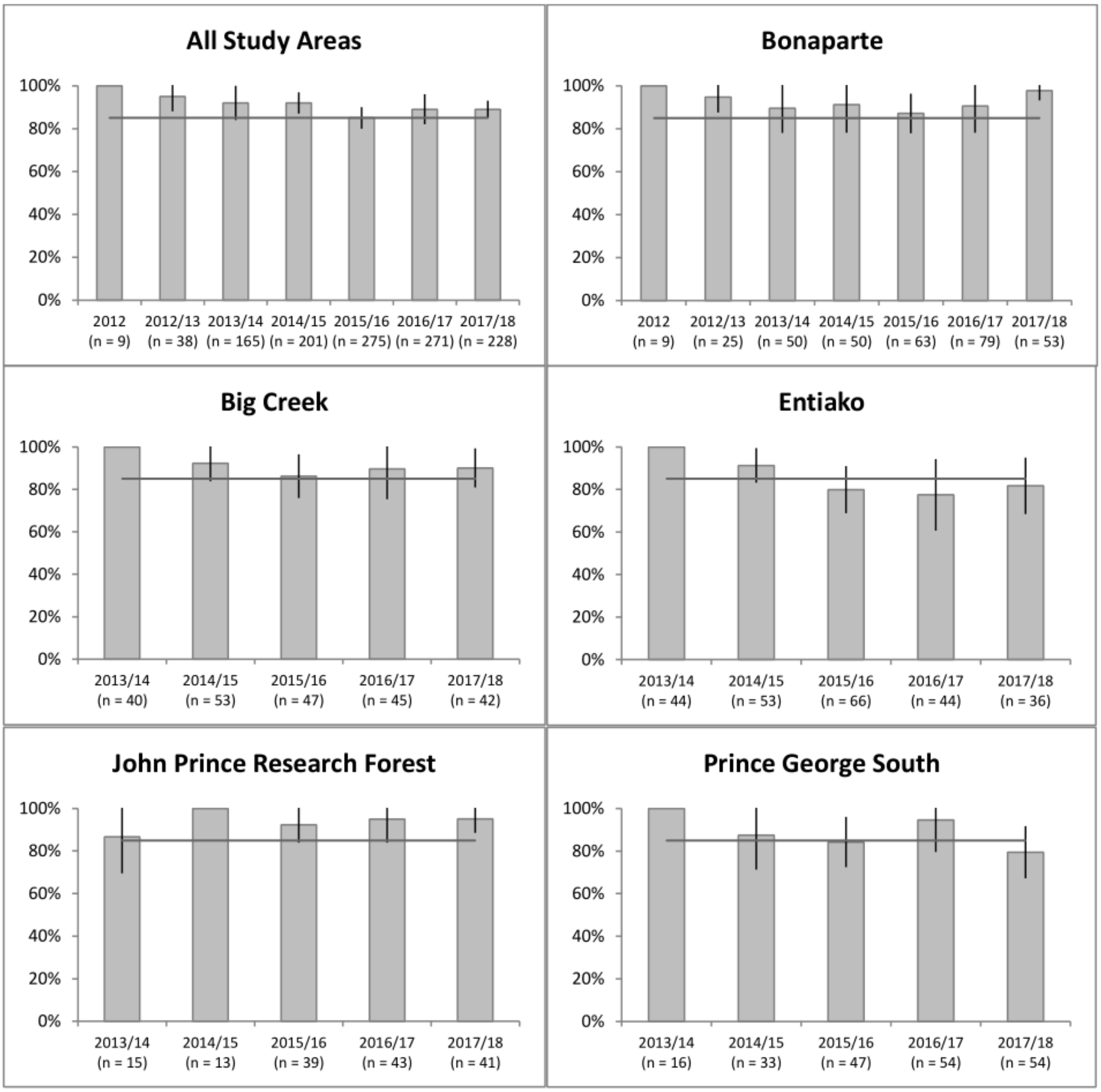

Figure 15. Survival rates of radio-collared cow Moose for all study areas combined and separated by study area, May 1 2012 – April 30, 2018. Red line indicated survival rate of 85%, which is generally indicative of a stable population.

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

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

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

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

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

4.5 Calf Production, Summer Calf Survival and True Recruitment

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

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

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

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

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

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

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

***Peritonitis:** The inflammation of the peritoneum, the lining of the peritoneal cavity, or abdomen, by an infectious agent, usually bacteria but may be fungi or even a virus. The initiating cause may be a puncture of an organ, intestinal tract or the abdomen wall for entry of a pathogen. Left untreated, peritonitis can rapidly spread into the blood (sepsis) and to other organs, resulting in multiple organ failure and death.

4.5 Mortality Causes

Ninety-seven of the 400 radio-collared cow Moose died between February 2012 and 30 April 2018 (Table 10; Figures 16 and 17). Probable proximate causes of death (see Appendix C) were 53% from predation, 19% from health-related causes, 16% from hunting, 3% natural accident, and 7% unknown (Figure 16; see Figures 19–23 for images from mortality investigations). We classified mortalities as unknown when there was minimal evidence available at the mortality site to reliably assign a cause of death; these instances occurred when mortality site investigations were significantly delayed due to radio collar malfunctions or predators moving the collar post-mortality such that a long delay occurred between the mortality event and the initiation of the mortality signal or the collar being positioned underneath the dead Moose thus limiting its transmission success. Cow mortalities peaked in spring with 49% of mortalities occurring between March and May (Figure 18, $n = 97$).

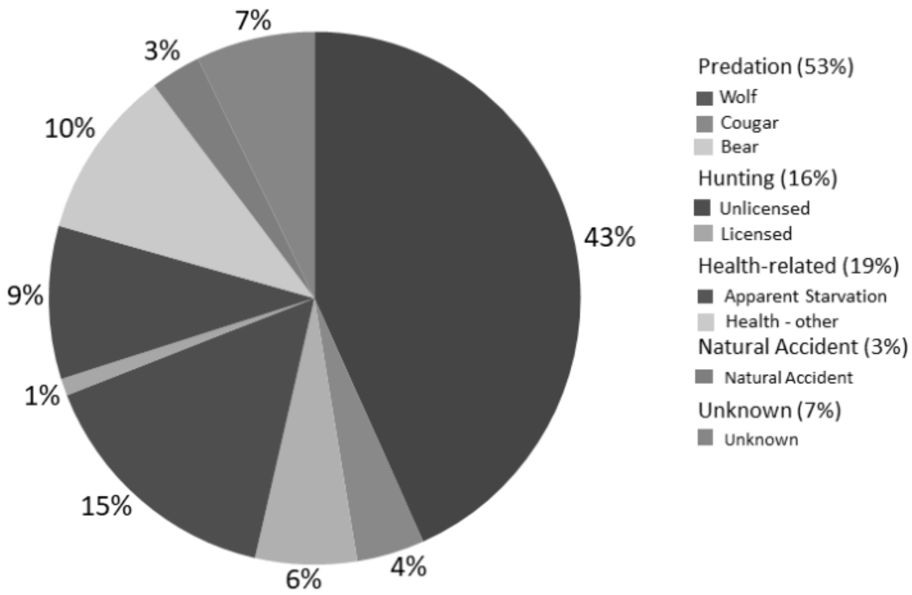

Figure 16. Probable proximate cause of death of radio-collared cow Moose (*n* = 97) in central BC from February 2012–30 April 2018. Cause of death proportions are not shown summing to 100% because of rounding.

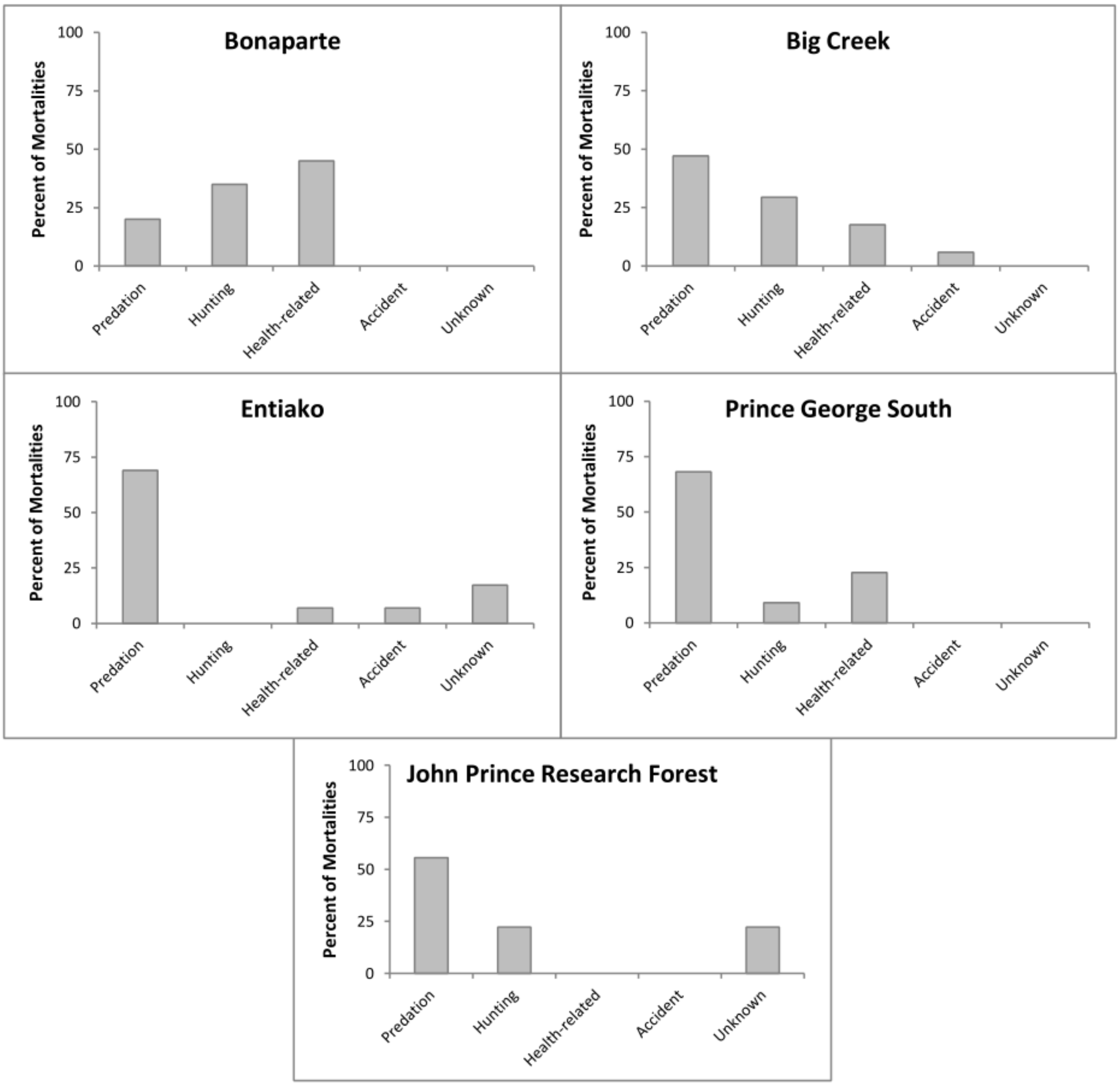

Figure 17. Probable proximate cause of death of radio-collared cow Moose (*n* = 97) by study area in central BC from February 2012–30 April 2018.

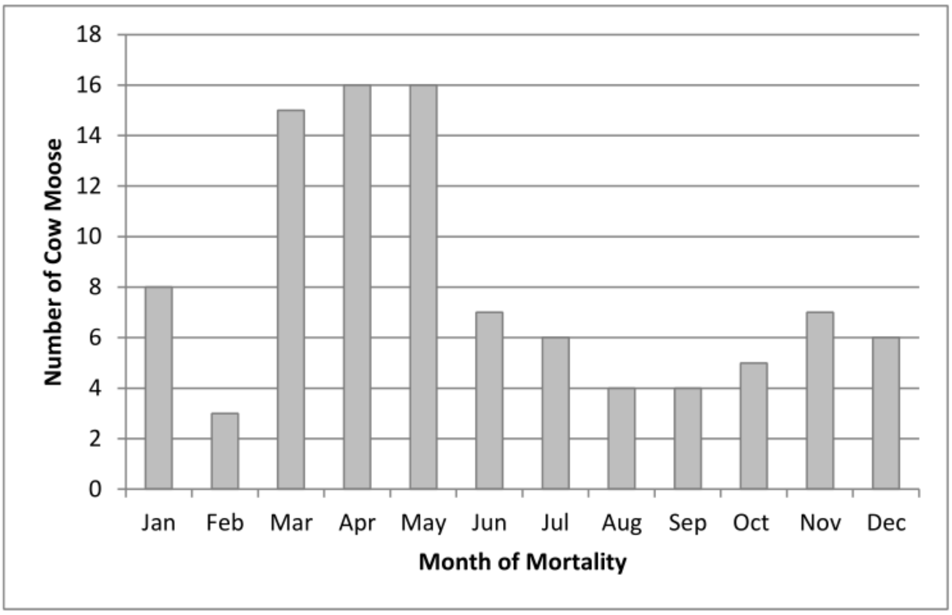

Figure 18. Month of death for radio-collared cow Moose (*n* = 97) in central BC from February 2012–30 April 2018.

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

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

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

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

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

4.6 Relationships between Body Condition and Age and Causes of Mortality

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

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

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

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

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

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

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

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

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

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

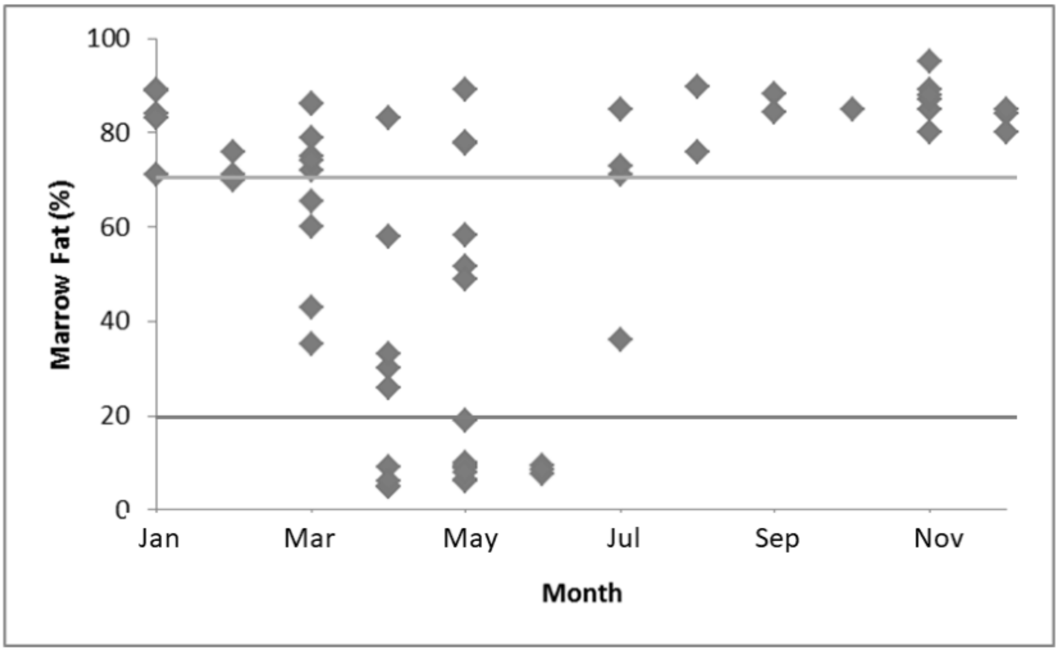

Figure 26. Body condition (as indexed by marrow fat) for each individual collared cow Moose mortality shown by month of mortality (*n* = 63) in central BC from February 2012–30 April 2018. Acute malnutrition is associated with marrow fat <20% (below orange line), poor body condition is associated with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

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

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

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

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

4.7 Late Winter Calf Surveys

From 2014–2018, we conducted 20 late winter (February and March) surveys across the five study areas to assess the survival of calves associated with radio-collared cows. Results varied among study areas with calf/cow ratios ranging from 8–40 calves/100 cows (Table 14).

5. DISCUSSION

5.1 Collection of Biological Data

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

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

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

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

5.2 Cow Survival

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

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

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

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

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

Our data suggest that calf survival is the more important factor than cow survival in explaining Moose population change. If so, then our study of Moose populations may have been trending towards an age distribution skewed towards older females. Survival rates and fecundity of cow Moose decline with age (Montgomery 2014). We did know the age distribution of cow Moose in our study areas or how it may have changed over time (see Heard et al 1997). As indicated above, we were unable to compare ages of Moose that died in ways unlikely unrelated to their age (i.e., accidents, hunter kills) due to insufficient sample size. We are currently investigating methods to characterize the age distribution of Moose populations in the study areas to assist in understanding whether or not age is a factor driving mortality patterns and survival rates estimated in this study (e.g., analyzing age distribution of hunter-harvested Moose throughout BC). Related to this, a process is currently underway to review biological data available from analyses of mortality samples to assign ultimate cause of death to these mortalities. This process recognizes that larger factors (ultimate cause of death) may have driven the actual (proximate) cause of death. This process combines the results from body condition analysis, tooth aging, and results from health testing. For example, a radio-collared cow Moose in Big Creek died from myopathy resulting from intense muscle activity struggling in deep mud. The proximate cause of mortality was determined to be a natural accident, but her body condition showed she was in a state of malnutrition with 5% marrow fat, which may have predisposed her to being unable to free herself from this hazard.

5.3 Calf Survival and Recruitment

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

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

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

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

5.4 Landscape Change and Survival Analyses

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

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

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

The Habitat Conservation Trust Foundation is supporting a comprehensive 2-year, cow-survival analysis with UNBC, which will be completed in April of 2019. This work includes assigning an ultimate cause of death to each mortality (i.e., integrating condition, health, and necropsy data) based on consultations with project staff and veterinarians, and assembling all available data layers including vegetation, cutblock and salvage logging, and fire and spraying histories. The completed analysis will examine similarities and differences in apparent causes for mortality across the project, and provide ranked support for hypotheses linking differences between surviving and dying animals to key management actions.

6. FUTURE RESEARCH DIRECTION

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

6.1 Monitoring Cow Survival Indefinitely

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

6.2 Forest Management Trials to Benefit Moose Populations

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

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

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

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

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

6.3 Monitoring True Calf Recruitment Rates

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

Early evidence from monitoring survival of Moose calves indicates that recruitment indices measured in mid-winter during surveys (i.e., calf/cow ratios) do not reflect actual recruitment into the adult, breeding population of Moose in some years and the difference can have significant ramifications on Moose population trends. As such, continued monitoring of survival and recruitment of older Moose calves is recommended to understand longer-term variation in this parameter and consequences for Moose population dynamics. We plan to continue calf monitoring for a minimum of five years with a minimum of 20–30 calves collared annually (see Boertje et al. 2007 and Jones 2016) in multiple study areas.

6.4 Assess Calf Survival in Relation to Landscape Change

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

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

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

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

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

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

6.6 Role of Nutrition and Health in Influencing Moose Populations

The role of nutrition in driving Moose population dynamics in central BC is currently unknown, but preliminary results in the 2016 and 2017 progress reports (e.g., cows in poor condition at capture, observations of apparent starvation mortalities, low pregnancy rates, and low calf survival) suggest further investigation into nutrition and health parameters, particularly those relating to reproductive health, is warranted. Projects are underway that investigate diet content of Moose in all seasons (JPRF and Prince George South) and how forage nutrition quality (examining differences in forage quality between cutblocks and forested habitats) and health factors (Macbeth 2017) may influence Moose populations. As discussed above, we also plan to begin estimating body fat of collared cows in some study areas in the late fall/early winter to characterize summer and fall nutritional status. Also, there is evidence of a link between nutrition and predation through predator-sensitive foraging, with the indirect foraging effects of predation usually outweighing the direct effect of killing (Montgomery et al. 2014).

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

6.7 Role of Predation on Moose Populations

Predation is currently being monitored through identification of cause of death and species of predator in mortalities for cow and 7-month old calf Moose. A multi-year (2017/18–2021/22) direct assessment of wolf predation rates and species selection through collaring wolves and conducting location cluster investigations in the PG South and JPRF areas is underway (Figure 27). This project will help inform interpretation of predation pressure on these Moose populations by providing more detailed assessment of territory size, pack numbers, predation rates, prey species selection, an increased sample size to assess age/condition of Moose selected and habitat selection information will result in a habitat risk layer for moose. Although this type of information is valuable to understanding these predator-prey systems, these projects are costly and require significant personnel time. As such, it is not possible to replicate this work in all study areas. The importance of other predation types on Moose population dynamics remains a research gap but could be addressed with new technological advances with camera trapping (Burton et al. 2015). The use of camera traps to develop a predation risk layer based on different types of predator species would be helpful to inform cow and calf survival. It would also provide important information on Moose habitat selection and behavior for the Forest Management Trial. Having a more detailed understanding of the role of predation and predator species in Moose survival could help develop priorities for management recommendations to benefit Moose survival.

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

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

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

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

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

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

- **Hunting:** Moose killed by humans for recreation, food, social or ceremonial purposes.
  - **Licensed hunting:** Moose killed by licensed hunters in accordance with hunting regulations.
  - **Unlicensed hunting:** Moose killed by hunters not in accordance with hunting regulations.
- **Predation:** Moose that have been killed by a predator.
- **Health-related:** Moose that died of an underlying health-related cause (starvation, parasitism, mineral deficiency, non-infectious disease, etc.) or pathogen (i.e., infectious disease) as identified through carcass field necropsy and/or subsequent pathology or no other clear causes of mortality was evident.
  - **Apparent starvation:** Moose that have died in very poor condition and are emaciated as evidenced by extreme gross examination (lack of bone marrow fat and lack of visible body fat). Bony structures of shoulders, back, loins, ribs and hips are visually evident. No other clear causes of mortality are obvious or found.
  - **Failed Predation Attempt**: Moose that have died from a failed predation attempt. Causes of death may include shock associated with blood loss, trauma and pain, dehydration, septicemia and other sequella of extreme exertion such as myopathy.
  - **Chronic Bacterial Infection**: A bacterial infection of more than several days duration of subcutaneous and deeper tissues.
  - **Peritonitis**: The inflammation of the peritoneum, the lining of the peritoneal cavity, or abdomen, by an infectious agent, usually bacteria but may be fungi or even a virus. The initiating cause may be a puncture of an organ, intestinal tract or the abdomen wall for entry of a pathogen. Left untreated, peritonitis can rapidly spread into the blood (sepsis) and to other organs, resulting in multiple organ failure and death
  - **Prolapsed Uterus**: The uterus is everted (inside out) from the abdominal cavity through the pelvic canal during a complicated parturition or calving, due to a misrepresentation or severe straining from other reasons.
  - **Unknown health-related:** Moose that were definitively not killed by predation, hunting or natural accident and no underlying health-related cause or pathogen was detected.
- **Natural accident:** Moose that have died naturally from a cause that was accidental in nature (i.e., drowning, mired in mud, avalanche, etc.).
- **Vehicle Collision:** Moose that have died as a direct result of a motor vehicle strike.
- **Unknown:** Moose that have died and 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 December 2017).

Dec 2017

BC Moose Research – Mortality Investigation Form

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

Found dead ☐ or Euthanized ☐ Method of Euthanasia: ________________________________

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

Personnel: ____

General Location: ____

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

Lat: ____________________ Long: ____________________

WILDLIFE HEALTH ID: ________________________

Ear Tag #: ____________ Collar Recovered: Y / N VHF Freq: ________________ Ser. No.: _______________

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

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

____

____

____

____

____

____

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

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

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

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

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

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

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

____

____

____

____

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

Ticks: Number of ticks sample 1 __________

Number of ticks sample 2 __________

Collect tick sample – 10 engorged (70% EtOH)

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

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

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

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

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

CAUSE OF DEATH (check appropriate boxes):

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

Comments (for proximate and ultimate COD):
____

SAMPLES TO COLLECT IN THE FIELD (Post-field sub-sampling described on processing sheet) Must be processed ASAP at office or lab	
☐ HEAD (or sample Obex and LN in the field if trained) ☐ TEETH (incisors or jaw – jaw preferred) ☐ INTACT LONG BONE #1 (femur or humerus) ☐ INTACT LONG BONE #2 (femur or humerus) ☐ MUSCLE (from leg, 1/4 apple size) ☐ HEART (1/4 apple size) ☐ LUNGS (1/2 apple size of right, front and back lobes) ☐ WHOLE KIDNEY + FAT ☐ WHOLE KIDNEY ☐ LIVER (apple size) ☐ INTESTINE *if abnormal and fresh ☐ SPLEEN (palm size) ☐ HAIR (100+ from top of shoulder; stuff 2 envelopes full) ☐ FECES (10-20 pellets) ☐ FETUS (whole if possible) ☐ CALF (if new born) ☐ PLACENTA OR UTERUS (portion) ☐ BLOOD (from heart/jugular vein in red top or EDTA)	☐ CYSTS (if unknown cause) ☐ TICKS ☐ LYMPH NODE *if abnormal ☐ OTHER ________________________ ☐ OTHER ________________________ ☐ PREDATOR DNA (hide with puncture marks) *Swab in field if possible* ☐ PREDATOR HAIR ☐ PREDATOR SCAT LABEL EACH SAMPLE WITH: • WLH ID • SPECIES • SAMPLE TYPE • DATE • STUDY AREA

BC Moose Research – Sample Processing and Tracking

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

PROCESSING SAMPLES IN THE LAB

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

FROZEN SAMPLES
- SEPARATELY IN WHIRLPAKS

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

*FROZEN: in separate whirlpaks: 2" colon with contents, 2" small intestine, ½ cup contents of abomasum.

**FORMALIN: separate from other formalin samples: 2" colon

BC Moose Research – Mortality Investigations

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

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

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

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

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

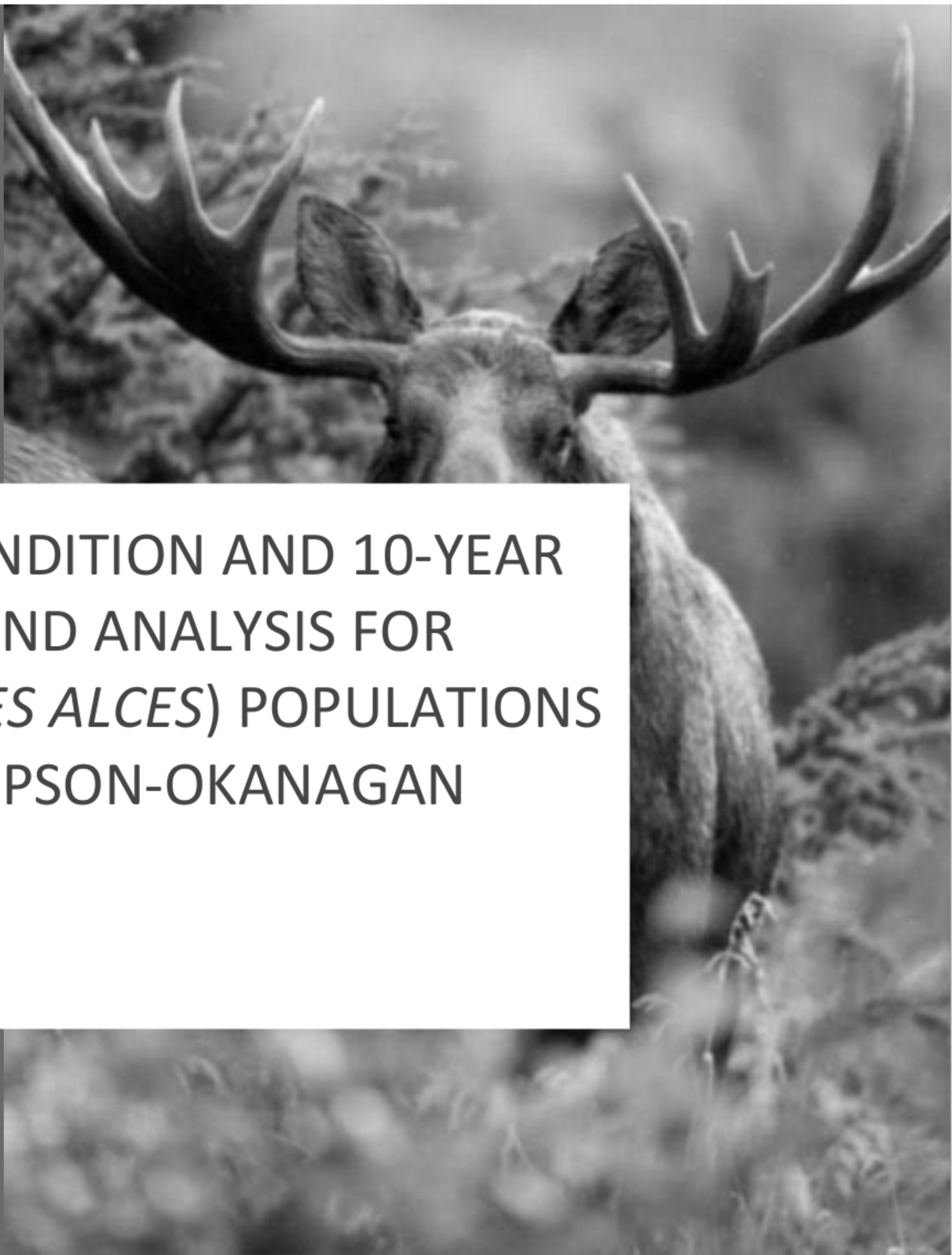
   - FORMALIN IS TOXIC, DO NOT BREATHE IT, USE ONLY WHEN THERE IS GOOD VENTILATION
   - WEAR GLOVES
   - TISSUES MUST BE FIXED AS SOON AS POSSIBLE AFTER COLLECTION
   - TISSUES MUST BE TRIMMED TO A SMALLER SIZE - MUST BE < 1CM THICK TO FIX PROPERLY. 1 X 1 CM SIZE IS IDEAL
   - IF ABNORMAL TISSUE, CAN TAKE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

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

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

#	Frequency	SN	WLHID	Last Fix Date	GPS WPT #	UTM Zone	Easting or Latitude	Northing or Longitude	Cow Located (Y/N)	Calf Present (#/No)	Ticks[1] (Cow)	Ticks[1] (Calf)	Comments/Cow Condition/ Incidental Observations
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													

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



CURRENT CONDITION AND 10-YEAR HISTORIC TREND ANALYSIS FOR MOOSE (*ALCES ALCES*) POPULATIONS IN THE THOMPSON-OKANAGAN REGION

MAY 2017

B.C. Ministry of Forests, Lands and Natural Resource Operations

PREPARED BY: Doug Lewis, RPF

Citation

Lewis, D. (2017). Current Condition and 10-Year Historic Trend Analysis for Moose (*Alces alces*) Populations in the Thompson-Okanagan Region. Ministry of Forests, Lands and Natural Resource Operations. 40pp.

Disclaimer

This report is in the process of being updated to reflect ongoing moose surveys, inventories and monitoring information, collected by FLNRORD Wildlife Section staff. The context, key factors and risk based assessment approach in this report are still relevant but may be modified slightly to be consistent with the provincial moose assessment protocol procedure. The provincial interim assessment procedure can be reviewed at: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/cef_assessment_protocol_moose_draft_v10.pdf

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Executive Summary

Moose are an important species in the Thompson Okanagan Region providing a number of socio-economic and cultural benefits to local residents, including First Nations. In the Thompson-Okanagan Region resident moose hunting generates an estimated $10 million annually as expenditures into the provincial economy, not including non-resident hunting expenditures, income from guide-outfitters, or the less tangible socio-economic and cultural benefits from recreational hunting and meat from successful hunts.

This assessment evaluates the risk of loss of hunting opportunities due to moose population decline in the Thompson Okanagan Region. The assessment evaluates two time periods (2003 and 2014) using an expert-based model, validated with inventory and monitoring data. Factors potentially affecting moose populations considered in the model include: predation (primarily wolves), regulated and non-regulated hunting, forest harvesting and wildfire effects on forage and thermal cover, and livestock effects on forage in wetlands. More current results will be included in a subsequent assessment using an updated assessment procedure that is currently being developed and expected for completion by end of 2019.

The 10-year historic trends (2003-2014) suggest the overall risk of lost hunting opportunities due to moose population decline in the Thompson-Okanagan Region is *Moderate* to *Low*. Risk has increased from *Low* in 2003 but varies across the region due to various factors affecting the moose population, including:

1) High wolf predation rates in the northern portions of the Thompson Rivers and Okanagan Shuswap Resource Districts due to a high density of wolves on moose winter ranges.
2) Increase in habitat-related hazards following MPB salvage on pine-dominated plateaus resulting in extensive cutover areas, reduced thermal/security cover, and open road networks. These conditions increase moose vulnerability to hunting and may reduce availability of effective late winter habitat. Low impacts from regulated and non-regulated hunting. However, hunting pressure can contribute to population impacts where other factors (predation, habitat loss) are affecting the population.

Several *High* risk areas have been identified where moose populations are stable to declining, and that support considerable moose habitat and hunting opportunity. In those high risk areas, regional wildlife and ecosystems staff are undertaking a number of management actions to monitor and manage impacts, including:

- Increased moose population surveys and censuses;
- Research, as part of an ongoing provincial project, using GPS collars to investigate causes of adult and juvenile mortality and habitat use ;
- Extension with forest licensees to raise awareness of habitat and road access issues; and,
- Modification of Limited Entry Hunt (LEH) and General Open Season (GOS) hunting in some Wildlife Management Units (WMU) to reduce hunting pressure.

Monitoring information from hunter harvest information and aerial surveys suggest observed trends in moose populations are consistent with modelled outcomes. Confidence in the assessment outcomes presented here is rated as *Moderate* to *High*.

Table of Contents

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1. Introduction

1.1 General Ecology and Habitat

Moose (*Alces alces*) are the largest member of the deer family (Cervidae), and are the largest ungulate species in British Columbia (B.C.) (BCMELP, 2000). Adult moose are horse-sized, standing as much as two metres tall and weighing on average between 340 to 420kg for adult cows and 450 to 500kg for adult bulls. Only male (bull) moose have antlers that are distinguished by the large, palmate form compared to the slender branching pattern of other cervids. Moose are also easily distinguishable from other cervids by their long, slender legs, large body, shoulder hump, and a dark brown-blackish coat.

Moose are herbivorous and utilize a variety of habitats from heavily forested to open, recently disturbed areas to wetland and riparian areas. In the spring and summer moose forage primarily on leaves and stems of wood plants, but will also use aquatic vegetation. In the winter months, when plant dormancy limits foraging opportunities, their diet shifts to the woody stems of shrubs. Being such large animals, moose must eat up to 20 kg of food every day in winter to meet their energy needs. Preferred browse plants include: willows (*Salix spp.*), red osier dogwood (*Cornus sericea*), Saskatoon (*Amelanchier alnifolia*), high bush cranberry (*Viburnum edule*), bog birch (*Betula glandulosa*), lodgepole pine (*Pinus contorta*), paper birch (*Betula papyrifera*), and mountain ash (*Sorbus Sitchensis*).

Four general seasons have been recognized as important for providing foraging, thermal, hiding or snow interception cover for moose, including: Summer (July to August), early Winter (September to December), Late winter (January to April) and Calving Season (May to June). Late winter and Calving seasons are considered the most critical as foraging and thermal cover habitats are most limiting. Seasonal movements are largely determined by the depth and duration of snow cover (BCMELP 2000). Their long legs allow moose to move through deep snow up to 60cm in depth enabling moose stay on high elevation ranges much longer than other ungulates (BCMWLAP, 2005). However, snow depths of 60 to 90cm may inhibit movements and >90cm may severely restrict movements. In mountainous regions of B.C. where snow accumulations are greater, moose usually migrate to lower elevation winter-spring ranges in valley bottoms returning to higher-elevation calving and summer ranges, although some moose remain in valleys year round. On plateaus, moose concentrate along river valleys that cut through the plateaus, and in burns, logged areas and wetland complexes. In many dry interior plateau habitats that receive less precipitation, lower snow accumulations may allow moose to remain at higher elevations until late winter or even throughout the year.

Moose are well adapted to snowy and cold environments and their thick winter coat allows them to tolerate temperatures down to -25°C. However, moose will seek out thermal cover to stay cool in the late Winter Season where temperatures above -5° C cause moose to increase respiration rates. Studies have shown that moose alter daily patterns of behaviour and habitat use to stay cool (Renecker and Hudson, 1986).

1.2 Distribution and Abundance

Moose are the most widely distributed ungulate in B.C., occupying most areas except the very dry valley bottoms of the Thompson and South Okanagan, and are generally absent from the coast (Figure 1). However, recent evidence suggests range expansion by moose into coastal temperate rainforest environments (Darimont et al. 2005). In the Thompson-Okanagan Region, moose are found throughout most ecosystems except the Bunchgrass (BG) and Ponderosa Pine (PP) Biogeoclimatic zones, although moose have been observed in aspen copses in both zones (Lemke, 2000).

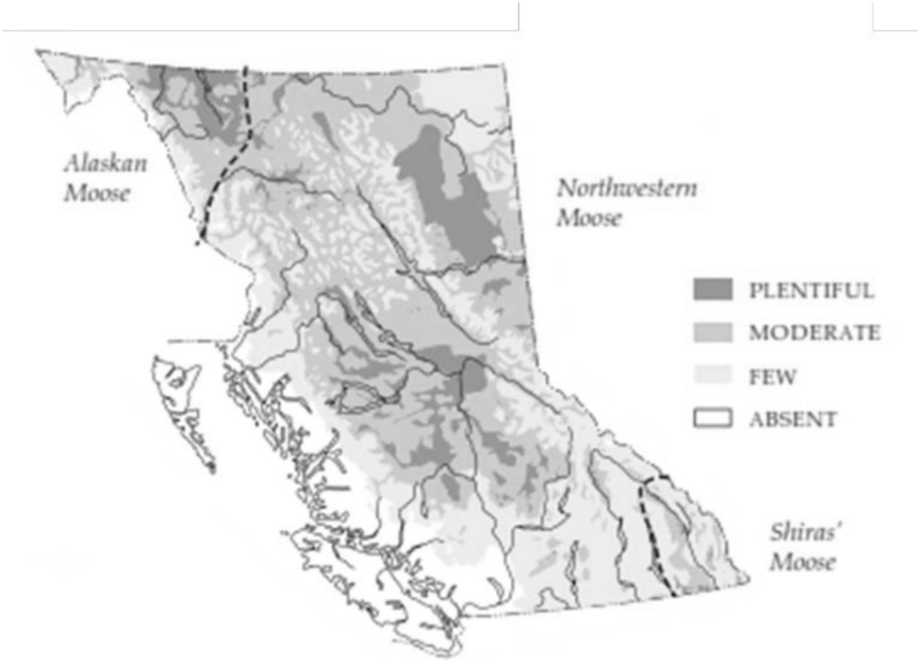

Figure 1. Current estimated distribution and relative abundance of Moose in British Columbia (Figure copied from BCMELP, 2000).

The current moose population in the Thompson-Okanagan Region is estimated at 10-15,000 animals[1]. Population densities vary considerably throughout the region depending on habitat quality and availability. In winter, typical moose population densities range from 0.3 moose/km^2 to 1.5/km^2 (BCMELP, 2000).

1.3 Socio-Economic and Cultural Importance

Moose are broadly recognized as important to the people of B.C., from their key role in ecosystem function, to the cultural, social and economic benefits derived from their use. First Nations peoples used moose prior to European contact and settlement (BC MELP, 2000). Moose were often a main source of meat; moose hides were used for clothing and shelter and bones and antlers were used to make a variety of tools. Moose continue to be a source of sustenance to First Nations communities and moose hunting is recognized as an important part of First Nations culture. Moose remain one of the most important game species to residents in B.C. (BC MELP 2000). Provincially, annual moose harvest from 2007-2015 was estimated at approximately 19,000-23,000[2]. In Region 3, which covers a large portion of the Thompson-Okanagan Region, annual resident harvest from 2007-2015 ranged from approximately 4,000-6,500 animals. Moose hunting generates license revenue, income for guide outfitters and considerable recreational opportunities for residents. Provincially, moose hunting resulted in approximately 375,000-500,000 annual hunter days during the period from 2007-2015. In Region 3, about 75,000-117,000 days were spent hunting moose annually in that same period.

The economic revenue generated from moose hunting in the Province and the Thompson-Okanagan Region can be considerable. Survey information from the 2012/13 hunting season estimated that B.C. resident moose hunter expenditures[3] exceed $70 million for that season. In Region 3 and 8, resident moose hunting

[1] Frequently asked questions: Moose harvest strategies in South-Central B.C. (Cariboo, Thompson, Okanagan, Kootenay, Omenica), Fish, Wildlife and Habitat Management Branch, B.C. Ministry of Forests, Lands and Natural Resource Operations, July 18, 2011

[2] Provincial big game harvest statistics provided by B.C. Ministry of Forests, Lands and Natural Resource Operations, Fish and Wildlife Branch.

[3] Expenditures include food and beverages, lodging, fuel, hunting and associated equipment, licenses and tags, processing and taxidermy and large purchases such as vehicles, campers, boats, etc. used primarily for hunting. Expenditures estimated here are for resident hunters only, non-resident

expenditures were estimated at $6.7 and $8.3 million respectively for that same year. These estimates do not include the less tangible recreational benefits from moose hunting and the socio-economic and/or cultural benefits derived from the meat the successful hunters take home.

1.4 Regulatory Framework for Moose Management in B.C.

Provincial Status

Moose are yellow listed and ranked as (S5) under Provincial Conservation Status[4], meaning moose populations are demonstrably abundant, widespread and secure. However, given their cultural and socio-economic importance as a hunted species, moose are a species of management concern in B.C. and specific habitat and population management guidelines have been established to manage moose populations.

Population Management

As stated in the *Draft Provincial Framework for Moose Management in British Columbia* (BCMFLNRO, 2013)[5]; "the goal of moose management is to ensure moose are maintained as integral components of natural ecosystems throughout their range, and maintain sustainable moose populations that meet the needs of First Nations, licensed hunters and the guiding industry. The objectives for moose management are to:

1. Ensure opportunities for consumptive use of moose are sustainable;
2. Maintain a diversity of hunting opportunities; and,
3. Follow provincial policies and procedures (e.g. provincial moose harvest management procedure) as guidance for regulatory options and management objectives".

To sustainably manage consumptive use, the *Wildlife Act of British Columbia* provides the Minister responsible to issue hunting licenses, set bag limits, hunting seasons for non-aboriginal residents and non-residents and set quotas for guide-outfitters based on resident/non-resident allocation. Regional MFLNRO Wildlife Biologists monitor moose populations to advise on appropriate hunting seasons, bag limits and quotas by management unit in each region. In B.C., sustainable harvest rates are around 3% to 9% depending on population objectives and demographics.

The following steps are used to determine Annual Allowable Harvest (AAH)[6]:

1. Biologists conduct a moose population assessment and determine a "maximum allowable mortality level";

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hunters' expenditures and guide-outfitter revenues are not included. Source: Expenditures of British Columbia Resident Hunters. 2013. Unpublished report conducted for B.C. Ministry of Forests, Lands and Natural Resource Operations, by Responsive Management. Available at: http://www.env.gov.bc.ca/fw/wildlife/docs/bc_hunting_expenditure_rpt_2013.pdf

[4] See the B.C. Species and Ecosystems Explorer at the B.C. Ministry of Environment website: http://www.env.gov.bc.ca/atrisk/toolintro.html to look up species conservation status and ranking definitions.

[5] Draft Provincial framework for Moose Management in British Columbia. B.C. Ministry of Forests, Lands and Natural Resource Operations, Fish Wildlife and Habitat Management Branch, Victoria , B.C. August 2013 http://www.env.gov.bc.ca/fw/wildlife/management-issues/

[6] Frequently asked questions: moose harvest strategies in South-Central B.C. (Cariboo, Thompson, Okanagan, Kootenay, Omenica), Fish, Wildlife and habitat Management Branch, B.C. Ministry of Forests, Lands and Natural Resource Operations, July 18, 2011

2. Biologists then estimate or otherwise account for First Nations harvest;
3. Others sources of human-caused mortality, such as road/rail mortality, may be estimated if substantive levels present; and,
4. The AAH is then determined by subtracting First Nations harvest. The AAH is therefore the number of moose available to be harvested by licensed hunters each year.

The number of moose available to licensed hunters is managed through hunting regulations, and includes:

- Restrictions on hunting females (cows) and young (calves) through Limited Entry Hunting (LEH) to ensure adequate adult female survival and population recruitment; and,
- Restrictions on timing and age and sex (spike fork harvest) for General Open Seasons (GOS).

Habitat Management

Under the B.C. Identified Wildlife Strategy moose are identified as an ungulate species that may require management of winter range habitats for winter survival[7].Two primary regulatory tools exist to manage winter range habitats:

1. The *Wildlife Act of British Columbia* provides the Minister responsible the ability to acquire, administer or designate areas (i.e. Wildlife Management Areas-WMAs) to manage and protect wildlife, and
2. The *Forest and Range Practices Act* (FRPA) contains objectives set by Government for wildlife under Section 7(2) of the Forest Planning and Practices Regulation and Section 9(3) of the Woodlot License Planning and Practices regulation, and authorizes the Minister responsible to establish ungulate winter range areas (UWRs) or Wildlife Habitat Areas (WHAs) and specify objectives and General Wildlife Measures (GWMs).

UWRs, WHAs and GWMs are established under a Government Action Regulation (GAR) Order under the *FRPA*. *Forest Act* tenure holders with replaceable forest licenses that are required to prepare a Forest Stewardship Plan (FSP) must specify results and strategies that are consistent with the objectives specified in the GAR order.

Legal objectives for identified moose winter range habitats in the Thompson-Okanagan Region vary considerably between Natural Resource Districts and Timber Supply Areas depending on the history of land use planning (Appendix 1). In general, habitat measures are focused on maintaining adequate levels of key habitat requisites including forage, thermal and hiding cover affected by forest harvesting and livestock/range management practices.

[7]B.C. Identified Wildlife Management Strategy http://www.env.gov.bc.ca/wld/frpa/species.html

2. Assessment Approach

The moose assessment uses a risk-based approach as described in Wise et al. (2004) and CSA (1997), where risk is the product of hazard and consequence defined by the risk equation**; Risk = Hazard x Consequence.** The assessment provides a risk rating for each moose 'planning cell' (see Section 2.1 Assessment Unit) interpreted against draft provincial moose management objectives[8], where risk is a defined as a loss of hunting opportunities due to a decline in moose populations[9]. Risk ratings are based on consequence and hazard ratings derived for each planning cell combined in a risk matrix (Fig. 2).

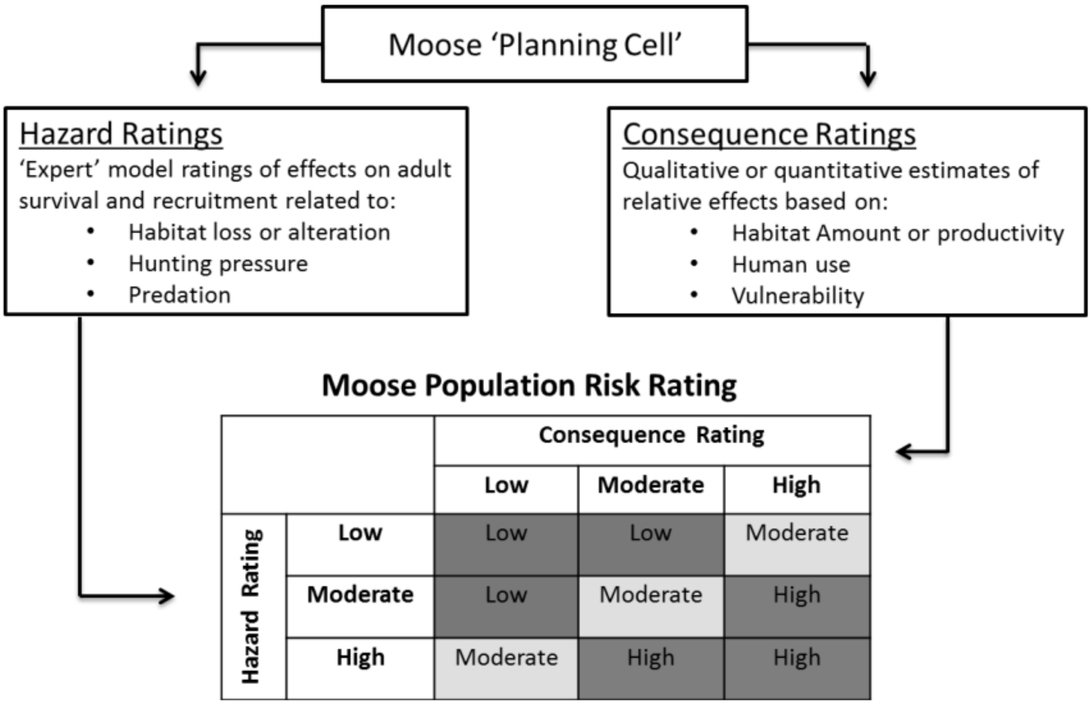

Figure 2. Risk matrix used in the Moose Population Risk Assessment

Factors that contribute to moose population decline (hazards) are measured using GIS indicators output as hazard ratings using an expert-judgement-based (expert) moose population assessment model (Wilson, 2014: Appendix 2 and 3). Consequence ratings are assigned based on qualitative estimates of the socio-economic loss associated with lost hunting opportunities. A more detailed explanation of how consequence and hazard ratings are used to assess moose population risk is provided in subsequent sections.

2.1 Assessment Units

The assessment was completed for the entire Thompson-Okanagan Region including the Lillooet and Merritt TSAs (Cascades Resource District), Kamloops TSA (Thompson River s District) and Okanagan Shuswap TSA (Resource District).

[8] Assessments related to specific legal habitat objectives for moose, where they exist and can be measured, are completed in different reports.

[9] Regulated moose hunting opportunities are managed annually to minimize impacts of hunting on the population. The decline described here is considered both persistent (5+years) and significant enough to not sustain previous regulated and non-regulated (e.g. aboriginal) hunting levels.

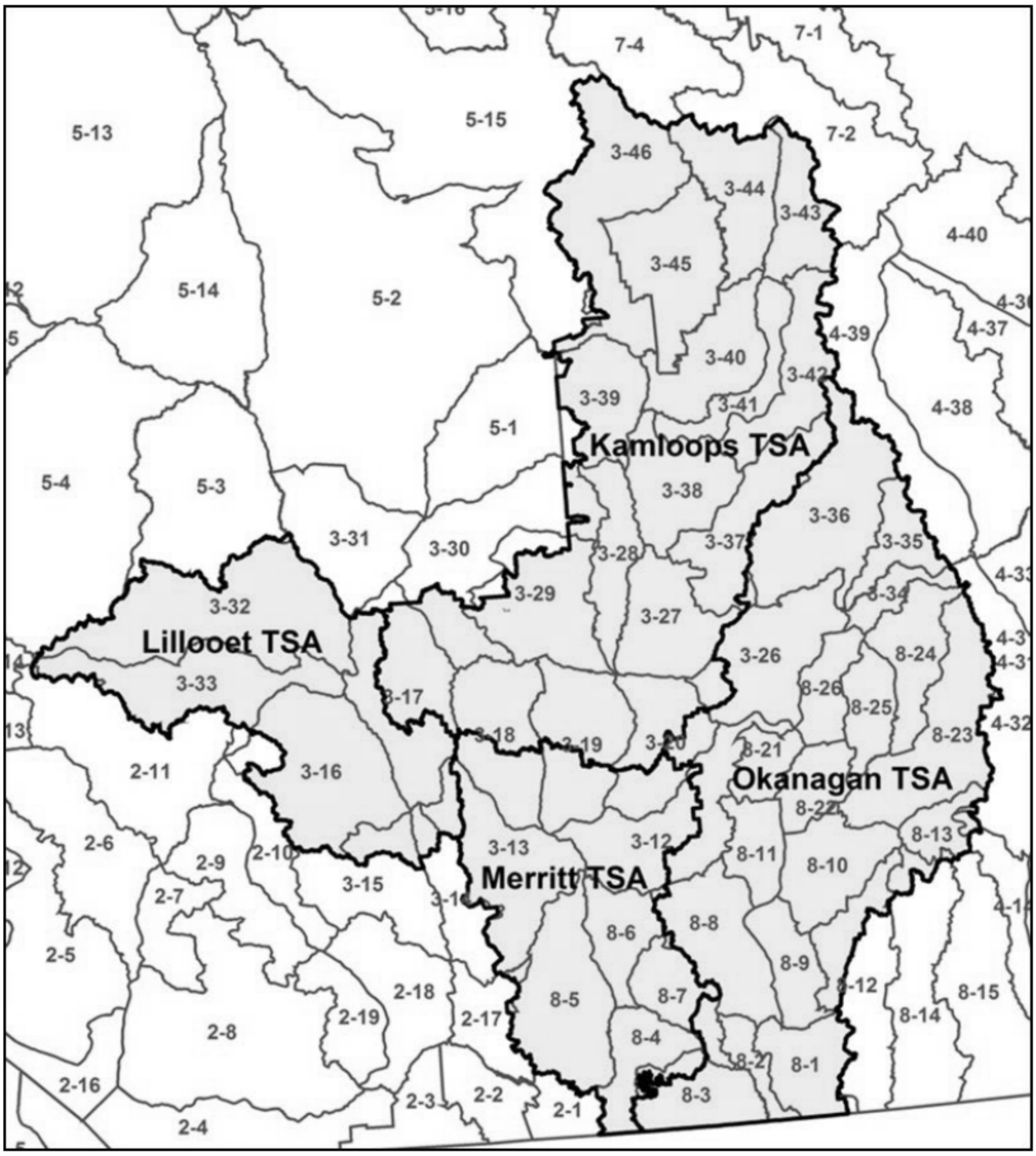

Figure 3. An illustration of the broader Thompson Okanagan Region assessment area showing the extent Wildlife Management Units (WMUs; green shaded areas) that are currently included in the assessment.

Existing Wildlife Management Units (Figure 3) used for moose population management were considered too broad to capture more local habitat and human access (hunting) related effects on moose. As a result moose 'planning cells' were developed as an assessment and reporting unit that divides existing WMUs into smaller sub-section based on logical boundaries to human development including existing major highways or roads, major rivers or lakes or topographic features (Figures 4 and 5). The division of the land-base into planning cells also facilitates the use of assessment outcomes in planning and implementation of mitigation activities directed at habitat or human access.

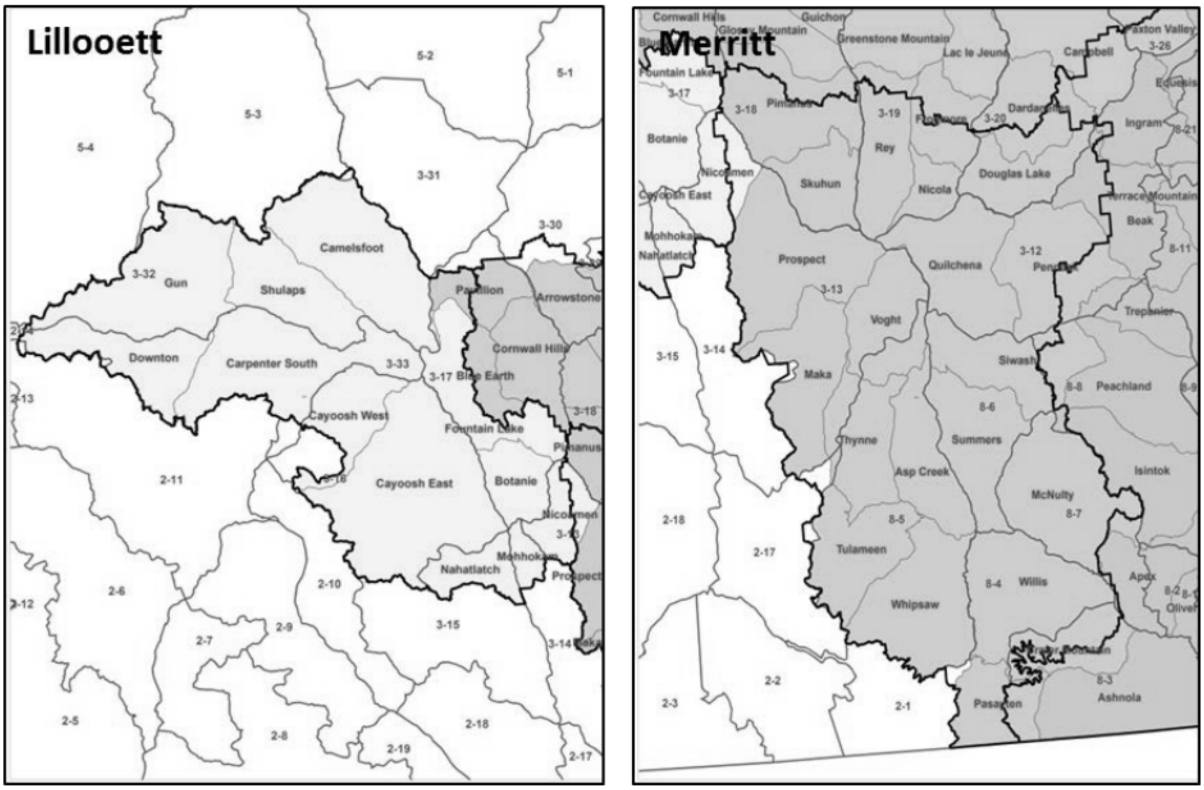

Figure 4. Lillooet (yellow) and Merritt (orange) assessment areas used in the Thompson-Okanagan Region Moose assessment. Green boundaries illustrate Wildlife Management Units (WMUs) whereas red lettering and grey lines illustrate the delineation of smaller moose planning cells relative to the WMUs.

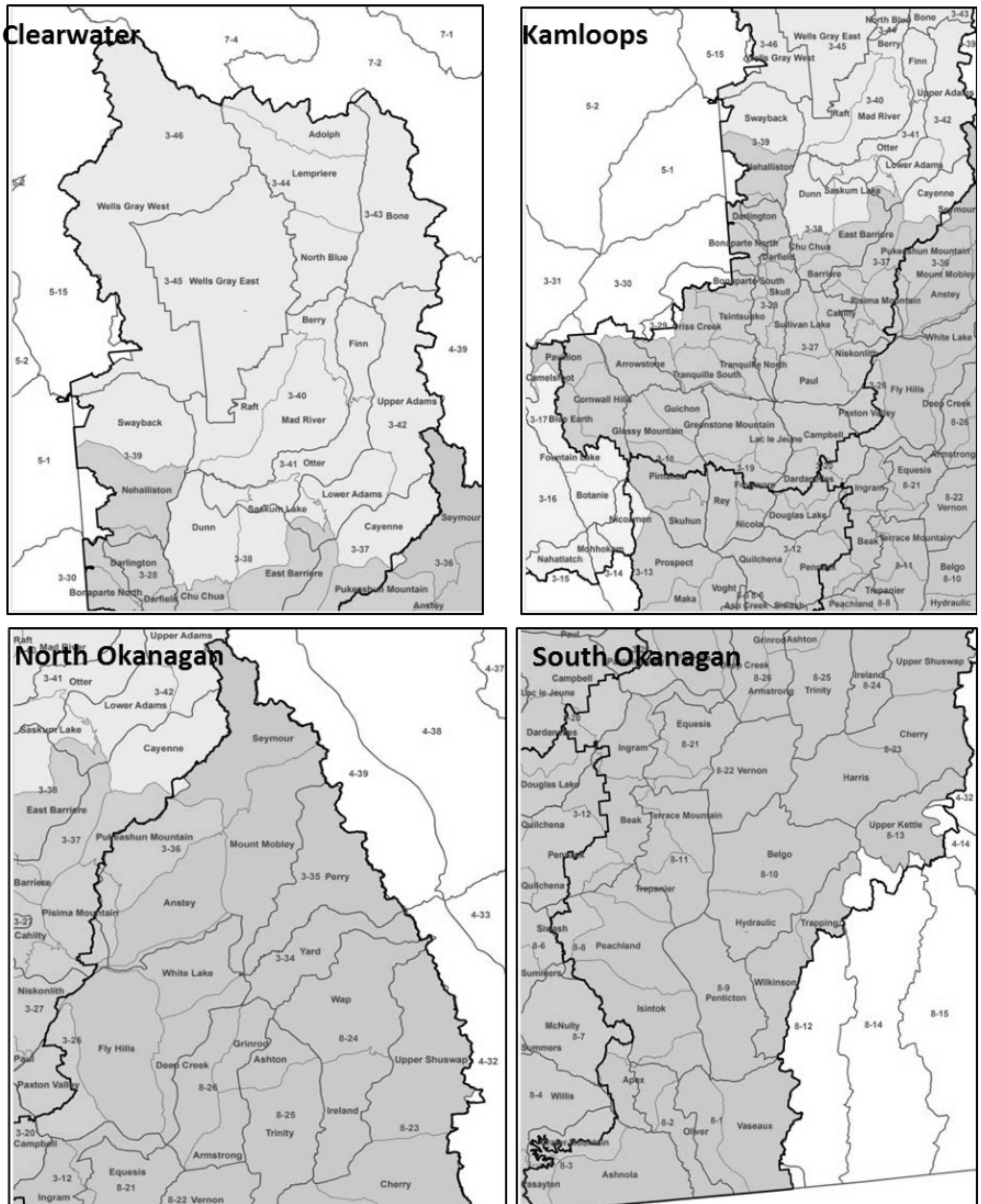

Figure 5. Clearwater (light blue), Kamloops (pink), North Okanagan (blue-left) and South Okanagan (blue right) assessment areas used in the Thompson-Okanagan Region moose assessment. Green boundaries illustrate Wildlife Management Units (WMUs) whereas red lettering and grey lines illustrate the delineation of smaller moose planning cells relative to the WMUs.

2.3 Assessment Scenarios

The assessment procedure runs an analysis of landscape condition and reports out at three time periods:

- **Historic condition to 2003** – historic landscape condition including existing levels of forest harvesting, road networks and other land use activity was re-created to 2003 using archived datasets.
- **Current condition (2014)** – current landscape condition including existing levels of forest harvesting, road networks and other land use activity was produced using updated datasets.

2.4 Consequence Ratings

Consequence is defined as is the effect on human well-being, property, the environment, or other things of value; or a combination of these (Vandine et al. 2004). Moose are primarily valued by humans for the socio-economic benefits derived from sustenance and recreational hunting. Provincial goals and objectives for moose management in B.C. are to "maintain sustainable moose populations that meet the needs of First Nations, licensed hunters and the guiding industry". [10]

In this procedure, consequence refers to the socio-economic and cultural effects due loss of hunting opportunities for First Nations, licensed hunters and the guiding industry due to moose population decline. The types of effects include:

- Social and cultural impacts to First Nations peoples due to loss of sustenance hunting, or for social or ceremonial purposes;
- Social impacts due to loss of recreational and sustenance hunting opportunities for non-aboriginal residents;
- Loss of economic revenue to the Province from reduced licensing fees;
- Loss of economic revenue in local communities from hunting-related tourism or activity (e.g. purchasing of fuel); and,
- Loss of economic revenue to guide outfitters.

Consequence ratings are used to express estimates of the likelihood of an effect or outcome should a harmful situation occur. Consequence ratings used in this assessment are intended to provide a qualitative estimate of the relative importance or worth of a moose planning cell, *at the regional level*, to providing hunting opportunities. Consequence ratings are based on two sources of information (Figure 6):

1. The total amount of and quality of capable winter habitat as an indicator of the ecological potential to support moose; and,
2. Hunting effort as an indicator of socio-economic worth of hunting, based on average annual number of hunter days from 1976-2010 using General Open Season (GOS) hunter survey data.

Consequence ratings should not be misinterpreted to infer that any individual planning cell is less important ecologically or to hunters/guide outfitters/First Nations that use that local area. Moose populations are important in all areas and will continue to be managed through existing regulations and management actions. The consequence ratings are intended to identify areas within the region that may require additional management attention for moose beyond existing measures. First Nations or individual stakeholders can apply their own consequence ratings to assess risk within their own area of interest.

[10] Draft Provincial framework for Moose Management in British Columbia. B.C. Ministry of Forests, Lands and Natural Resource Operations, Fish Wildlife and Habitat Management Branch, Victoria , B.C. August 2013 http://www.env.gov.bc.ca/fw/wildlife/management-issues/

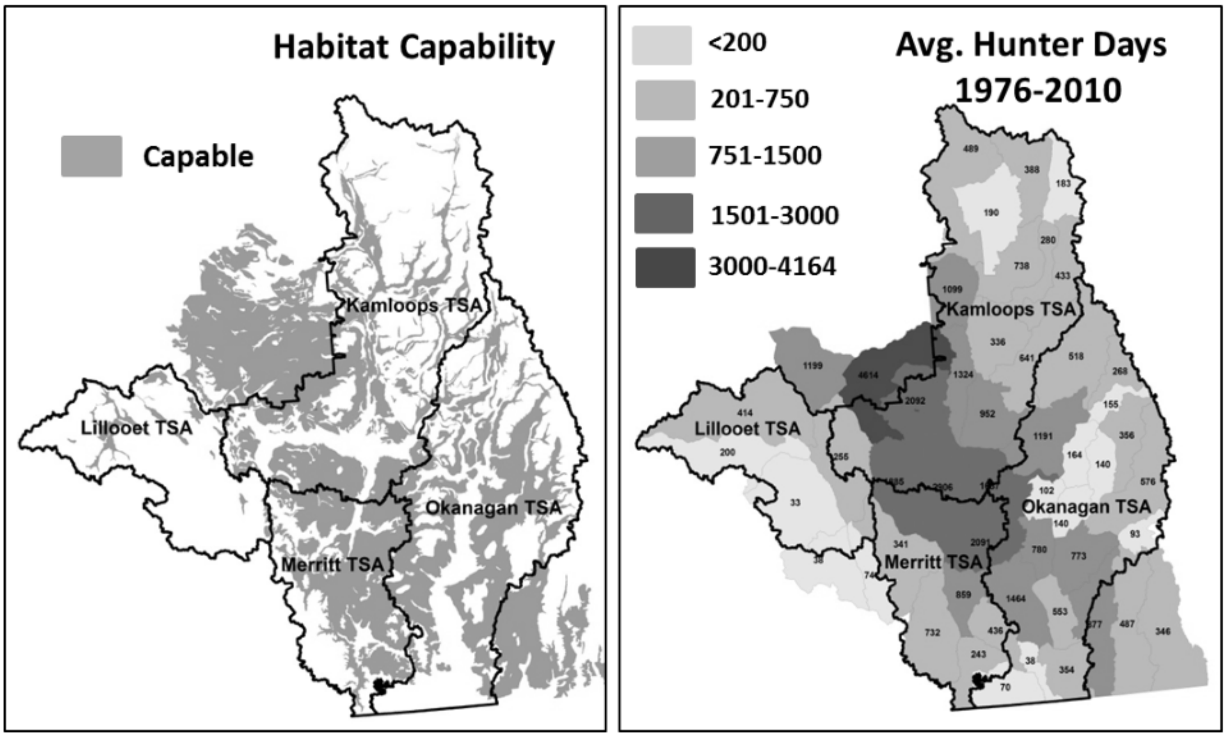

Figure 6. Habitat Capability (left) in the Thompson Okanagan region and average hunter days by WMU from 1976-2010 (right) based on hunter survey information.

To derive consequence ratings, hunter days for each moose planning cell were first estimated based on hunter information from overlapping WMUs and the amount and quality of capable winter habitat. Planning cells within a WMU with less capable habitat were assigned a lower proportion of hunter days. Each planning cell was then assigned consequence rating of *Low, Moderate* or *High*. In general, *High* consequence planning cells have >60% of the area as capable habitat, a higher proportion of *Moderate-Highly* rated capable habitat and >500 estimated average annual hunter days. *Low* consequence planning cell generally have <30% capable winter habitat and support <150 average annual hunter days.

The *Moderate* and *High* rated planning cells focus on planning cells with the highest concentration of moderate-high capability habitat and average hunter days. These areas fall in the central portion of the region on the Bonaparte, Guichon and Okanagan plateaus that straddle the Kamloops, Merritt and Okanagan-Shuswap areas (Figure 7). The 51 *Moderate* and *High* rated planning cells out of the 115 total planning cells in the Thompson-Okanagan region account for close to 60% of the total capable habitat in the region, as much as 60-65% of the total moose population and 70% of total average hunter days.

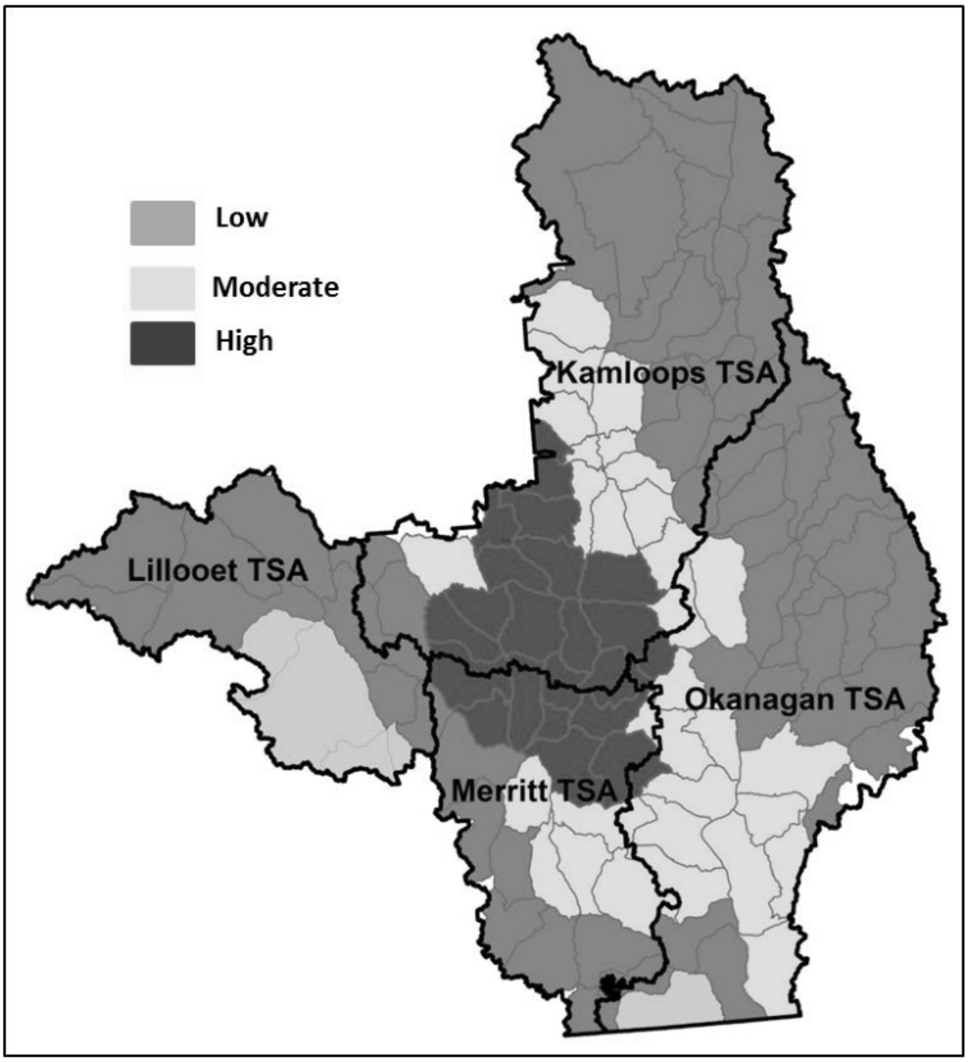

Figure 7. Consequence ratings by moose planning cells in the Thompson-Okanagan Region.

2.5 Hazard Ratings

Hazards are defined as a source of harm or potential for harm (Wise et al. 2004). Many anthropogenic or non-anthropogenic factors can individually or collectively contribute to potentially harmful situations for moose. Three hazard categories are considered in this assessment, including:

- **Habitat loss or alteration** – changes in the availability of transient (e.g. early seral) winter foraging and thermal/security cover habitat;
- **Hunting** – mortality through regulated LEH and GOS and non-regulated (Aboriginal) hunting; and,
- **Predation** – adult and juvenile mortality based on the density of wolves as the primary predator and the concentration of wolves on moose winter range.

Hazard ratings are used to express the likelihood of potential for harm that will contribute to moose population decline (Table 1). The analysis of hazards use measured GIS-based indicators of both land-base characteristics that cause moose to be more sensitive to landscape change, and indicators of change resulting from human and natural processes. Hazard ratings reflect complex interactions between multiple indicators used in the Expert-based model (Wilson, 2014). The relationships between the amount and/or extent of measured GIS-indicators and the probability of a *Low, Moderate* or *High* impact to moose are used to define the likelihood of a hazardous situation, and are detailed in the expert model.

Table 1. Terminology used to describe hazard ratings[11]. From Lewis et al., 2016.

Hazard Rating	Likelihood of Occurrence	Probability of Occurring (%)
Low	<33%	Unlikely that harmful situation exists that will contribute to moose population decline
Moderate	33-66%	About as likely as not that a harmful situation exists that will contribute to moose population decline
High	>66%	Likely that a harmful situation exists that will contribute to moose population decline

2.6 Risk Ratings

Risk is the chance of injury or loss as defined as a measure of the probability and the consequence of adverse effects to health, property, the environment, or other things of value (Wise et al. 2004). In this assessment, risk refers to the risk of lost hunting opportunities due to moose population decline. Risk ratings provide an estimate of the likelihood that risk will occur (Table 2), and are based on the relative weightings of the various hazards that affect moose adult survival and recruitment as described in the expert model (Wilson, 2014) and the importance of the area for moose hunting (consequence).

Table 2. Terminology and description used in risk ratings.

Risk Rating	Likelihood of Occurrence	Consistent with Draft Provincial Moose Management Objectives?	Risk Description
Low	<33%	Yes	Unlikely that hunting opportunities will be lost, Increasing to stable moose population that can sustain hunting effort and success at desired levels.
Moderate	33-66%	Yes	About as likely as not hunting opportunities will be lost, and moose population can sustain hunting effort and success at desired levels.
High	>66%	No	Likely that hunting opportunities will be lost. Moose population cannot sustain hunting effort and success at desired levels.

The risk ratings derived from the expert model are interpreted against the following policy objectives identified in the *Draft Provincial Framework for Moose Management in British Columbia (2013):*

1. Ensure opportunities for moose consumptive use are sustainable; and
2. Maintain a diversity of hunting opportunities for moose.

Under a high risk rating, populations are likely to have declined or are declining to a level that consumptive use cannot be sustained at desired levels, and diverse hunting opportunities (including Aboriginal ,

[11] Likelihood statements follow recommended terminology from the Intergovernmental Panel on Climate Change (IPCC) Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties, July 2005.

recreational, guide-outfitting) cannot be maintained[12]. Thus, the high risk rating is considered to be inconsistent with the draft provincial objectives.

2.7 Use of Inventory and Monitoring Data to Validate Assessment Results

To help validate expert model results used in the hazard analysis, existing inventory or monitoring information are used to evaluate whether hazards identified to cause moose population decline are resulting in observable changes in moose numbers. The following inventory and monitoring sources were used:

- Hunter Reporting
    - Hunter success and hunter effort (# of days) reported annually since 1984
- Aerial Composition Survey
    - Bull:Cow:Calf ratio
    - Rough population estimate based on # of moose counted
- Aerial Stratified Random Block (SRB) Survey
    - Stratify habitat by quality (Low, Moderate, High)
    - Count number of moose spotted from aircraft in each strata
    - Population estimated (corrected) based on # of moose spotted
    - Also provide a composition estimate (Bull:Cow:Calf)

Hunter reporting (hunter success from LEH) is used to estimate population abundance using a statistically derived relationship, and provides evidence of trends over time (See Appendix 4). Aerial composition survey and SRB survey data is used to estimate population abundance at a given time, and provides increased confidence when used with population estimates derived from the hunter reporting data. Composition estimates provide additional evidence of trends in the proportion of males to females (cow: bull ratio) or young to adult females (cow: calf ratio). This information provides insight into whether effects are related to predators (adult female survival or calf recruitment, or hunting pressure affecting primarily males (cow: bull ratio).

2.8 Communicating Uncertainty and Confidence

All forms of assessment, particularly those involving complex ecological systems and unpredictable human behaviours, involve uncertainty (Table 3). Strategic-level assessment procedures, such as this, have particular uncertainties inherent with the broad-scale and time frames involved, generalizations used to characterize ecological systems and human behaviours and 'coarse' data or information sources used in the analysis. Uncertainty and is an integral part of risk and risk management, therefore understanding and communicating types of uncertainty and confidence is fundamental to understanding assessment outcomes and informing management actions.

Table 3. A typology of uncertainties, sources and considerations to reduce uncertainties. Adapted from IPCC (2005).

[12] The draft provincial moose management objectives are not measurable, so present a challenge to evaluate if objectives are being achieved. In this assessment, use of the expert model to determine the likelihood of moose population decline, and interpretation of high likelihood as inconsistent with the draft provincial objectives, is the assessor's interpretation of a measurable 'assessment endpoint' consistent with guidance from the *USEPA Framework for Ecological Risk assessment (1992) and Generic Ecological Assessment Endpoints for Ecological Risk Assessment* (2003).

Type	Examples of Sources	Considerations to Reduce Uncertainty
Unpredictability	Projections of human behaviours, chaotic components (e.g. natural disturbances) of complex systems	Use of scenarios spanning a plausible range, clearly stating assumptions, limits considered.
Structural Uncertainty	Inadequate model, lack of agreement on model structure, ambiguous system boundaries or definitions, significant processes wrongly specified or not considered	Specify assumptions and system definitions clearly, compare models with observations for a range of conditions, assess maturity of the underlying science and degree to which understanding is based on fundamental concepts tested in other areas.
Value Uncertainty	Missing inaccurate or non-representative data, inappropriate spatial or temporal resolution, poorly known or changing model parameters	Analysis of statistical properties of sets of values (observations, model ensemble results, etc.), Bootstrap and hierarchical statistical tests, Comparison of models with observations.

Confidence ratings (Table 4) are estimated based on the extent that each type of uncertainty (Table 3) affects the assessment outcomes[13]. Confidence ratings and descriptions of key types and sources of uncertainty will accompany assessment results.

Table 4. Terminology and descriptions of confidence used to assign confidence ratings to moose assessment results.

Terminology	Degree of Confidence
Very High Confidence	At least 9 out of 10 chance of being correct
High Confidence	About 8 out of 10 chance
Medium Confidence	About 5 out of 10
Low Confidence	About 2 out of 10
Very Low Confidence	Less than 1 out of 10 chance

[13] Confidence statements follow recommended terminology from Table 2 in the Intergovernmental Panel on Climate Change (IPCC) Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties, July 2005

3. Assessment Results

3.1 Current Condition and Historic Trend

Moose Population Hazards and Risk

The 10-year historic trends (2003-2014) suggest an increased in hazard from 2003 to 2014 (Figure 8) that varies considerably across the region due to a number of factors:

1. High wolf predation rates in the northern portions of the Thompson Rivers and Okanagan Shuswap Resource Districts due to a high density of wolves on moose winter range have resulted in declines in moose populations in those areas. Anecdotal observations and survey information suggests the distribution of wolves has shifted south into the central portion of the region, and wolf density has recently declined in the northern portions.
2. Increase in habitat-related hazards in the Kamloops, South Okanagan and parts of the Merritt areas due to loss of thermal cover habitats, more extensive early seral areas and open road networks following MPB salvage on pine-dominated plateaus. Extensive cutover areas, reduced thermal/security cover, and open road networks can increase moose vulnerability to hunting and may reduce availability of effective late winter habitat where adjacent forage and thermal cover is reduced.
3. Regulated and non-regulated hunting impacts are generally considered low. However, hunting pressure can contribute to population impacts where other factors (predation, habitat loss) are affecting the population.

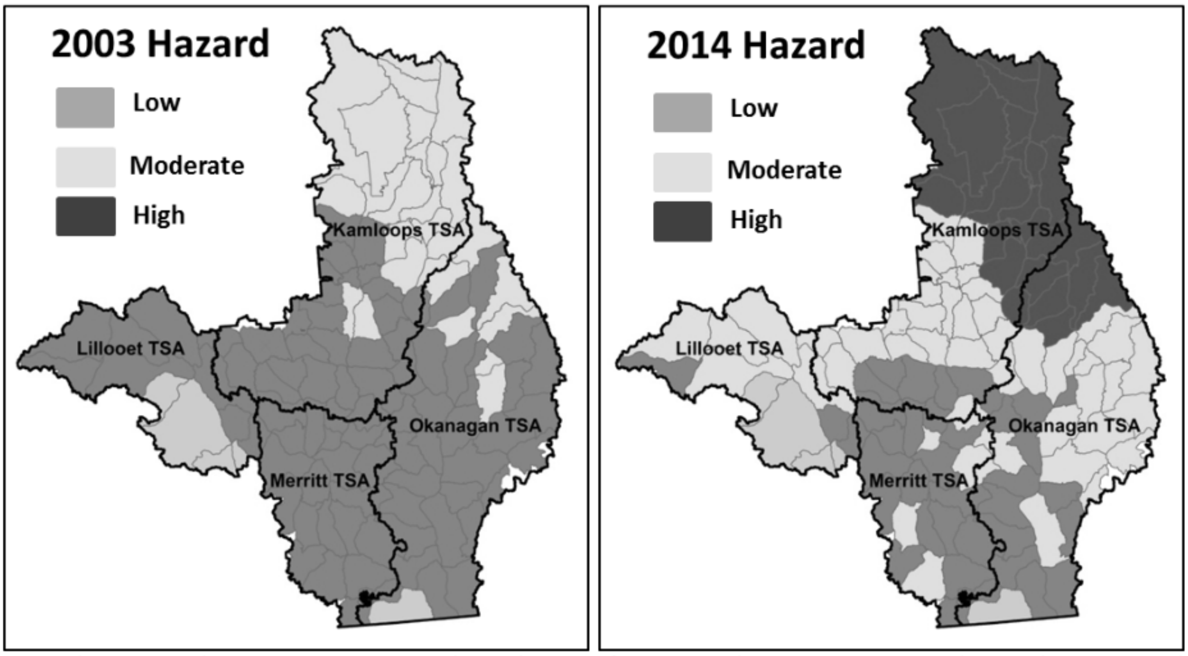

Figure 8. Thompson-Okanagan Region Moose hazard ratings for 2003 and 2014. Grey areas indicate where no capable moose habitat is identified. Tabular results by planning cells are summarized from Appendix 6 for Lillooet TSA and Appendix 10 for Okanagan TSA (south portion).

The 10-year historic trends suggest an **overall Moderate-Low risk** of loss hunting opportunities in the Thompson Okanagan Region, although **small areas of High risk do occur**. The combination of hazards and consequence play a large role in the variability in risk ratings across the region (Figure 9).

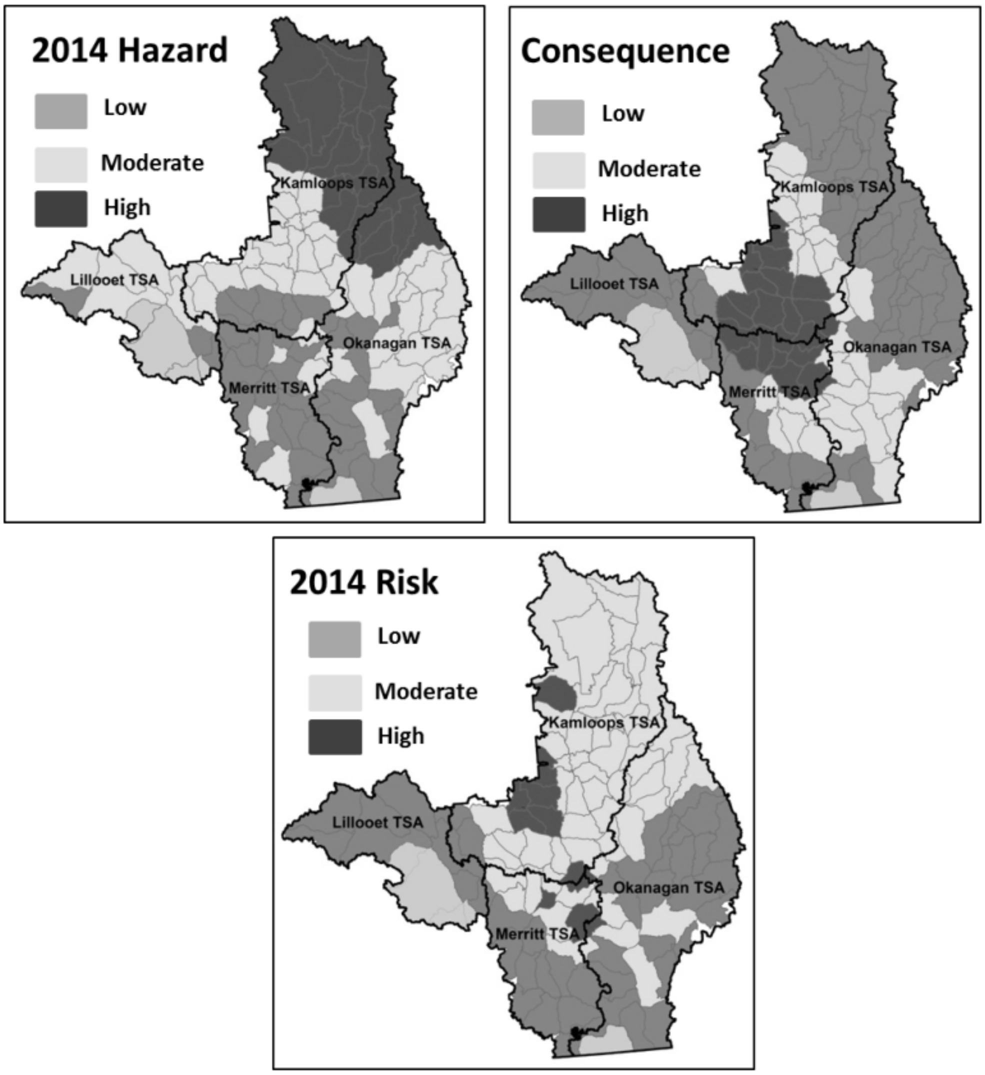

Figure 9. 2014 Spatial representation of 2014 Hazard, Consequence and 2014 Risk ratings for moose in the Thompson Okanagan Region.

For example, high predation hazard (primarily predation by wolves) is the biggest factor influencing moose decline in the region with an increase in wolf density and distribution from north to south. These declines in moose populations in the northern areas largely fall in areas of Low consequence for moose, where capable winter habitat is relatively restricted to valley bottoms and populations are small relative to plateau areas in the middle portion of the region. In some northern WMUs (3-43/3-44) moose densities were very high in the early 2000s (estimated >1/km^2 in 2003 - 0.96/km^2-SRB survey - Serrouya and Poole 2007). The high moose density is believed due to increase in early seral forage habitat following logging in the 1980-1990s. Increase in wolf density is a functional response to high prey density and results in an increase predation rate. Between 2003 and 2014, moose numbers have declined to a much lower density, where population estimates are based on LEH hunter survey statistics and a 2013 SRB survey (Figure 10).

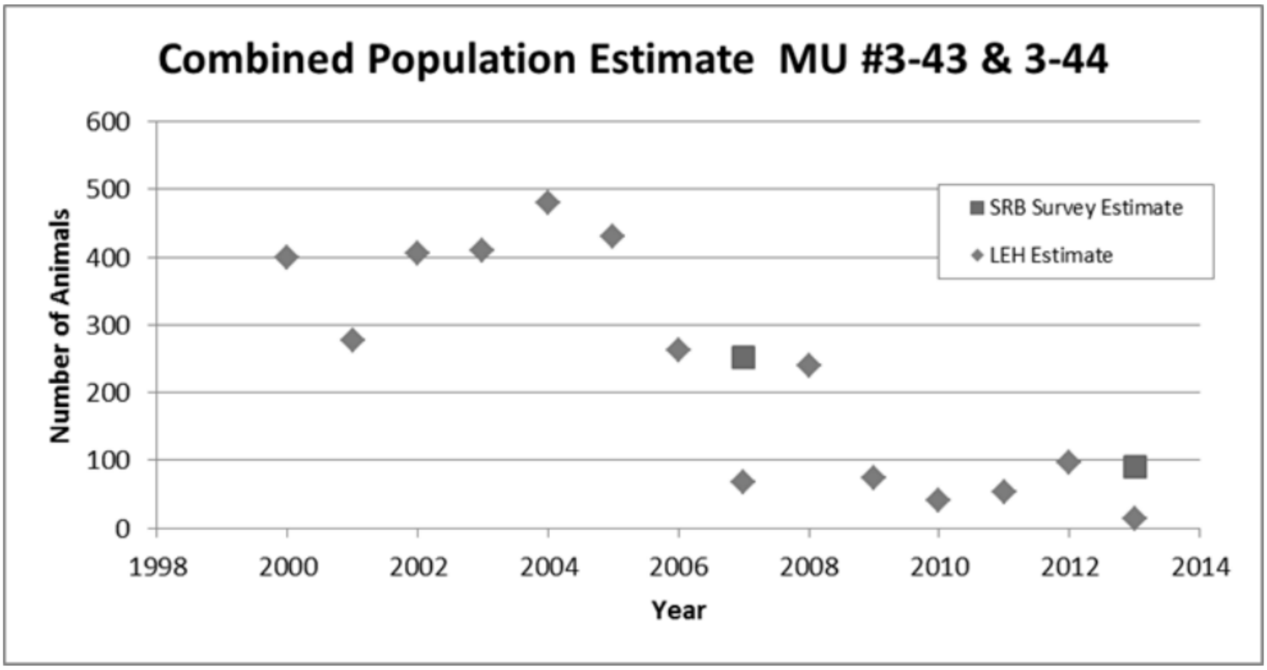

Figure 10. Estimated number of moose for MUs 3-43/3-44 for the years from 1999-2014 based on an extrapolation from LEH hunter survey data (blue dots) and SRB flights (red squares).

In several planning cells North of Kamloops (WMUs 3-29/3-30)the combination of habitat hazard resulting from high levels of early seral and low thermal/security cover, increasing hunting pressure with increase roads and cutover areas and increased predator pressure has resulted in *Moderate* hazard. For example, population estimates in MU 3-29 suggest populations up to 2014 are relatively stable (Figure 11); however, due to the importance of the area to supporting hunting opportunities (High Consequence), the result is a *High* risk situation.

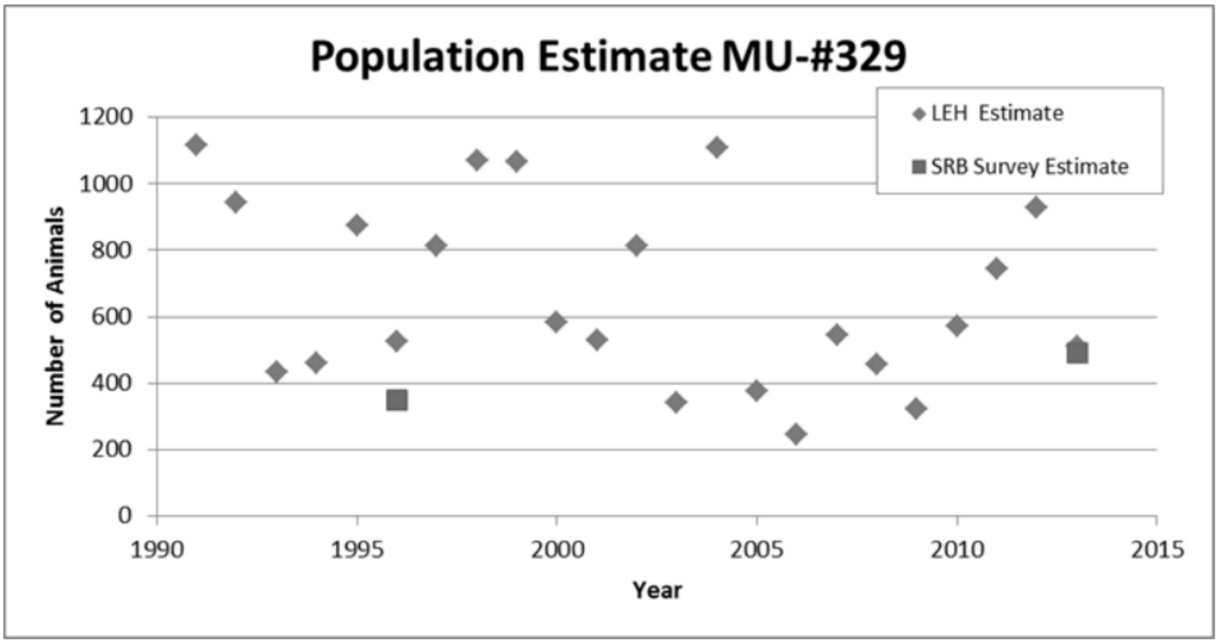

Figure 11. Estimated number of moose for MU 3-29 for the years from 1990-2014 based on an extrapolation from LEH hunter survey data (blue dots) and SRB flights (red squares).

Recent calf census information from MU 3-29 and 3-30 suggests that elevated management concern is warranted in the High Risk planning cells that overlap these MUs. In MU 3-29/3-30 cow: calf ratios over the past 10 years are low (<40 calves per 100 cows) and may be declining (Figure 12). Low calf numbers are indicative of increased wolf predation on the population, impacting recruitment into the population.

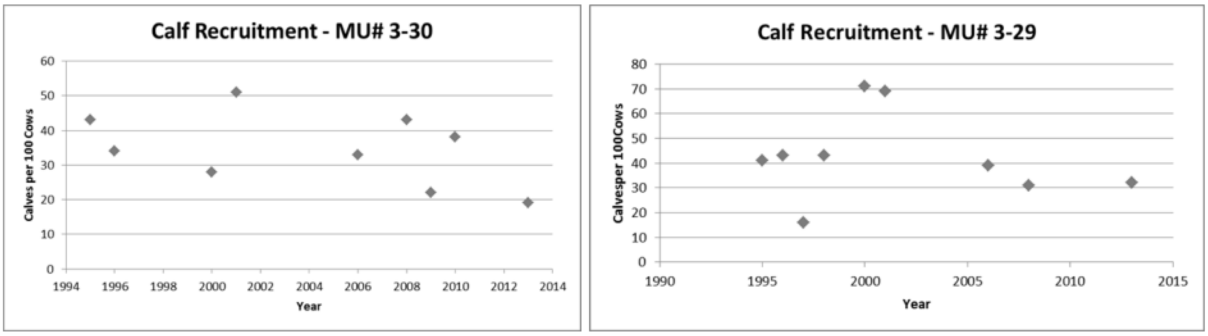

Figure 12. Estimates of calf recruitment (calf: cow ratio) for MU 3-29 and 3-30 from composition and SRB survey flight surveys.

In some High Risk planning cells identified in the Merritt and South Okanagan (e.g. Pennask – MU 3-12) the High risk is driven by a combination of moderate hazard due to habitat-related concerns and High consequence. Habitat related hazards are currently flagged (i.e. high amounts of early seral and loss of thermal/security cover), but populations have been increasing in the absence of significant predation pressure (Figure 13). In these circumstances, further investigation of the extent of habitat related hazards is warranted, as these conditions may exacerbate impacts in the future should predation increase.

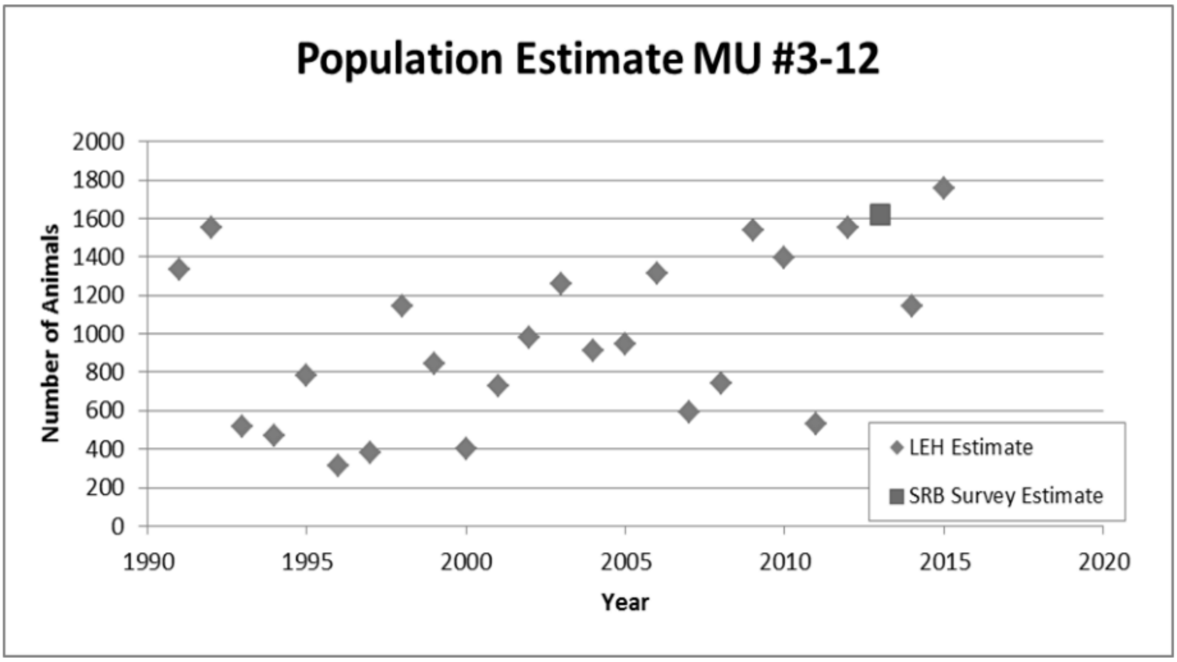

Figure 13. Estimated number of moose for MU 3-12 for the years from 1990-2014 based on an extrapolation from LEH hunter survey data (blue dots) and SRB flights (red squares).

3.2 Ongoing Management Responses to Hazard and Risk

The assessment identified several *High* risk areas where factors potentially leading to moose population decline exist, and that support considerable moose habitat and hunting opportunity. In those high risk areas, regional wildlife and ecosystems staff are undertaking a number of management actions to monitor and manage impacts, including:

- Increased moose population surveys and censuses;
- Research, as part of an ongoing provincial project, using GPS collars to investigate causes of adult and juvenile mortality and habitat use;
- Extension with forest licensees to raise awareness of habitat and road access issues; and,
- Modification of LEH and GOS hunting in some WMUs to reduce hunting pressure.

3.3 Confidence in Risk Ratings

Confidence in the current condition and trend assessment is rated as ***Moderate to High.***

The following factors contribute to increased confidence in the assessment results:

- Inventory and monitoring data primarily collected through hunter harvest reporting and overview composition flights indicate trends in moose populations consistent with modelled outcomes; and,
- Experts have a high degree of confidence in understanding of the ecology of moose and the relative effects of factors considered in the analysis. Regional wildlife biologists involved in the project feel the expert model structure adequately reflects the ecological system, thereby reducing structural uncertainty.

The following sources of uncertainty contribute to a reduced confidence in the assessment:

- Uncertainty regarding how habitat quality is modelled. The current model uses a 2-class (yes/no) to define capable habitat. Significant variability in habitat quality and condition exists that can influence assessment outcomes;
- Unpredictability in human hunting behaviour. The model assumes regulated, non-regulated and illegal hunting pressure is constant and consistent across all areas. In using the road density indicator, the model considers all roads have equal hunter use and hunting pressure regardless of road condition or status (open, de-activated, closed/gated) or proximity to population centres. Consistent information is not currently available to reasonable capture differences in road use or hunting pressure; and,
- Uncertainty in how well the early seral indicator used in the expert model is adequately reflected in calculation of habitat and hunting hazard. Currently, the early seral indicator is calculated as the percent early seral forest across all capable habitats. MPB salvage harvesting has been concentrated in lodgepole-pine dominated stands that are often associated with higher capability moose winter range habitats and proximity to important foraging areas (e.g. wetland complexes).

  Higher habitat-related hazard levels may be higher than currently estimated if:
  1. Salvage harvesting has been concentrated on limited moderate to high capable winter habitats;
  2. Extensive harvesting limits the availability of thermal habitats adjacent to foraging habitat; and,
  3. Harvesting and open road networks are concentrated near important wetland complexes where moose congregate.

4. Next Steps

The current assessment procedure provides a useful first approximation for evaluating the risk of lost hunting opportunities due to moose population declines. However, during the analysis and subsequent reporting, several areas have been identified to improve the assessment procedure to reduce uncertainties associated with indicators, data sources and expert-based model structure. The assessment can also be improved by more clearly defining estimates of hazard, consequence and risk using quantifiable measures for both target moose population densities (e.g. moose\km^2) and hunting opportunities (e.g. hunter days by WMU). As part of next steps to improve the assessment procedure and complete an updated current condition assessment, work is currently underway in the Thompson-Okanagan region in the following areas:

Refining Winter Habitat Capability

- Current habitat capability mapping utilizes a two-class (yes/no) system given limitations and differences of expert-derived ratings that vary across the region. Current work is underway to develop a consistent and repeatable empirically-derived approach to estimating habitat capability that considers climatic envelope and forage availability. The revised approach can accommodate climate-related effects on factors (winter temperature and snow depth) that affect moose distribution and abundance.

Refining Habitat Suitability

- A key uncertainty recognized in the existing assessment is the effect of forest harvesting on the adjacency of thermal/security cover and forage. An updated assessment procedure will incorporate improved methods developed in the Cariboo Region to account for habitat-related effects associated with extensive cutover areas.

Providing Population estimates

- The current assessment procedure does not provide estimates of potential moose densities based on habitat capability and expected moose density. The current procedure provides a relative estimate of change (i.e. declining, stable, and increasing) without an absolute estimate of the difference between expected and potential moose density. Absolute estimates of expected moose density will be needed to assist with quantitative targets for moose densities and hunting opportunities (see clarifying risk benchmarks section below). Work is currently underway in the Thompson-Okanagan Region to develop an empirical model that captures both habitat and population effects on the population and will be provided in the future.

Clarifying Risk Benchmarks

- The current assessment procedure defines risk as loss of hunting opportunities without clearly quantifying the extent of loss and how that compares to desired levels. Work is currently underway to define quantitative targets for levels of hunting opportunities (i.e. First Nations harvest, Guide-outfitting, LEH opportunities, GOS hunter days/kills) that can be sustained based on habitat potential. Improved information is needed to better understand First Nations use and requirements.

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Appendix 1 – Summary of Moose Habitat Regulations by Resource District

NR District or TSA	Area	Management Strategies
Lillooett Section 7(2) FPPR	88,383 ha	***Distribution**:* • Winter range foraging habitat is to be distributed proportionately in moose winter range, located in forest types at the elevation and on the slope aspects typical of ungulate winter ranges for moose in south central B.C. according to the attributes below ***Attributes*** • Provide security and thermal cover and manage high value moose habitat • Protect forage and shelter values in moose winter range and provide for early seral stages of shrubs • Within moose winter ranges provide and maintain adequate browse of palatable species (e.g., willow, birch, aspen, red-osier dogwood) approaching a natural distribution. Available at: http://www.env.gov.bc.ca/wld/frpa/notices/index.html
Merritt Section 7(2) FPPR	694,072 ha	***Distribution*** • *Winter range* foraging habitat and cover is to be distributed proportionately within in moose winter range, located in forest types at the elevation and on the slope aspects typical of ungulate winter ranges for moose in south central B.C. according to the attributes below ***Attributes*** 1. *Foraging habitat:* • Maintain a minimum of 15% of the net forest land base in early seral stands: early seral is defined as o In the ICH and IDF zones - < 25 years o In the MS and ESSF zones -<35 years) 2. *Cover:* *Cover is defined as coniferous stands of at least 16m in height with a relatively high canopy closure to provide both snow interception and security cover* • *At least* 50% of cover is to be in patches 20ha or greater, • *Where possible, cover is to be* in close proximity to riparian features Available at: http://www.env.gov.bc.ca/wld/frpa/notices/index.html
Okanagan-Shuswap	231,168 ha	***Schedule 1 – General Wildlife Measures*** 1. Forest practices are to result in not less than 33% of gross

GAR Order Ungulate Winter Range # U-8-006		forested area of each moose winter range unit to be maintained as mature forest cover in stands at 16m tall with a canopy closure class of not less than 6, where such cover is available. Where the defined forest cover is not available, stands exhibiting the next lower class for height and canopy closure are to be used. 2. Within each moose winter range, retain at least 50% of the mature cover requirements, detailed in GWM1, in patches 20ha, or greater, wherever practicable. 3. Forest practices are to result in greater than- 50% of the perimeter of mineral licks and key forage areas (>0.5 ha) such as, old burns, riparian features and/or non-productive brush, being in trees > 3m tall in height for a distance of 10m from the mineral lick or forage area. 4. To the extent practical, a minimum of 15% of the net forest land base of each winter range is to <25 years for ICH and IDF units and <35 years MS and ESSF units. 5. Forest practices are to maintain, or not prevent the re-establishment of, deciduous component of the stands that existed prior to those practices. 6. Do not use broadcast herbicide treatments Available at: http://www.env.gov.bc.ca/wld/documents/uwr/u-8-006_ALAL_ord.pdf
Kamloops LRMP Higher level Plan (Land Act) Objectives	181,874 ha	***Objective:*** Maintain thermal and visual cover for moose, and enhance browse production ***Strategies:*** • Maintain suitable forest cover attributes with respect to thermal cover and forage production • Ensure adequate forage is maintained during silvicultural activities (brushing and weeding, stand tending) • Provide visual screening of swamps and openings along highways, secondary roads, and main forestry roads • Pursue mixed forest management with similar species distribution to natural stands (including deciduous) • Ensure grazing management practices that maintain browse species such as red osier dogwood and willow • Establish access management guidelines • Incorporate management objectives for critical moose habitat into local level planning for the area • Available at: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/land-use-plans-and-objectives/thompsonokanagan-region/kamloops-lrmp/kamloops_lrmp.pdf

Appendix 2 – Structure of Expert Based Bayesian Belief Model

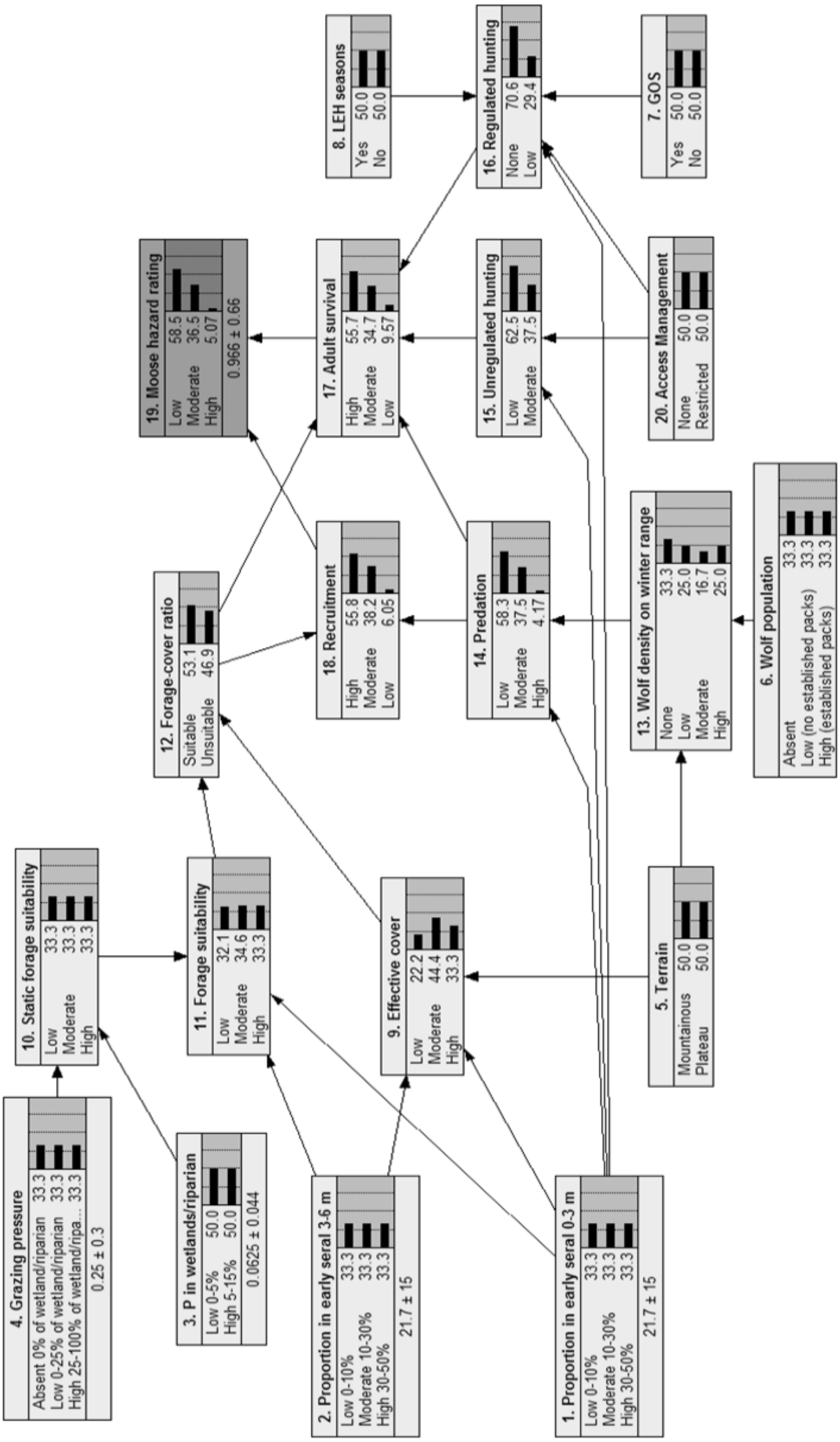


Illustration of the Bayesian Belief Network (BBN) expert-judgement-based Moose Population Hazard Model from Wilson (2014).

Appendix 3 – Description of GIS Indicators used as inputs to the Expert Model

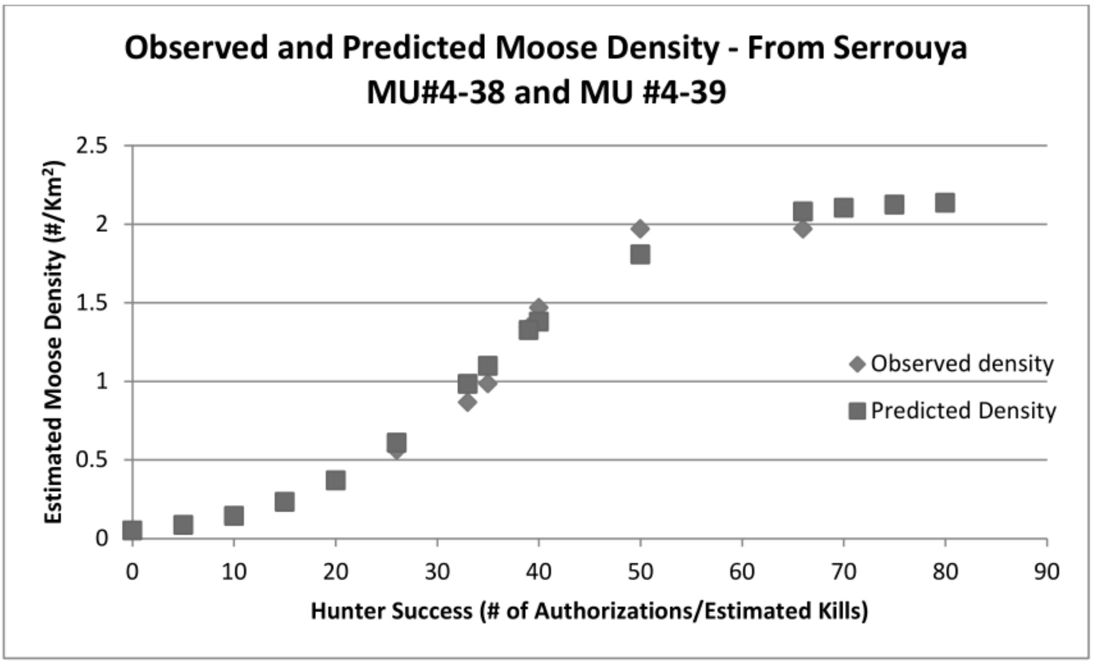
Indicator Metric	Description and Assumptions	Data Source and calculation
Percent early seral 0-3m tall	Proportion of total capable winter range area in a planning cell that is covered by young forest 0-3m tall. Used in several ways in the model to represent: 1. area of potential foraging habitat created in disturbed forests 2. area of potential thermal cover that is unavailable 3. Relative vulnerability of moose to hunting assuming less visual cover and open road networks 4. Relative vulnerability to predation assuming increased predator efficiency with less visual cover and road accessibility	"Capable winter Range" is defined by combining 3 expert derived winter range mapping layers from the Thompson-Okanagan Region: 1. Okanagan winter range (Gyug, 2007) 4-class system modified from provincial BEI rating – includes Okanagan and part of Merritt TSA (old MoE region 8) 2. Southern Interior Moose Winter Range (Lemke, 2003) Kamloops and portion of Merritt TSA 3. Lillooet TSA (Jury, 2014) 2-class system using updated linework from the Lillooett TSA moose winter range polygons • These 3 layers were combined to define a two-class system (yes/no) for the whole region. • VRI RESULTS layer used to identify forested stands with trees 0-3m tall • Calculation = area (ha) early seral 0-3 m tall/area (ha)of forested capable winter range in moose planning cell
Percent early seral 3-6m	Proportion of total capable winter range area in a planning cell that is covered by young forest 3-6m tall Separated from 0-3m tall to consider: 1. Re-growth of tree cover reduces foraging suitability 2. Re-growth of visual cover – reduced hunting vulnerability and predation	• VRI RESULTS layer used to identify forested stands with trees 3-6m tall • Calculation = area (ha) early seral 0-3 m tall/area (ha) of forested capable winter range in moose planning cell.
Grazing Pressure	Proportion total potential winter feeding habitat (wetland & riparian) that is overlapped by range tenures. This indicator is used to represent the potential for	Uses a static ' potential winter feeding habitat' layer derived from: 1. Wetlands from Freshwater Atlas 2. A 10m buffer on all streams B.C. Freshwater Atlas 3. Stands with >30% deciduous as defined in

	livestock impacts on browse species (willows) in wetlands and riparian areas on moose winter ranges.	VRI results • This layer is the same APPROACH AS USED BY THE CARIBOO REGION and was created by the Mark McGirr • Uses Range tenure layer from BCGW to capture extent of existing range tenures that overlap with static winter forage areas • Calculations= area (ha) of potential winter feeding habitat that overlaps with existing range tenures
Percent in Wetlands	Proportion of winter range area in a planning cell that is occupied by wetlands. Used to identify the contribution of 'static' foraging habitat to overall forage availability at the planning cell level.	• Uses static potential winter feeding habitat layer described above • Uses capable habitat layer as described above • Calculation – area (ha) potential winter feeding habitat/total capable winter habitat in planning cell
Terrain	Differentiates capable winter range habitats as occurring in "mountainous' or 'plateau' terrain. Indicator is used to reflect elevation differences in winter habitat in response to snow levels. The terrain indicator affects calculation of two nodes: 1. Wolf populations concentrate in higher densities on winter ranges in mountainous terrain. 2. Downgrades the importance of forested thermal cover in mountainous terrain as moose can utilize aspects or migrate to higher elevations in spring/summer to avoid heat stress	Uses BCGW Ecosection layer to classify the region as either: • Mountainous = ecosections labelled mountains, highlands, range or foothills • Plateau habitat = plateau, basin, upland or highland (North Okanagan Only) Moose planning cells were then classified as either mountainous or plateau based on the % of the planning cell that fell in that ecosection.
Wolf Population	Relative wolf density at the planning cell level is estimated by regional wildlife biologists	A layer was created by population each moose planning cell with an expert-derived rating of wolf density. Wolf density was rated as • Absent – wolves not present • Low– no established packs, wolves are present in low density • High – established packs – wolves present in higher density

Access Management	This indicator is intended to capture the effects of access control on regulated and un-regulated hunting mortality	Characterized as Yes/No at the planning cell level based on existing regulations
Limited Entry Hunting (LEH)	Captures the relative influence of Limited Entry Hunting on adult survival	Characterized as Yes/No at the planning cell level based on existing regulations
General Open Season (GOS) Hunting	Captures the relative influence of general Open Season Hunting on adult survival	Characterized as Yes/No at the planning cell level based on existing regulations

Appendix 4 – Deriving Moose Population Estimates from Hunter Success data from Limited Entry Hunt Statistics

Moose population estimates are based on LEH hunter success information collected from an ongoing predator/prey research project in the Revelstoke area. A logistic equation was fit to data collected by Rob Serrouya comparing hunter success data (# of authorizations/estimated kills) from the LEH hunter statistics with population abundance estimates from Stratified Random Block (SRB) Surveys in Management Units (MU) #4-38 and 4-39. These estimates were collected in successive years in the same MUs and reflect population response to an increase in allowable hunter harvest (increased # of LEH available).



The logistic equation was then used to estimate population density in other MUs in the Thompson Okanagan Region by first estimating the population density for the MU based on the equation and then multiplying that density by the total area of capable habitat. Key assumptions used in estimating population density from the equation include:

1. Consistent hunter effort from year to year in all areas regardless of the amount of total capable habitat. Essentially, total hunter days is proportional to the proportion of total MU area that is capable habitat. (This assumption is supported by relationship comparing, see the MU stats tab in the excel spreadsheet); and,
2. Hunter success not affected by habitat alteration or access.

High and *Moderate* habitat strata composed most (>80%) of the surveyed area in the SRB survey for MU 4-38 and MU 4-39. In comparable wet belt habitats with similar high proportions of *High-moderate* capable habitats (e.g. MU 3-43.3-44) the estimated density was multiplied by the total capable area for MU 3-44 and 3-43. The resulting estimated combined population density for MU3-43 and MU 3-44 in 2007 was comparable to observed densities from the SRB survey.

On drier plateau habitats (e.g. ESSF dc2, MSdm3) (e.g. MU 3-30, 3-29), SRB survey estimates identify significantly greater amounts of Low suitable habitat strata (e.g. Lemke, 2013). For example, total area of *Low* strata composed approximately 50% and 80% of MU 3-30B and MU 3-29 respectively. Observed densities on *Low* habitat strata were approximately 50% and 20% of observed moose densities on *High and Moderate* habitat strata for MU 3-30B and MU 3-29 respectively (Lemke, 2007). Thus, to estimate moose densities in other MUs where SRB data is unavailable, density estimates from the equation were multiplied by a habitat modifier to account for lower observed densities on Low habitat strata. The modified density was then multiplied by the proportion of total capable habitat as *Low or Moderate-High* habitat. For example, 50% of the capable area in MU 330-B was multiplied by a modifier of 0.5, whereas 80% of the area in MU 3-29 was multiplied by a modifier of 0.2. The resulting estimated population abundance for MU 330-B and MU 3-29 closely matched the observed estimates from the 2013 SRB survey (Lemke, 2013). For all other MUs, the amount of low quality habitat strata in each MU was estimated from available SRB surveys or older habitat capability modelling that incorporated 4 or 6 classes.

Appendix 5 – Merritt TSA Hazard and Risk Ratings Table

Moose Population Hazard and Risk - Merritt TSA 2003 - 2014											
Planning Cell	% Early Seral (0-3m)		Habitat Hazard		Predation Hazard		Hunting Hazard		Cons.	Moose Risk	
	2003	2014	2003	2014	2003	2014	2003	2014		2003	2014
Asp Creek	8.6	18.2	L	L	L	L	L	L	MOD	LOW	LOW
Crater Mtn.	1.6	14.3	L	L	L	L	L	L	LOW	LOW	LOW
Dardanelles	12.1	33.6	L	M	L	L	L	M	HIGH	MOD	HIGH
Douglas Lake	6.7	8.3	L	L	L	L	L	L	HIGH	MOD	MOD
Frogmore	10.1	28	L	L	L	L	L	L	HIGH	MOD	MOD
Maka	4.4	4.6	L	L	L	L	L	L	LOW	LOW	LOW
McNulty	17.1	27.2	L	L	L	L	L	L	MOD	LOW	LOW
Nicola	19.4	33.3	L	M	L	L	L	M	HIGH	MOD	HIGH
Pasayten	9.6	8.8	L	L	L	L	L	L	LOW	LOW	LOW
Pennask	9.5	30.5	L	M	L	L	L	M	HIGH	MOD	HIGH
Pimanus	9	29.7	L	L	L	L	L	L	HIGH	MOD	MOD
Prospect	1.9	4.4	L	L	L	L	L	L	LOW	LOW	LOW
Quilchena	5.7	16.1	L	L	L	L	L	L	HIGH	MOD	MOD
Rey	5.1	18.9	L	L	L	L	L	L	HIGH	MOD	MOD
Siwash	12.3	28.9	L	L	L	L	L	L	HIGH	MOD	MOD
Skuhun	9.9	27.9	L	L	L	L	L	L	HIGH	MOD	MOD
Summers	12.8	26.6	L	L	L	L	L	L	MOD	LOW	LOW
Thynne	8.4	10.3	L	L	L	M	L	L	LOW	LOW	LOW
Tulameen	2.8	4.5	L	L	L	L	L	L	LOW	LOW	LOW
Voght	3.5	12.5	L	L	L	L	L	L	MOD	LOW	LOW
Whipsaw	24.8	14.0	L	L	M	M	L	L	LOW	LOW	LOW
Willis	17.1	18.2	L	L	L	L	L	L	LOW	LOW	LOW
			LOW	LOW	LOW	LOW	LOW	LOW			
									OVERALL RATING	LOW	MOD

Appendix 6 – Lillooet Hazard and Risk Ratings Table

Moose Population Hazard and Risk - Lillooet TSA 2003 - 2014											
Planning Cell	% Early Seral (0-3m)		Habitat Hazard		Predation Hazard		Hunting Hazard		Cons.	Moose Risk	
	2003	2014	2003	2014	2003	2014	2003	2014		2003	2014
Botanie	15.0		L	L	L	L	L	L	LOW	LOW	LOW
Camelsfoot	16.5	8.2	L	L	L	M	L	L	LOW	LOW	LOW
Carpenter S.	16.8	10.3	L	L	L	M	L	L	LOW	LOW	LOW
Cayoosh East	N/A	N/A									
Cayoosh West	N/A	N/A									
Downton	35.1	9.9	L	L	L	L	L	L	LOW	LOW	LOW
Fountain Lake	21.2	8.2	L	L	L	M	L	L	LOW	LOW	LOW
Gun	9.9	6.0	L	L	L	M	L	L	LOW	LOW	LOW
Mohokam	N/A	N/A									
Nahatlatch	N/A	N/A									
Nicoamen	9.9	6.2	L	L	L	L	L	L	LOW	LOW	LOW
Shulaps	21.7	18.1	L	L	M	M	M	M	LOW	LOW	LOW
			LOW	LOW	LOW	MOD	LOW	LOW			
									OVERALL RATING	**LOW**	**LOW**

Appendix 7 – Clearwater Hazard and Risk Ratings Table

Moose Population Hazard and Risk - Kamloops TSA- North 2003 - 2014												
Planning Cell	**% Early Seral (0-3m)**		**Habitat Hazard**		**Predation Hazard**		**Hunting Hazard**		**Cons.**	**Moose Risk**	
	2003	**2014**	**2003**	**2014**	**2003**	**2014**	**2003**	**2014**		**2003**	**2014**
Adolph			L	L	M	H	L	L	LOW	LOW	MOD
Lempriere			L	L	M	H	L	L	LOW	LOW	MOD
Bone			L	L	M	H	L	L	LOW	LOW	MOD
Wells Gray W.			L	L	M	H	L	L	LOW	LOW	MOD
Wells Gray E.			L	L	M	H	L	L	LOW	LOW	MOD
North Blue			L	L	M	H	L	L	LOW	LOW	MOD
Berry			L	L	M	H	L	L	LOW	LOW	MOD
Finn			L	L	M	H	L	L	LOW	LOW	MOD
Upper Adams			L	L	M	H	L	L	LOW	LOW	MOD
Raft			L	L	M	H	L	L	LOW	LOW	MOD
Mad River			M	L	M	H	L	L	LOW	LOW	MOD
Swayback			L	L	M	H	L	L	MOD	MOD	HIGH
Otter			L	L	M	H	L	L	LOW	LOW	MOD
Lower Adams			L	L	M	H	L	L	LOW	LOW	MOD
Dunn			L	L	L	H	L	L	LOW	LOW	MOD
Cayenne			L	L	M	H	L	L	LOW	LOW	MOD
Nehalliston			M	M	L	M	L	L	MOD	LOW	MOD
Darlington			M	M	L	M	L	L	MOD	LOW	MOD
E. Barriere			M	L	M	H	L	L	LOW	MOD	MOD
Pukeashun			L	L	M	H	L	L	LOW	MOD	MOD
			LOW	LOW	MOD	HIGH	LOW	LOW			
									OVERALL RATING	**LOW**	**MOD**

Appendix 8 – Kamloops Hazard and Risk Ratings Table

Moose Population Hazard and Risk - Kamloops 2003 - 2014												
Planning Cell	**% Early Seral (0-3m)**		**Habitat Hazard**		**Predation Hazard**		**Hunting Hazard**		**Cons.**	**Moose Risk**	
	2003	**2014**	**2003**	**2014**	**2003**	**2014**	**2003**	**2014**		**2003**	**2014**
Bonaparte N.			M	M	L	M	L	M	HIGH	MOD	HIGH
Darfield			M	M	L	M	L	M	MOD	LOW	MOD
Chu Chua			M	M	L	M	L	M	MOD	LOW	MOD
Barriere			M	M	L	M	L	L	MOD	LOW	MOD
Bonaparte S.			L	M	L	M	L	L	HIGH	MOD	HIGH
Tsintsunko			M	M	L	M	L	L	HIGH	MOD	HIGH
Skull			M	H	M	M	L	M	MOD	MOD	MOD
Sullivan Lake			H	H	M	M	M	M	MOD	MOD	MOD
Cahilty			M	M	L	M	L	L	MOD	LOW	MOD
Pisima Mtn.			L	L	L	H	L	L	LOW	LOW	MOD
Criss Creek			M	M	L	M	L	L	HIGH	MOD	HIGH
Tranquille N.			M	M	L	M	L	L	HIGH	MOD	HIGH
Tranquille S.			M	L	L	M	L	L	HIGH	MOD	HIGH
Paul			L	M	L	M	L	L	HIGH	MOD	HIGH
Niskonlith			M	M	L	M	L	L	LOW	LOW	LOW
Pavillion			L	M	L	M	L	L	LOW	LOW	LOW
Arrowstone			L	M	L	M	L	L	MOD	LOW	MOD
Blue Earth			L	M	L	M	L	L	LOW	LOW	LOW
Cornwall Hills			L	L	L	M	L	L	LOW	LOW	LOW
Glossy Mtn.			L	M	L	L	L	L	HIGH	MOD	MOD
Pimanus			L	M	L	L	L	L	HIGH	MOD	MOD
Guichon			L	M	L	L	L	L	HIGH	MOD	MOD
Greenstone			M	M	L	L	L	L	HIGH	MOD	MOD
Rey			L	M	L	L	L	L	HIGH	MOD	MOD
Frogmore			L	M	L	L	L	L	HIGH	MOD	MOD
Lac le Jeune			L	M	L	L	L	L	HIGH	MOD	MOD
Dardanelles				M		L		M	HIGH	MOD	HIGH
Campbell			M	M	L	L	L	L	HIGH	MOD	MOD
Paxton valley			L	M	L	M	L	M	HIGH	MOD	HIGH
			MOD	MOD	LOW	MOD	LOW	LOW			
									OVERALL RISK RATING	**LOW**	**MOD**

Appendix 9 – Okanagan North Hazard and Risk Ratings Table

Moose Population Hazard and Risk – Okanagan TSA- North 2003 - 2014											
Planning Cell	% Early Seral (0-3m)		Habitat Hazard		Predation Hazard		Hunting Hazard		Cons.	Moose Risk	
	2003	2014	2003	2014	2003	2014	2003	2014		2003	2014
Anstey	8.2	4.9	L	L	M	H	L	L	LOW	LOW	MOD
Armstrong	8.9	6.5	L	L	L	L	L	L	LOW	LOW	LOW
Ashton	16.8	14.2	M	M	M	M	L	L	LOW	LOW	LOW
Deep Creek	21.8	16.2	M	M	L	M	L	L	LOW	LOW	LOW
Fly Hills	29.3	22.8	M	M	L	M	L	L	MOD	LOW	MOD
Grinrod	19.4	12.7	M	L	L	M	L	L	LOW	LOW	LOW
Ireland	10.4	7.2	L	L	L	M	L	L	LOW	LOW	LOW
Mount Mobley	15.1	9.6	L	L	M	H	L	L	LOW	LOW	MOD
Perry	13.3	10.1	L	L	H	H	L	L	LOW	MOD	MOD
Seymour	17.9	10.9	L	L	H	H	L	L	LOW	MOD	MOD
Trinity	16.3	11	L	L	M	M	L	L	LOW	LOW	LOW
Up. Shuswap	9.7	7.5	L	L	L	M	L	L	LOW	LOW	LOW
Wap	10.2	5.6	L	L	L	M	L	L	LOW	LOW	LOW
White Lake	13.9	10.1	L	L	H	H	L	L	LOW	MOD	MOD
Yard	15.1	12	L	L	M	M	L	L	LOW	LOW	LOW
			LOW	LOW	MOD	MOD	LOW	LOW			
									OVERALL RATING	LOW	LOW

Appendix 10 – Okanagan South Hazard and Risk Ratings Table

Moose Population Hazard and Risk – Okanagan TSA- South 2003 - 2014											
Planning Cell	% Early Seral (0-3m)		Habitat Hazard		Predation Hazard		Hunting Hazard		Cons.	Moose Risk	
	2003	2014	2003	2014	2003	2014	2003	2014		2003	2014
Apex	6.6	6	L	L	L	L	L	L	LOW	LOW	LOW
Beak	43	32	M	M	L	L	L	M	HIGH	MOD	HIGH
Belgo	21	15.3	M	M	L	M	L	L	MOD	LOW	MOD
Cherry	8.9	6.8	L	L	L	M	L	L	LOW	LOW	LOW
Equesis	11.7	7.7	L	L	L	L	L	L	LOW	LOW	LOW
Harris	18.6	13.9	M	M	L	M	L	L	LOW	LOW	LOW
Hydraulic	26.2	22.4	M	M	L	M	L	L	MOD	LOW	MOD
Ingram	27.1	24	M	M	L	L	L	L	MOD	LOW	MOD
Isintok	13.9	11.3	M	M	L	L	L	L	MOD	LOW	MOD
Oliver	8.5	5.3	L	L	L	L	L	L	LOW	LOW	LOW
Peachland	13.4	9.4	L	L	L	L	L	L	HIGH	MOD	MOD
Penticton	34.6	30.6	H	H	L	L	L	M	MOD	LOW	MOD
Terrace Mtn.	12.9	9.9	L	L	L	L	L	L	MOD	LOW	LOW
Trapping	17.6	11.1	M	M	L	M	L	L	LOW	LOW	LOW
Trepanier	17.5	12.8	M	M	L	L	L	L	HIGH	MOD	MOD
Up. Kettle	23.2	15.2	M	M	L	M	L	L	LOW	LOW	LOW
Vaseaux	20.8	11.6	M	M	L	L	L	L	MOD	LOW	MOD
Vernon	17.3	12.8	M	M	L	L	L	L	LOW	LOW	LOW
Wilkinson	15.9	9.1	L	L	L	L	L	L	MOD	LOW	LOW
			MOD	MOD	LOW	LOW	LOW	LOW			
									OVERALL RATING	LOW	MOD

Evaluating the Landscape Change Hypothesis for Moose Declines in British Columbia

Authors
Abstract
Keywords

Human-induced landscape change can have lasting negative impacts on ecosystems (Southworth et al. 2002, Cardinale et al. 2006, Haddad et al. 2015) and survival of species (Fahrig 1997, Wilcove et al. 1998). When humans remove or alter important wildlife habitats it can impact animal abundance and distribution (Blom et al. 2004, Markovchick-Nicholls et al. 2008, Presley et al. 2009) (Weins 1990, Ceballos and Ehrlich 2002, Christie et al. 2015), especially those species that are reliant on rare or vulnerable habitat types (Bergerud 1974, Wittmer et al. 2000). Altered habitats can also decrease the reproductive (Hockin et al. 1992) or survival rates of species when the alterations favour those species' predators, such as by increasing predator search efficiency (Bergerud 1988). Some ungulate populations have declined from increased mortality from predators and hunters when their habitats are fragmented (Ogutu et al. 2009, Setsaas et al. 2018).

Moose populations have declined in recent decades across many areas of North America (Lenarz et al. 2009, Decesare et al. 2014, Timmermann and Rodgers 2017), while other areas have maintained stable or increasing populations (Wattles and DeStefano 2011, Harris et al. 2015, LaForge et al. 2016, Tape et al. 2016). Factors influencing moose population declines include human-caused habitat alterations (Rempel et al. 1997, Brown 2011), climate change (Rempel 2011, Ditmer et al. 2017) which may influence plant phenology (Monteith et al. 2015), nutritional stress (DelGiudice et al. 2011), and parasites and pathogens (Murray et al. 2006, Lenarz et al. 2009). Predation and hunting impact moose populations (Ballard et al. 1991, Gasaway et al. 1992, Hayes et al. 2003) and the efficiency of both can be further influenced by human-induced landscape change (Rempel et al. 1997, Brown 2011, Schrempp et al. 2019).

Moose populations in some areas of central British Columbia (BC) declined by 50 to 70% beginning in the early 2000s causing concern with First Nations and stakeholders (Kuzyk 2016; Kuzyk et al. 2018). Much of the decline happened concurrently with a Mountain Pine Beetle (*Dendroctonus ponderosae*; MPB) outbreak that killed up to 100% of large (i.e.; >30 cm) pine trees in some areas, and subsequent extensive and intensive salvage logging and road building to harvest dead pine prior to it becoming degraded (Alfaro et al. 2015). Thus, the MPB outbreak resulted in large-scale natural and human induced alterations to the landscape. Initially, it was predicted that these changes would ultimately have positive effects on moose population growth, as forest canopy removal due to beetle kill or salvage logging was expected to increase the distribution and abundance of moose forage - primarily shrubs and young, deciduous tree species, in regenerating forest stands (Janz 2006; Bunnell et al. 2004). However, others have hypothesized that moose may have negative effects from salvage logging, such as higher thermal stress on moose due to the loss of forest canopy (Ritchie 2008) or higher disturbance, vehicle collisions, predation and hunter harvest of moose due to increased road networks (Stotyn et al. 2008).

More recently a landscape change hypothesis was proposed for moose declines in BC which suggested that MPB-induced landscape changes led to the moose population declines, with the causal mechanism being that landscape changes had increased the efficiency of predators and hunters in these areas and resulted in lower moose survival rates (Kuzyk and Heard 2014). Efficiency for hunters and predators would increase because: 1) moose would be more visible in young cutblocks because of less screening cover; 2) moose would be more easily located if they were concentrated in smaller remnant patches of older-aged

forests; 3) the new proliferation of roads would make travel easier.
We tested the landscape change hypothesis by deploying xx GPS-collars on a sample of adult female moose over 4? years in 5 different areas with unique landscape characteristics and estimated annual survival rates of moose in each landscape. Then we used generalized liner mixed models (GLMMs) to estimate whether and what type of relationship there was between annual adult female moose survival rate and the proportion of young (less than 8 year old) cutblocks, burnt areas, and beetle disturbed areas in each landscape. These landscape characteristics were considered broad indicators of human and natural disturbance types that could influence moose hunter and predator efficiency. Cutblocks represented roads and open areas created by humans, and fires and beetle disturbances represented open areas from natural disturbance types. We estimated cow moose survival rates considering only predation and hunting mortalities. Cow survival was thought to have a greater proportional effect on population growth than calf survival because population declines occurred over a relatively short time period (Gaillard et al. 1998). We assumed ~~thought~~ that the proposed mechanisms of increased vulnerability would apply to both cows and calves, although we expected the dominant mortality factors (i.e., hunters or predators) to vary between females and calves. Given those assumptions, we chose to collar cows to monitor survival rates with respect to landscape change. We also tested the hypothesis by estimating moose density in each study area and year using data from aerial stratified random block (SRB) surveys. We used this data to calculate annual moose population growth rate (λ) in each area and used GLMMs to estimate the relationship between landscape characteristics and annual population growth rate.

We rejected the landscape change hypothesis if moose survival rate or population growth rate was not significantly negatively related to the proportion of young cutblocks, burnt areas, and beetle disturbed areas across the five landscapes and four years. If there was a significant negative relationship, then we would conclude that the MPB outbreak ~~may have led to~~ and moose population declines are correlated. Our approach also allowed us to disentangle the relative effects of human and natural disturbance types on moose. We predicted that cutblocks would have a greater negative effect on moose survival and population growth rate than burnt or insect disturbed areas, as cutblocks are associated with roads that facilitate predator and human travel, whereas the natural disturbance types are not.

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STUDY AREA

We conducted this research in ~~The~~ five study areas across the interior plateau of central BC ~~were called the~~ (i.e., Bonaparte, Big Creek, Entiako, Prince George South (PG South), and John Prince Research Forest (JPRF; Figure 1, Table 1). Most of the plateau was 1200 m to 1500 m above sea level and characterized by rolling terrain with a mosaic of conifer forest at various seral stages and wetland areas. The climate was generally continental, with warm, dry summers and cold winters with complete snow coverage. Dominant biogeoclimatic zones of the interior included Sub-Boreal Spruce and Engelmann-Spruce Subalpine Fir in the north, and Sub-Boreal Pine-Spruce and Interior Douglas-Fir in the south (Meidinger and Pojar 1991).

Forestry was the dominant land use ~~primary activity~~ in all five study areas. Salvage logging increased in all areas after a large-scale MPB outbreak during the early 2000s (Alfaro et al. 2015). However, the amount and rate of pine tree mortality, salvage logging and access development varied spatially and temporally among the study areas. Each study area had experienced some small degree of wildfire activity. Access for recreational use, such as hunting, all-terrain vehicle use, and hiking, was primarily through resource roads created for logging.

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All study areas contained multi-prey, multi-predator species assemblages. Moose were the most abundant wild ungulate in all study areas except in the Bonaparte, where mule deer (*Odocoileus hemionus*) were also more abundant. In addition to moose, the interior plateau supported other large mammals, including elk (*Cervus canadensis*), mule deer, white-tailed deer (*O. virginianus*), caribou (*Rangifer tarandus*), gray wolf (*Canis lupus*), grizzly bear (*Ursus arctos*), black bear (*U. americanus*) and cougars (*Puma concolor*), all of which occurred at varying densities and distributions (Shackleton 1999; Mowat et al. 2013; Kuzyk and Hatter 2014). Free-ranging cattle (*Bos taurus*) were common in the Bonaparte and Big Creek areas, and to a lesser extent in the PG South and Entiako areas. Feral horses (*Equus caballus*) occurred in the Big Creek study area.

METHODS

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Moose captures and Collar Deployment

Moose captures were conducted in accordance with the British Columbia Wildlife Act under permit CB17-277227. Cow moose were captured randomly on the landscape using chemical immobilization by aerial darting or and aerial net gunning. We immobilized moose Aerial darts were remotely delivered with either a Pneudart or Dan-Inject darting system. with Carfentanil citrate (1.4 mL at 3 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) and xylazine hydrochloride (0.5 mL at 100 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) in earlier years and were combined in each dart to immobilize moose with naltrexone hydrochloride (9 mL at 50 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) as a reversal agent. and BAM II (3.5mL; 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) in recent years. , was used as the sole immobilizing agent. After refinement of BAM II dose testing (Thacker et al. 2019), 3.5 mL of BAM II was considered effective for predictably and safely immobilizing cow moose. Naltrexone hydrochloride (1 mL at 50 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) and atipamezole hydrochloride (7 mL at 25 mg/mL; Chiron Compounding Pharmacy Inc, Guelph, ON) were used to reverse the effects of BAM II upon completion of moose handling and sampling. We fit each cow moose with a GPS radio collar that collected 1-2 fixes per day (Vectronic Aerospace VERTEX Survey Globalstar radio collars, Berlin) or >2 fixes per day (Advanced Telemetry Systems G2110E radio collars, Isanti, MN or Vectronic Aerospace VERTEX Survey Iridium radio collars, Berlin).

Moose Survival Rates and Mortality Causes

The GPS-collars were programmed to send a mortality notification alert via email and text message if no movement was detected for 8 hours. Following receipt of a collar mortality notification we conducted mortality site investigations as soon as logistically feasible, typically within 24–48 hours, to determine cause of death. Ground telemetry techniques were sometimes used to determine the mortality location when concealed by thick vegetation or snow cover. We determined the probable proximate (i.e., direct) cause of mortality following a standardized protocol (Kuzyk and Heard 2014). Site investigation included standardized scene photography for context and evidence recording. Samples from cow moose were collected during mortality site investigations to understand the proximate and ultimate cause of death. Samples available for collection varied depending largely on proximate cause of death (e.g., wolf kills typically had bones but no soft tissues remaining while health-related mortalities often had all samples available). For each mortality, we collected at least one long bone, usually the femur, or if none were available, the jaw, to assess body condition through bone marrow fat analysis (Neiland 1970). Marrow fat is the last fat store to be used as body condition deteriorates, therefore high dry weight proportions do

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not necessarily represent individuals in good body condition, but low scores are a definitive indicator of poor nutritional status (Mech and Delgiudice 1985). We considered animals with a marrow dry weight <70% to be in poor body condition and those with <20% to have been experiencing malnutrition that would lead to mortality from starvation (Sand et al. 2012). Bones were bagged and frozen as soon as practical to maintain representation of marrow when the moose was alive. Marrow was removed from an approximately 10-cm long section from the center of each bone, dried in an oven at 60°C, and weighed daily until the weight stabilized, indicating all moisture had been evaporated. The final dry weight divided by the initial wet weight was the index of body condition. When available, an incisor was extracted during mortality site investigations to determine the age of the moose. Cementum aging was conducted by Matson's Lab (Manhattan, MT). A variety of frozen and fixed (in formalin) tissue samples were collected when available and were archived or sent for analysis at the Animal Health Centre (BC Ministry of Agriculture, Abbotsford, BC) or other laboratories as appropriate to provide health-related information baselines such as trace minerals and to help interpret ultimate cause of death.

(previous years had mortality sensors set between 4 and 24 hours). In some cases, collars remained in sufficient motion post-mortality to prevent the mortality signal from being triggered, particularly for predation events where the collar was frequently moved when predators were feeding.

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Annual survival rates were calculated weekly for cow moose from 1 May 2014 to 30 April 2018 using a Kaplan-Meier estimator (Pollock et al. 1989). The biological year started on 1 May to coincide with the start of parturition for moose in northern (Gillingham and Parker 2008) and southern British Columbia (Poole et al. 2007). All captured cow moose were selected randomly and thus considered as representative of the population with equal risk of mortality. We calculated annual survival rates by individual study area pooling individual cow moose across all study areas using only mortalities that could be attributed to predation and hunters. Only cow Moose that lived >5 days post-capture were included in the estimate to avoid the potential bias or effects of capture-related stresses and physiological changes on survival (Neumann et al. 2011). Survival rates were calculated weekly and summarized by biological year (1 May–30 April) using a Kaplan-Meier estimator (Pollock et al. 1989) and excluded non-predation and non-hunting mortalities.

Moose Density Surveys

Moose density surveys were typically conducted over 5 to 7 consecutive days from December to March using a stratified random block s (SRB) design (Gasaway et al. 1986, Heard et al. 2008). Stratification of surveys followed Gasaway et al. (1986) or Heard et al. (2008). We estimated moose densities at the They were conducted in each study area at the beginning of this study and 5-6 years later to determine population change (i.e. lambda) through the research period. Certain surveys were modified to include habitat- based stratification (Heard et al. 2008). All survey types produced comparable density estimates. A sightability model correction factor developed in central BC (Quayle et al. 2001) was used to estimate account for detection probabilities to correct sampling-based estimatesy. These surveys followed established standards for accuracy and precision (90% CI) with allowable error from ±15–25% of the estimated population size (RISC 2002).

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Habitat Estimates

Study area boundaries were delineated annually by establishing drawing a minimum convex polygons (MCP) around the annual (May 1 – Apr 30) distribution of GPS radio-collared cow moose locations in each study area using a GIS (Arcview 10.3, x) (put whatever program was used here). MCPs ranged from 6,700 km^2 to 18,000 km^2 in size. The proportion area of cutblocks (< 8 years old), burns and MPB infested forest stands less than eight 8 years old, was estimated in each study area using publicly available spatial data , large-scale spatial datasets of these features collected by the Province of BC. The proportion of each disturbance type area was calculated by dividing the area of disturbance by the area of each MCP.

We estimated the area of cutblocks in each area using the BC governments consolidated cutblock data (https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-). We estimated the area burned using historic fire perimeter data collected by the BC government (https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical). We estimated the area disturbed by MPB using forest health aerial survey data collected by the government of British Columbia (https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/aerial-overview-surveys/methods), accessed through an FTP site (https://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/). These forest health data identify the location and intensity of MPB disturbed forest stands, and we summarized the area of severe (30 to 49%) and very severe (>50%) levels of disturbance from mountain pine beetle to indicate the area of MPB disturbed forest stands. Annual spatial layers of cutblocks, Harvest, fire and MPB infestation data were developed for each study area using a GIS. Because calculated annual survival rates cross calendar years but the specific timing of annual landscape change occurred at a specific time in any given year, we chose to compare survival rates with layers developed for the latter year that any given survival rate represents. calculated for a calendar year. Thus, they do not perfectly align with the biological year over which we estimated annual cow moose survival.

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Modelling Approach

We developed a two sets of generalized linear mixed models (GLMMs) to test our predictions of how MPB-induced habitat change might influence cow moose survival and population λ (i.e., the dependent variables). We calculated a set of GLMMs (Bolker et al. 2009) for each dependent variable that included all combinations of landscape covariates (i.e., the proportion of less than eight year old cutblocks, burnt areas and MPB infested stands) as independent variables, and compared them using corrected Akaike Information Criteria (AIC_c) scores (n = 7 models for each dependent variable). AIC_c was used to identify the model(s) that most precisely explained the dependent variable with the least bias (Anderson and Burnham 2002; Burnham and Anderson 2004). Thus it was used to evaluate our sub-set of plausible hypotheses on the effects of human and natural disturbance types on moose survival and population λ. Models were ranked by calculating AIC_c scores and their weights, where models with a higher weight indicate that they have greater evidence or support for influencing moose survival or population λ. Where models had similar weights ,or a difference in AICc scores less than two we considered these models equally supported and averaged their coefficients to calculate a singular best supported model for each dependent variable (i.e., the 'top' model).

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We further tested our hypotheses by examining the model coefficients estimated for the covariates (i.e., landscape measures) in the top models. Coefficients indicated the effect sizes (i.e., to what degree each variable influences the dependent variable). Thus, for the top models that included more than one coefficient we compared the coefficient values to assess which were having a greater effect on moose. Furthermore, we evaluated the p-values of each model coefficient estimate to assess their statistical significance. Coefficients with non-significant p-values (i.e., $p > 0.05$) indicate that the null hypothesis (i.e., no effect of the covariate) should be supported.

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We calculated GLMMs because we repeatedly measured survival rate and λ in similar study areas across multiple years. Each study area and year was treated as a unique sample or 'block' in our experimental design (Bolker et al. 2009). We were interested in estimating the overall (i.e., 'treatment') effect across study areas and years, thus we included random effects for each study area and year in our model. These random effects estimated the effects of each covariate within a study area or year and removed that effect from the fixed effect coefficient estimates. Each GLMM included fixed and random effect intercepts and slopes for the covariates included in the model. GLMMs were fit with a Gaussian distribution using the package lme4 (Bates et al. 2015) in program R (R Core Team 2019).

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RESULTS

From February 2012–30 April 2018, we captured and radio-collared 400 cow Moose of which 14 were recaptured to replace collars with dead batteries or close to anticipated battery end life (Tables 2 and 3).

Table 1. Survival rates of radio-collared cow Moose in central BC from February 2012–30 April 2019.

Year	Survival Estimate (± 95% CI)	Number of Collars
2013/14	92 ± 8%	165
2014/15	92 ± 5%	201
2015/16	85 ± 5%	276
2016/17	89 ± 7%	272
2017/18	89 ± 4%	228

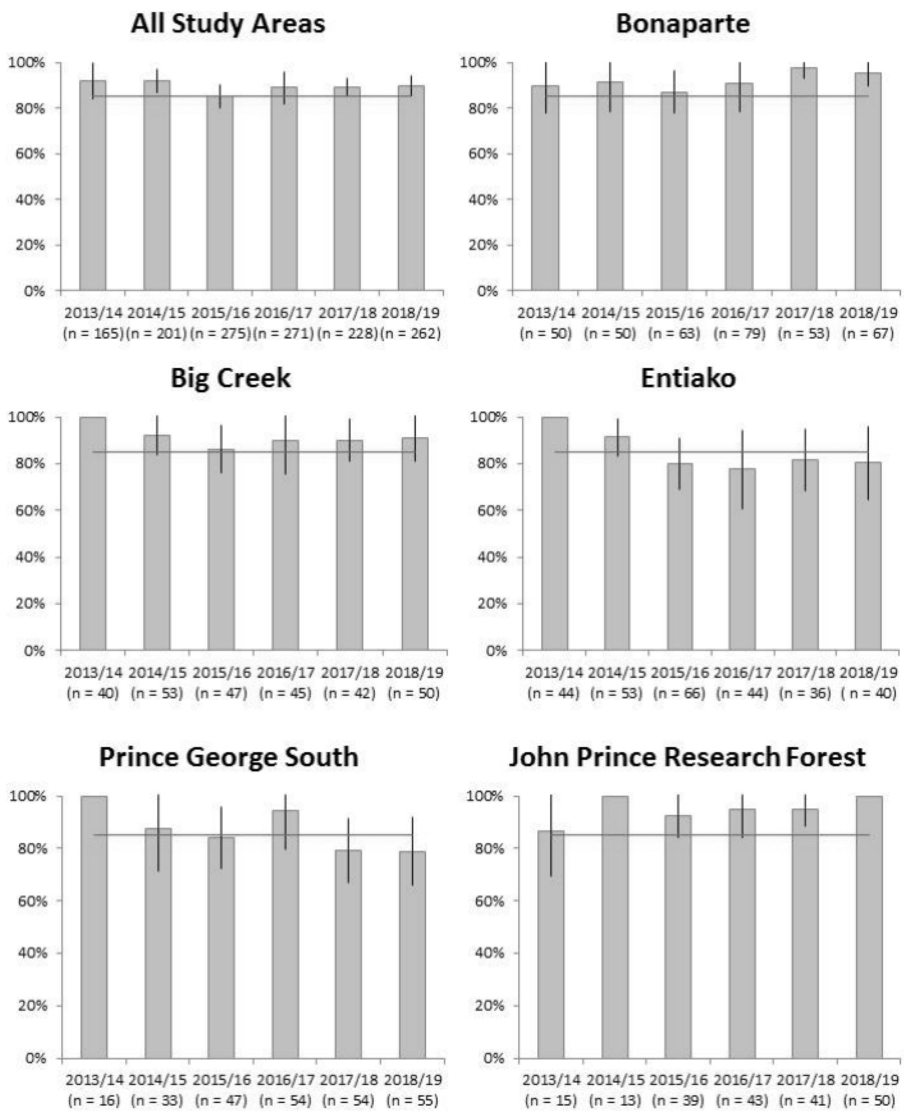
All Study Areas
100%
80%
60%
40%
20%
0%
2013/14 (n = 165)
2014/15 (n = 201)
2015/16 (n = 275)
2016/17 (n = 271)
2017/18 (n = 228)
2018/19 (n = 262)
Bonaparte
2013/14 (n = 50)
2014/15 (n = 50)
2015/16 (n = 63)
2016/17 (n = 79)
2017/18 (n = 53)
2018/19 (n = 67)
Big Creek
2013/14 (n = 40)
2014/15 (n = 53)
2015/16 (n = 47)
2016/17 (n = 45)
2017/18 (n = 42)
2018/19 (n = 50)
Entiako
2013/14 (n = 44)
2014/15 (n = 53)
2015/16 (n = 66)
2016/17 (n = 44)
2017/18 (n = 36)
2018/19 (n = 40)
Prince George South
2013/14 (n = 16)
2014/15 (n = 33)
2015/16 (n = 47)
2016/17 (n = 54)
2017/18 (n = 54)
2018/19 (n = 55)
John Prince Research Forest
2013/14 (n = 15)
2014/15 (n = 13)
2015/16 (n = 39)
2016/17 (n = 43)
2017/18 (n = 41)
2018/19 (n = 50)

Table 2. Moose density and trend estimates resulting from aerial surveys in five Moose research study areas in central BC, where cow Moose survival has been monitored.

Study Area	Moose Density at Project Start ± 90% CI (winter year)[1]	Moose Density at Project End ± 90% CI (winter year)[1]	Annual Population Trend
Bonaparte	296 ± 18/1000 km^2 (2012/13)	254 ± 41/ 1000 km^2 (2017/18)	-2.8 %
Big Creek	170 ± 39/1000 km^2 (2011/12)	220 ± 38/ 1000km^2 (2016/17)	-5.9%
Entiako	267 ± 45/1000 km^2 (2012/13)	217 ± 46/ 1000 km^2 (2018/19)	-3.1%
Prince George South	630 ± 102/1000 km^2 (2011/12)	400 ± 78/1000 km^2 (2016/17)	-7.3%
John Prince Research Forest	770 ± 93/1000 km^2 (2011/12)	490 ± 84/1000 km^2 (2016/17)	-7.3%

[1]Reported Moose densities are from Stratified Random Block (SRB) surveys (RISC 2002) conducted in the study areas

Table Number of mortalities and probable proximate cause of death of radio-collared cow Moose in central BC from February 2012 – 30 April 2019.

Study Area	Mortalities	Probable Proximate Cause of Death
Bonaparte	24	7 predation (5 Wolf, 2 Cougar), 7 hunting (1 licensed, 6 unlicensed), 10 health-related (3 apparent starvation, 2 failed predation attempt, 1 chronic bacterial infection, 4 unknown health-related)
Big Creek	21	11 predation (8 Wolf, 1 Cougar, 2 bear), 5 hunting (unlicensed), 4 health-related (XXXXXXX,1 apparent starvation, 1 failed predation attempt, 1 peritonitis*), 1 natural accident
Entiako	34	25 predation (20 Wolf, 5 bear), 2 health-related (1 prolapsed uterus, 1 unknown health-related), 2 natural accident, 5 unknown
Prince George South	31	21 predation (14 Wolf, 2 Cougar, 5 bear), 3 hunting (1 licensed, 2 unlicensed), 7 health-related (6 apparent starvation, 1 pleuritis)

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John Prince Research Forest	9	5 predation (Wolf), 2 hunting (unlicensed), 2 unknown
Totals	119	69 predation (52 wolf, 5 cougar, 12 bear), 17 hunting (2 licensed, 15 unlicensed), 23 health-related (10 apparent starvation, 3 failed predation attempt, 1 chronic bacterial infection, 1 peritonitis, 1 pleuritis, XXXXXXX, 1 prolapsed uterus, 5 unknown health-related), 3 natural accident, 7 unknown

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DISCUSSION

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A Novel Approach Using Bioclimatic Envelope Modelling to Estimate Moose Winter Range Distribution and Population Carrying Capacity

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Introduction

Bioclimatic envelop modelling (BEM) is a modelling approach that uses species occurrence information to define a climate 'envelope' consisting of climate variables that best describes the limits to a species spatial range (Araujo and Peterson, 2012). The approach typically uses statistical modelling techniques to derive the range of a species by comparing occurrence data to specific climate variables (refs). The BEM approach can work well for species' distributions where limits are not known, but may be less accurate where due to uncertainties associated with factors that are not controlled by climate alone (Heikkinen et al 2006).

Species such as moose (*Alces alces*) lend themselves well to the use of a BEM approach to estimate their distribution as factors such as snow depth, winter temperature and forage that limit moose winter habitat use are well documented (Peek 2007, Renecker and Schwartz 2007). BEM approaches have been used to link climatic constraints to the geographic distribution of wide-ranging carnivores such as wolverine (Gulo gulo) (Copeland eta l. 2010), have been shown to explain moose distribution and abundance in Ontario (Rempel 2010). Likewise, climate envelopes have been used to explain the geographic distribution of plants and tree species throughout much of western North America (Rehfeldt et al. 2006). In applying a BEM approach, climate information can be easily derived from existing climate datasets for BC such as ClimateBC (Wang et al. 2016).

A BEM approach has several advantages over more traditional expert-based rating approaches for estimating winter range distribution and abundance. Expert-based ratings utilize the knowledge of experienced wildlife biologists to provide qualitative rating of an area's potential to provide habitat (Habitat Capability) based primarily on abiotic factors (e.g. snow depth, temperature, slope), = and habitat quality (Habitat Suitability) based on biotic factors (i.e. forage) associated with habitat type (e.g. wetland, riparian, forest) and forest age or structure. A BEM approach can incorporate a similar suite of climatic variables that influence moose distribution and abundance but in a more transparent and repeatable way. The benefit of the BEM approach is that use of empirically derived climate variables allows for greater transparency when applying assumptions regarding factors that limit moose distribution and can be tested using independent data sources (e.g. inventory data). The BEM approach more easily allows for backcasting to explain observed changes over time and forecasting under future land use and climate change projections.

In this approach, two climate variables, snow depth and winter temperature, are used to estimate the probable winter occurrence of moose in southern interior of BC. The bioclimatic envelopes of three key tree/tall shrub deciduous browse species; 1) Aspen (*Populus tremuloides*), 2) Birch (*Betula papyrifera*) and 3) Willow (*Salix spp.*) are used to approximate three climate zones; 1) Dry-Cold, 2) Moist-Cool, and 3) Wet-Cool. Each climate zone represents an assemblage of tree/shrub deciduous browse species that are commonly utilized by moose as winter forage. The probability of occurrence of each key browse species is estimated based on climate variables to provide an index of relative browse forage production in cleared/disturbed forests each climate zone. The browse forage productivity estimates are then used to scale available browse biomass (Kg/ha) estimates in disturbed forests to account for variability in species and biomass productivity across the diverse range of climatic conditions in southern interior BC.

Methods

Study Area and Assessment Units

The study area includes the entire Thompson Okanagan Region including the Lillooet and Merritt TSAs (Cascades Resource District), Kamloops TSA (Thompson River s District) and Okanagan Shuswap TSA (Resource District). Existing Wildlife Management Units (WMUs; Fig. 1) used for moose population management were considered too broad to capture more local habitat and human access (hunting) related effects on moose.

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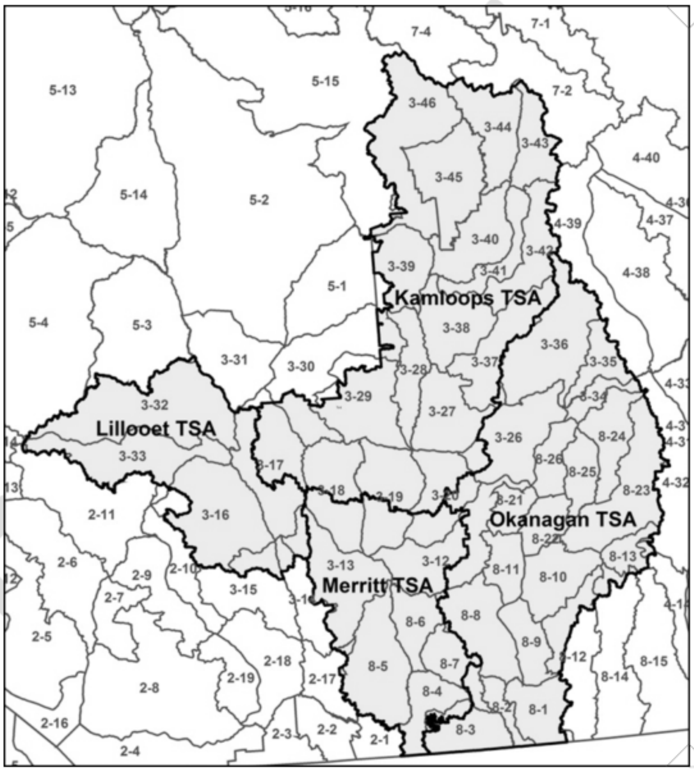

Figure 1. An illustration of the broader Thompson Okanagan Region assessment area showing the extent Wildlife Management Units (WMUs; green shaded areas) that are currently included in the assessment.

Deriving Climate Variables

The Biogeoclimatic Ecosystem Classification (BEC; https://www.for.gov.bc.ca/hre/becweb/index.html) system was chosen to summarize climate information as Biogeoclimatic (BGC) units (zones to variants) as variation between units has been shown to be largely explained by climate data (Delong et al. 2010, Wang et al. 2006). Summary information for all climate variables was summarized at the BGC subzone\variant level using the 1:20,000 BEC analysis units version 11 (https://catalogue.data.gov.bc.ca/dataset/bec-map). First, the BGC analysis shapefile was 'dissolved' in ARCGIS by 'BGC label' such that one polygon for each unique BGC subzone variant was created. Next, a set of random points were generated for each BGC subzone/variant in ArcGIS, assigned X,Y coordinates and exported to Microsoft Excel (.csv format). All spatial point locations were formatted and ran through ClimateBC version 5.60 (Wang et al. 2016) to calculate annual and seasonal climate variables for the normal period of 1981-2010. Climate data for each point location from ClimateBC was then summarized in R Studio software (R Studio Team, 2015) to provide a spatial and temporal mean and standard deviation (Table 1) by BGC subzone/variant. Additional climate variables were derived from the Climate BC data for each BGC unit and include; Annual Dryness Index (ADI), GSPDD5 and Snow depth (SD) (Table xx). Both ADI and GSPDD5 provide an index that incorporates the interaction of temperature and precipitation variables. ADI is calculated as Growing degree days >5°C (DD5)^0.5 divided by Mean Annual Precipitation (MAP). GSPDD5 is calculated by multiplying growing season precipitation (GSP; April-September precipitation) by DD5 divided by 1000. Snow Depth (SD) is derived by summing autumn (Sept-Nov) and winter (Dec-Feb) Precipitation as Snow (PAS; mm snow water equivalency (SWE)) to provide total PAS for the period from Sept-March. To estimate snow depth from PAS, I divided PAS by a Mar 1st snow bulk density estimate of 0.35, based on measured snow bulk densities for March 1st from summarized Ministry of Environment snow survey data from the same BEC subzone.(https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/snow-survey-data). The ClimateBC estimated March 1st snow depths were compared to measured March 1st snow depth data, summarized by BEC subzone, to ensure the estimates were comparable (Fig 2).

Table 1. List of Climate variables

Climate Variables
Seasonal variables (Climate BC)
Tave_wt - winter (Dec-Feb)mean temperature (°C)
Ppt_sp - spring (Mar-May)precipitation (mm)
Ppt_sm – summer (Jun-Aug)precipitation (mm)
PAS_wt * - winter (Dec-Feb)precipitation as snow (mm)
PAS_at* -autumn (Sept-Nov) precipitation as snow (mm)
Annual variables (ClimateBC)
MAP - Mean Annual Precipitation (mm)
DD5* – Degree-Days above 5°C, growing degree days
T_AVG – Average Temperature (°C)
Derived Variables
GSP -Growing Season Precipitation (mm) = PPT_sp + PPT_sm
GSPDD5 =(GSP * DD5)/1000
ADI (Annual Dryness Index) = DD5^0.5/MAP
PRatio(Precipitation Ratio) = GSP/MAP
SD -Snow Depth (cm) = ((PAS-wt+PAS_at)*0.35)/10
*derived variables in ClimateBC

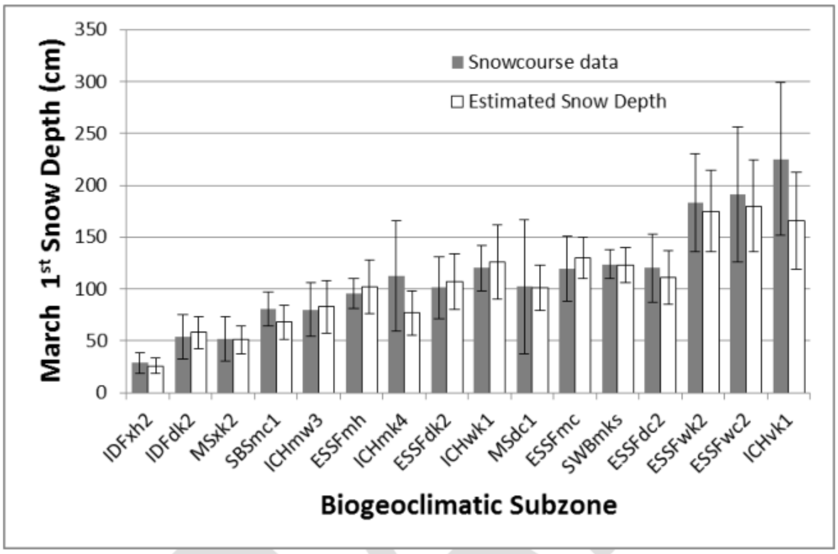

Figure 2. A comparison of snow depths estimated from ClimateBC data by applying a snow bulk density to Precipitation as Snow (PAS)measurements (mm; snow water equivalency)against summarized Ministry of Environment snow survey data showing mean and standard deviation of annual March 1st snow depths for years (xx)

Estimating Capable Winter Habitat Based on Climate Variables

Habitat Capability is defined as the ability of the habitat, under the optimal natural (seral) conditions for a species to provide its life requisites, irrespective of the current condition of the habitat (BCMELP 1999). Habitat Capability Ratings refer to the value assigned to a habitat based on the potential to support a particular species for a specified season and activity compared to the best habitat in the province (BCMELP 1999). In BC, Habitat Capability Ratings are applied to ecosystem mapping units based on BC's Biogeoclimatic Ecosystem Classification (BEC) system. The ratings are typically applied to an ecosystem unit based on expert knowledge and assumptions about species' use of habitat. In deriving the ratings, experts consider factors that can affect habitat use by moose in the winter period, including both abiotic factors such as snow depth, temperature, slope and biotic factors such as forage availability[1].

[1] Factors other than habitat quality that affect animal density such as annual variability, social interactions, predation, disease and human disturbance are not considered (BCMELP, 1999).

In this approach, Winter Habitat Capability for Moose was approximated based on two abiotic variables that have been shown to limit moose abundance and use of habitats, snow depth (SD) and winter temperature (WT) (Fig 3). Moose are negatively affected by snow depths >90cm (35 inches) and moose movements are largely restricted at snow depths >120cm (Franzmann and Schwartz, 2007, Telfer and Kelsall, 1979). Moose are well adapted to cold temperatures (<-30º Celsius), but can experience heat stress when winter (Dec-Feb) temperatures exceed -5ºCelsius (Franzmann and Schwartz, 2007, Renecker and Hudson, 1986, 1990)). Effects include increased heart, metabolic and respiratory rates (Renecker and Hudson, 1986). Moose will increase energy expenditures as animals attempt to dissipate excess heat. Stress imposed by heat may limit the southern distribution of moose (Kelsall and Telfer, 1974).

The two variables are used to estimate the winter distribution for moose by deriving a Climatic Envelope Score (CES) that reflects the combined probability that moose will use an area as winter habitat, where:

$$CES = SD \, x \, WT$$

Snow depth (SD) is calculated based on the probability that March 1st snow depth <120cm.

Winter temp (WT) is calculated probability that winter temperature < -5º Celsius.

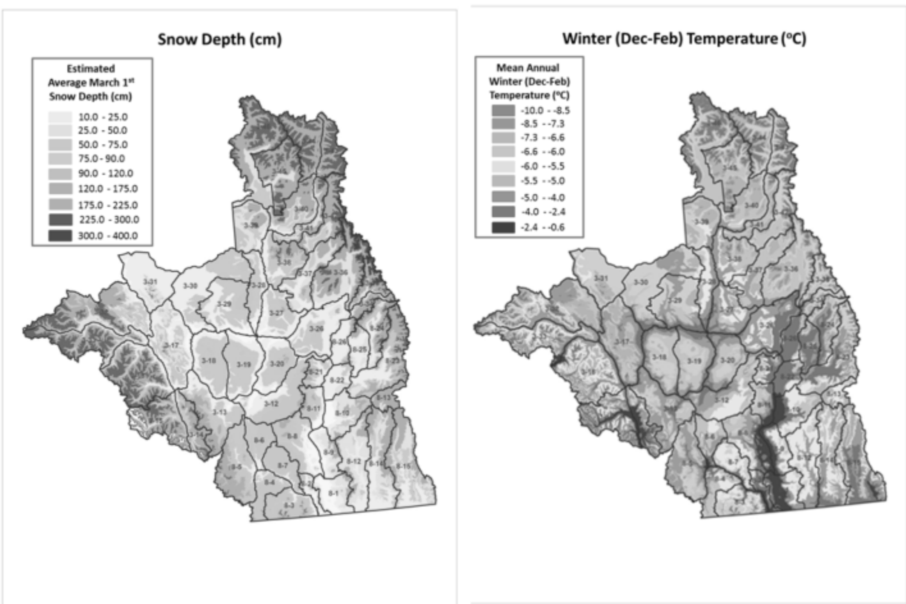

Figure 3. Estimated average March 1st snow depth (cm) and mean annual winter temperature (ºC) based on ClimateBC data for the normal period of 1981-2010, summarized at the Biogeoclimatic subzone variant unit level across the Thompson Okanagan Region.

The CES provides a combined probability that results in a relative score from 0-1 that can be used as an index of habitat capability based on these two abiotic variables (Fig 4).

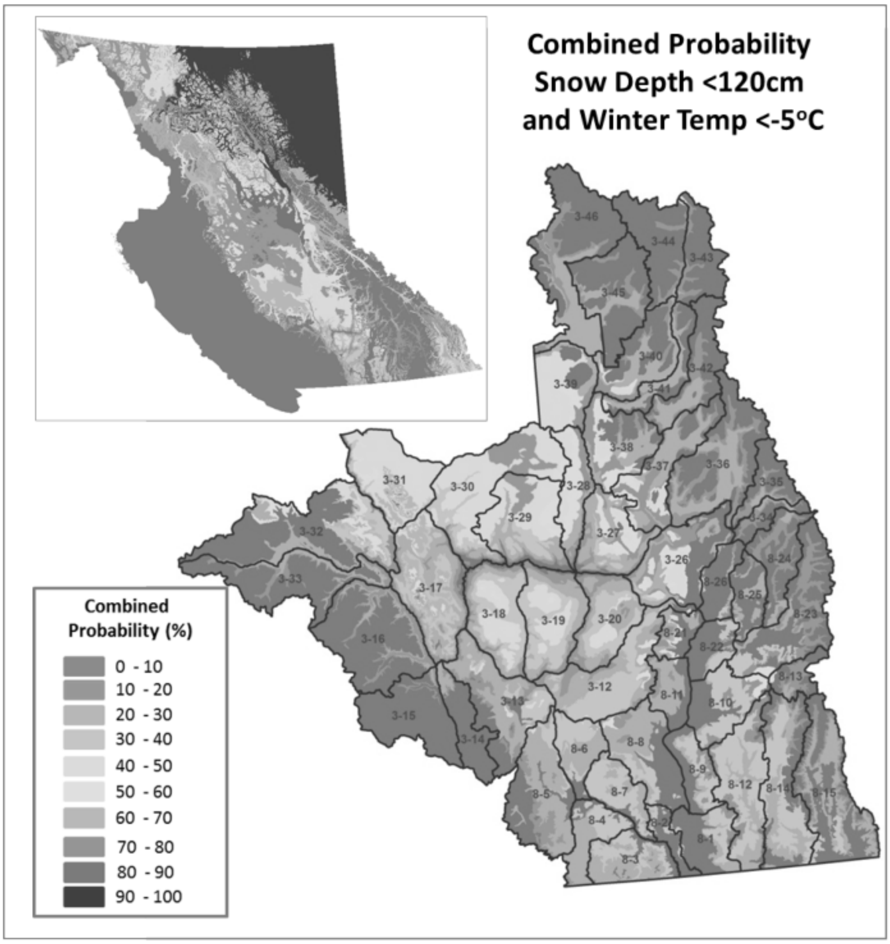

Figure 4. The combined probability that snow depth <120cm and winter (Dec-Feb) temperature <-5°C based on ClimateBC data for the normal period 1981-2010, summarized at the Biogeoclimatic subzone variant level. Higher probability indicates a higher likelihood of moose use and abundance. Inset box shows combined probability values for the province.

The availability of key forage browse species is another factor that is often considered in habitat capability ratings for moose. However, moose appear to utilize a broad range of forage sources in winter, mainly tied to the relative abundance of various conifer and deciduous species that occur in a given area that moose can utilize (See Appendix 2; Renecker and Schwartz 2006). Thus, forage specificity is unlikely to be a key factor constraining moose winter distribution as compared to abiotic factors such as snow and temperature. Climate variables that have been used to explain the distribution of key browse species such as aspen, are also highly correlated to abiotic factors such as snow depth (Fig. 5). Consequently, snow depth and temperature represented through the CES is used to represent capable winter habitat for moose in this approach, recognizing that these climate variables also capture forage considerations when describing capable habitat.

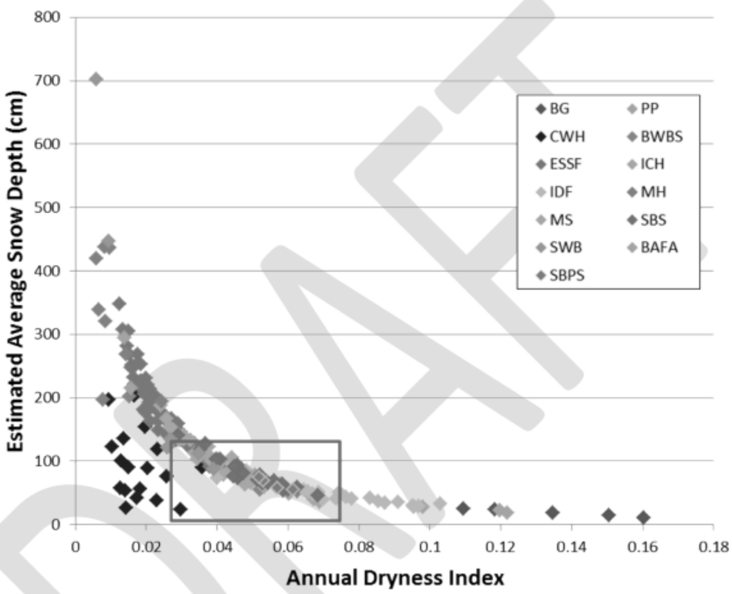

Figure 5. Relationship between Annual Dryness Index (ADI) and estimated average snow depth (cm) plotted against BEC subzone variant units in the province. A strong relationship exists in non-maritime influenced (CWH and MH) ecosystems. The inset red box is used to illustrate the approximate climatic envelope from moose based on snow depth and ADI values of 0.03-0.07 that represent the 95% range of Trembling Aspen

Comparison to Moose Inventory Data

Moose winter occurrences (Dec-Feb), collected by inventory flights between 1985 and 2018 were compared against average estimated snow depth (cm), winter temperature and the Climate Envelope Scores (CES) (Fig.). In general, the upper limit of 120cm average snow depth (Fig. 6 top) appears to fit well with the limit of moose observations, although a small proportion of observations occur in BGC subzones with average winter snow depth >120cm. Moose observations were associated with a more broader range of average winter temperatures, utilizing areas with average winter temperature that exceeds the -5°C constraint (Fig. 6 middle). A high proportion (>80%) of total moose winter observations occurred in areas with a CES of >0.15 (Fig 6. bottom). At the same time, almost 50% of the total study area is <0.15 CES, representing mainly lower elevation grassland or dry forests where winter temperature is limiting, or higher elevation wet ESSF forests, sub-alpine forest or alpine areas where average estimated annual snow depths would limit moose distribution.

As a preliminary estimate, a combined probability or CES score of 15% was used as a lower limit at which habitats were not considered capable moose winter range. However, several areas had to be manually removed or included to best reflect actual moose use and distribution. For example, several higher elevation Biogeoclimatic subzone variants (ESSF dc1-3, xc1-3, xcw, xcp,wk1,mh and BAFun) were removed as capable habitat based on the low number or lack of winter observations, despite relatively high combined probability or CES scores. These ecosystems fall within upper elevation plateaus where average snowfalls were generally 90-100cm, but winter temperature was not limiting resulting in a higher CES score. In these ecosystems, mean annual snow depths (>90cm) reflect conditions where moose travel and mobility would be highly restricted (Renecker and Hudson 2006) and available tall shrub browse species are limiting compared to lower elevation habitats (i.e. ICH wk1). Thus, the benefits to obtain limited forage would not outweigh the energetic costs. In contrast, several lower elevation habitats including the ICHdw1,dw4,mw2 and IDFmw1 were manually included in the capable habitat areas. In these ecosystems, winter temperatures are suggested as being potentially limiting, but not snow depth. Moose winter observations also indicate a relatively high level of use, possibly associated with certain years where average temperatures are lower than average. In such circumstances, snow is not limiting and forage browse may be more available.

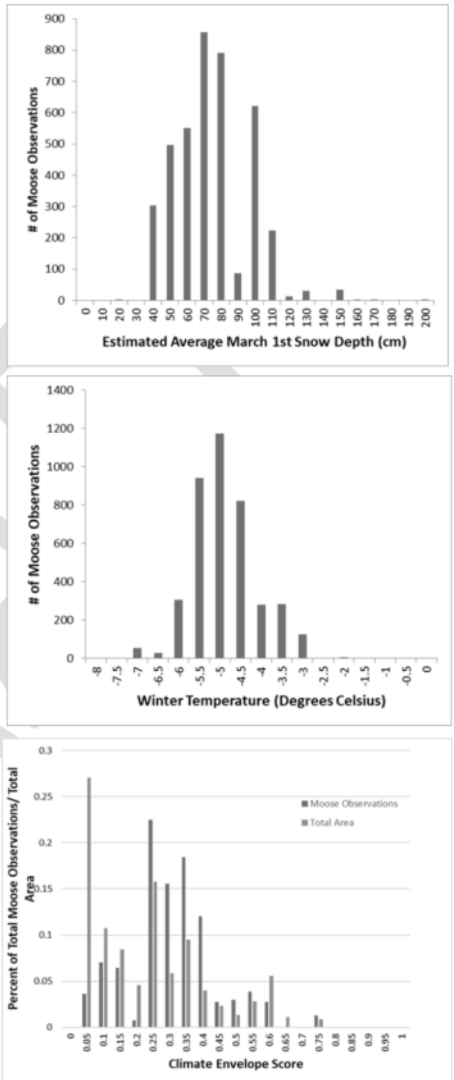

Figure 6.

Browse Estimates and Carrying Capacity

I used an approach consistent with Telfer (1995) to estimate moose carrying capacity based on the amount of available deciduous browse associated with different land cover types and forest succession. The approach is based on two key assumptions;

- Moose use areas in proportion to the amount of browse (Spencer and Halaka 1964, Telfer 1978)
- Moose numbers increase as browse increases (Lutz 1960, Spencer and Hakala 1964, Loranger et al. 1991)

The approach requires three steps;

1. delineate different land cover classes to approximate potential browse sources
2. estimate browse production by land cover class
3. account for changes in browse production through time

Land Cover Classes Used to Approximate Browse Sources

I used existing data sources to characterize land cover classes that provide deciduous browse forage for moose including both 'static' forage sources such as riparian forest, wetlands, self-sustaining deciduous stands and 'dynamic' forage sources consisting of early seral conifer forests created through forest harvesting or wildfire (Fig. 7). To identify wetlands, I used the BC Freshwater Atlas (FWA[2]) wetland layer. Riparian forests were identified by applying a 10m buffer (5m either side) around the 1:20,000 FWA stream layer. Self-sustaining deciduous forests were identified using the provincial Vegetation Resource Inventory (VRI) layer to identify all deciduous (Aspen and Birch) leading (>30%) stands. Early seral forest was identified as forest <40 years old using the provincial VRI layer.

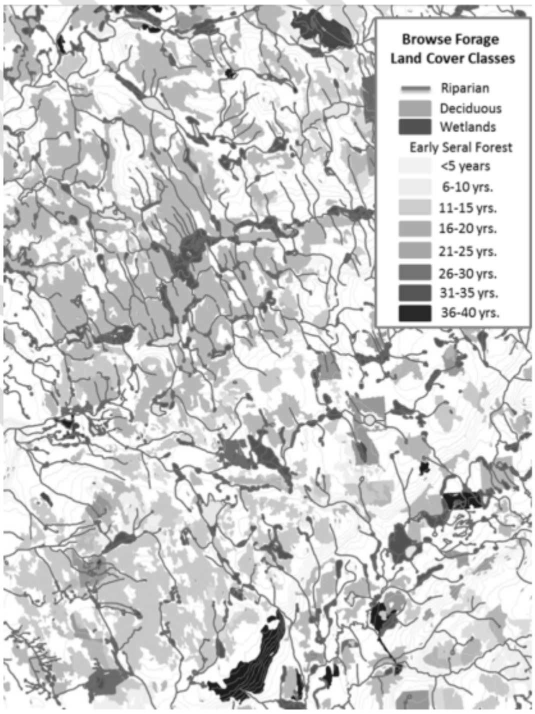

Figure 7. Land Cover Classes used to characterize moose browse forage sources.

[2] https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/freshwater)

Estimating Browse Production by Land Cover

Browse estimates for both static and dynamic forage sources were applied based on estimates from available published literature. For riparian forests browse estimates of 50Kg/ha were based on the median value provided by Telfer (1995). I assigned estimates of 100 Kg/ha of annual browse forage to wetland and deciduous cover types based on information summarized in Franzmann and Schwartz (2006).

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Conifer-leading forest is the dominant vegetative cover on moose winter ranges in southern BC, and the only 'dynamic' forage source where anthropogenic (forest clearing) and natural disturbances e.g. wildfire, insects) affect available browse. Available browse can vary substantially depending on disturbance history and post-disturbance forest structure. In boreal forests of Alberta, Telfer (1995) estimated that 85-90% of total browse was associated with forested areas and that between 56-77% was associated with young (<20yrs old) forest depending on the rate of forest disturbance (wildfire).

To characterize the change in browse over time following forest disturbances, a review of existing published literature that reported change in browse was completed (Fig. 8, Appendix 3). I used the median value of 205 Kg/ha for forests 0-20 yrs. reported by Telfer (1995) from the boreal forest of Alberta based on the current annual growth of twigs as derived from several sources as the maximum amount of browse biomass per unit area (Table xx). I approximated the curve in browse biomass increase up to 20 years and decline from 20-40 years by estimating browse in discreet 5 year time classes (Fig xx).

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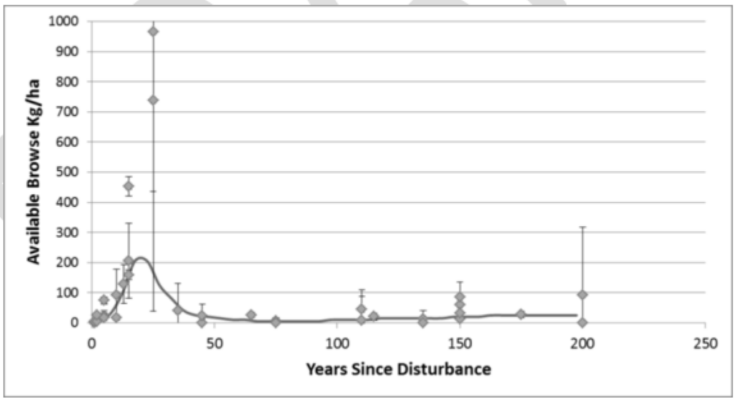


Figure 8. Estimates of average (grey diamonds) and standard deviations of total available forage biomass (Kg/ha) at different years following disturbance from several published studies. The red line indicates the value chosen to represent total available biomass following disturbance.

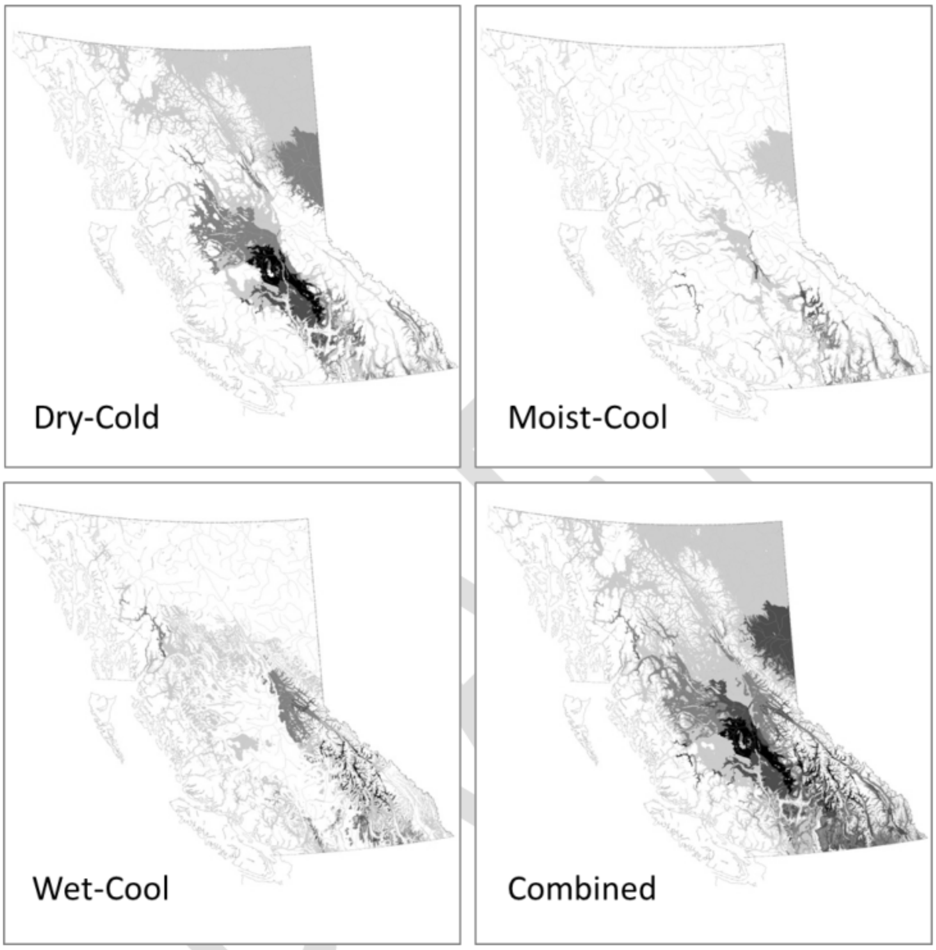
Most estimates of post-disturbance browse in the reported literature occur in relatively highly productive moose habitat. In southern interior of BC, moose occupy a broad range of climatic conditions where both the availability of different shrub browse species and post-disturbance site productivity could result in a range of browse production.

To estimate potential forage biomass a Browse Productivity Index (BPI)was developed to account for variability in both tree\tall shrib browse species and post-disturbance browse biomass associated with ecosystem [productivity. The BPI was developed by approximating the bioclimate envelope of 3 key tree /tall shrub browse species using climatic variables. For Aspen, the bioclimate envelope was approximated using parameters for two derived climate variables that explained (ADI and PRatio) as reported in Rehfeldt et al.(2009, 2006). The gamma distributions reported for each . For Birch , the bioclimate envelope was approximated based on two climate variables DD5 and GSP based on the distribution of climate variables reported in USGS considering similar variables that explain the distribution. Birch (Betula papyrifera) shows a similar set of climate variables, but was associated with greater growing season precipitation during the warmest months

Browse Species	Climate Variable	Parameters x (SD)
Aspen	ADI	0.055 (0.14)
	PR	0.54 (0.1)
Birch	ADI	0.3 (.008)
	T_AVG	4 (2)
Willow	GSP~~DD5~~	
	DD5	

The BPI provides a score of 0-1, with higher scores reflecting a greater probability the climate envelope is suitable for the species. Higher BPI scores are intended to reflect a conditions with greater percent cover and thus biomass (table xx). For example, the area of Aspen and Birch leading stands (>30% cover) was plotted relative to climate variables.

s.13



To estimate The BPI was multiplied by the maximum estimated forage biomass in each discreet 5 yr. period to net-down forage biomass estimates. recognizing those BGC subzones that best fit the climatic envelope for a would only produce browse comparable with median values shown in Fig xx.

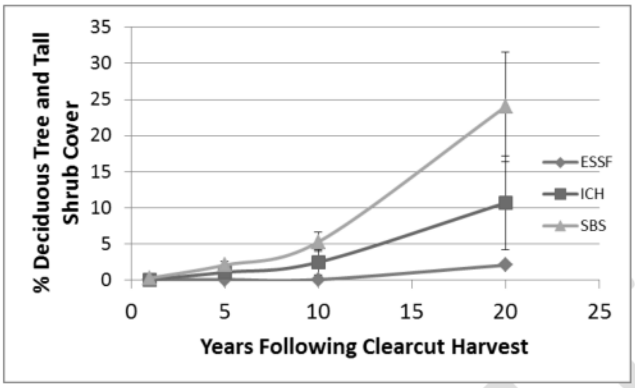


Figure xx. Relative differences in percent (%) deciduous tree and tall shrub cover in clearcut and slash-burned forest stands from three Biogeoclimatic zones (ESSF, ICH, SBS) in the interior of British Columbia.

Estimating Moose Carrying Capacity

I followed the approach of Telfer (1995) to estimate Moose Carrying Capacity (potential # moose) and potential density (#moose/Km^2) based on browse yield. This approach is based on a number of key assumptions:

1. The amount of available browse that can be utilized is 50% of available browse. .
2. Moose require approximately 5kg (oven dry weight) per day (Gasaway and Coady 1974)
3. Moose have a 210-day season of browse dependency (approximately Mid-late October to May)

Area Capable Winter Range	Browse Yield	Available Browse	Total Moose Days	Moose Carrying Capacity (# Moose)	Carrying Capacity Density (#/Km^2)
Riparian Wetland Deciduous Cutblocks & openings	50Kg/Ha 100Kg/Ha 100Kg/Ha Varies by age and climate	Multiply by 0.5 assuming 50% browse utilization	Divide by 5, assuming moose require 5Kg/day	Divide by 210 – assumes moose use browse forage for 210 days/Yr.	Divide by Km^2

The outcome provides a moose carrying capacity (# Moose/Km2) that an area has the potential to produce under ideal circumstances. Many other factors such as predation, hunting, disease, vehicle induced mortality will determine the observed moose density in a given area

The difference between the

Calibrating Estimates Using Inventory Data

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Appendix 1: Workflow to Prepare Climate Data

Analysis Steps

1) Generate Random points in each Biogeoclimatic Subzone

- In ArcGIS Start with the 1:20k BEC Analysis layer from BCGW,
- Using the Geoprocessing tool 'Dissolve' to aggregate features in the BEC Analysis layer by BEC label to create aggregated polygons by BGC subzone variant (should be 222 unique BEC labels at the provincial scale).[file: 'BEC_zones_dissolve_07192017.shp'],
- Use the command 'Create Random Sampling Points' in 'XTools Pro/Data Management Tools' to create 1000 random points for each BEC Label (file has over 23,000 points),
- Use the Geoprocessing Tool 'Intersect' command to intersect the random points with the Dissolved BEC layer so that each random point is assigned a BEC label,
- Use XTools Pro/ Surface Tools to add X,Y,Z coordinates to assign each point an X,Y coordinate specifying WGS 1984 as the coordinate system. (file: 'BEC_random_points_1000_labelled.shp')
- Export attribute table to excel (file: BEC_Random_Points_1000_07192017.xls)

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2) Run Points through ClimateBC

- In Excel, format attribute table columns for Climate BC (ID1, ID2, x, y) and save as .csv file (See users' guide for ClimateBC)(File: BEC_Random_points_07192017_fix.csv)
- Run .csv table in ClimateBC, specifying 'seasonal' and for the 'normal period' of interest (in this case the 1960-1990 or 1991-2014 average period – other historic or future periods under climate projections could be used)(File: BEC_Random_points_07192017_fix_Normal_1961_1990S.csv)

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3) Summarize ClimateBC data by BEC subzone

Using R Studio Software:

- summarize the temporal mean Precipitation as Snow (PAS; measured as mm snow water equivalency) for each point for the years of 1991-2014
- then, summarize the spatial mean, min, max, standard deviation of the temporal mean by season of all the points for that BGC subzone

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- Calculate accumulated March 1st PAS by summming winter (Dec (prev.year) -Feb) of the current year, and summer (Jun-Aug) and fall (Sept-Nov)precipitation from the previous year.

4) Estimate Snowdepth

- PAS is a derived variable in ClimateBC that uses seasonal precipitation and temperature to estimate mm snow water equivalency. To estimate accumulated March 1st snow depth, the PAS variable must be multiplied by a snow bulk density factor. Snow bulk density is a measure of
- March 1st Snow bulk density was estimated from snow survey information summarized from the BC MoE

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- A snow bulk density factor of 0.35 was used for all BEC subzones as a preliminary estimate. The accumulated snow depth estimate assumes that snow is accumulating and none is lost to melting.

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Results

Comparison between snowcourse data and estimates for a subset

Appendix 2:

Hodder et al. (2013) – Diet content and overlap of sympatric mule deer, moose and elk during a deep snow winter on north-central British Columbia, Canada John Prince Research Forest – Fort St. James - Sub Boreal Spruce (SBS) dw3, dk, mk1	
Composition of winter diet based on fecal pellet analysis - * mean values reported	
Conifers (64%)	**Deciduous (36%)**
Subalpine fir (*Abies lasiocarpa*) – 45%	Saskatoon/Serviceberry (*Amelanchier alnifolia*) – 4%
Douglas fir (*Pseudotsuga menziesii*) – 17%	*Betula spp.* – 4%
Other conifer – 2%	*Populus spp* – 4%
	Salix spp. – 11%
	High-brush Cranberry (*Viburnum edule*) – 4.5%

Rea, R.V. (2014) – A preliminary assessment of moose winter diets in the Aleza Lake Research Forest in north-central British Columbia Aleza Lake Research Forest - northeast of Prince George, BC - Sub Boreal Spruce (SBS) wk1	
Composition of winter diet based on fecal pellet analysis - * mean values reported	
Conifers (43%)	**Deciduous (51%)**
Subalpine fir (*Abies lasiocarpa*) – 43%	Paper Birch (*Betula papyrifera*)- 16%
	Red Osier Dogwood (*Cornus stolonifera*)- 2.5%
	Beaked Hazelnut (*Corylus cornuta*) – 10%
	Trapper's or Labrador Tea (*Ledum spp.*)– 3%
	Trembling Aspen (*Populus tremuloides*) – 12%
	Willow (*Salix spp.*) – 22.5%
	Other shrub – 3%

Baker, B.G. (1990) – Winter habitat selection and use by moose in the West-Chilcotin region of British Columbia West Chilcotin plateau – east of Tweedsmuir Provincial park Sub Boreal Pine Spruce zone (SBPS) – dc and xc2	
Composition of winter diet based on fecal pellet analysis	
Conifers (10-30%)	**Deciduous (60-70%)**
Lodegepole pine (*Pinus contorta*) – 10-30%	Bog Birch (*Betula glandulosa*) – 28-35%
Other conifer - <1%	Willow (*Salix spp.*) – 7-19%
	Saskatoon/Serviceberry (*Amelanchier alnifolia*) – 5-13%
	Other shrubs – 12-19%

Serrouya, R, and D'Eon (2002) Moose habitat selection in relation to forest harvesting in a deep snow zone of British Columbia Lake Revelstoke Valley- north of Revelstoke, BC Interior Cedar hemlock (ICH)wet cold –(wk1), very wet cold – (vk1), - moist warm -(wm 3)	
Winter forage transects and 5.65m radius 'use' plots. Top six most abundant browse spp reported based on visual estimates of percent cover of browse species within 2m of the snow surface - * shown in relative order of abundance in 'use' plots	
Conifers Western red Cedar (*Thuja plicata*) Pacific yew (*Taxus brevifolia*)	**Deciduous** Willow (*Salix spp.*) Douglas maple (*Acer glabrum)* Balsam poplar (*Populus balsamifera*) Beaked hazelnut(*Corylus cornuta*) Alder (*Alnus spp.*)

Eastmann, D.S. 1977. Habitat selection and use in winter by moose in sub-boreal forests of north-central British Columbia , and relations to forestry. Near Prince George , BC – Sub Boreal Spruce (SBS)wet cold (wk1), moist cold(mk1), very wet cold (vk1) and possibly dry warm (dw3) - * estimated from map					
Estimated as a percent basis of total diet from a combination of rumen analysis and trailing					
Conifers	**Nov-Jan**	**Feb-Apr**	**Deciduous**	**Nov-Jan**	**Feb-Apr**
Subalpine fir (*Abies lasiocarpa*)	5-17	23-26	Douglas maple (*Acer glabrum*)	4-t	4
Lodgepole pine (*Pinus contorta*)	t	t	Sitka Alder (*Alnus sitchensis*)	1-4	t-1
Douglas fir (*Pseudotsuga menziesii*)	t-1		Saskatoon/Serviceberry (*Amelanchier alnifolia*)	1-6	1
Western Red cedar (*Thuja plicata*)	t	3	Bob Birch (*Betula glandulosa*)	2	0
			Paper Birch (*Betula papyrifera*)	19-27	12-32
			Red-Osier Dogwood (*Cornus stolonifera*)	11-23	3
			Black twinberry (*Lonicera involucrata*)	t	t
			Devil's club (*Oplopanax horridus*)	-	-
			Trembling Aspen (*Populous tremuloides*)	1-3	5-8
			Black Cottonwood (*Populus balsamifera*)	t-1	1-3
			Rose (*Rosa spp.)*	t-1	t-2
			Willow (*Salix spp.*)	27-29	21-36

	Sitka Mountain Ash (*Sorbus sitchensis*)	3	1
	Spirea (*Spirea spp.*)	t	-
	Vaccinia (*Vaccinium spp.*)	t-1	t
	Squashberry/high brush cranberry (*Viburnum edule*)	4-6	1-5

Appendix 3: Summary of Forage Biomass Estimates

Telfer (1995)Northwestern Boreal Forest Alberta						
• **Reported values are the median and range (in parentheses) of current annual deciduous twig biomass (conifers not included) in Kg/ha from up to 10 different studies in the northwestern boreal forest of Alberta**						
		Conifer Forests			**Riparian**	**Muskeg**
		Age Class (yrs)			Various Ages	
0-20	**21-50**	**51-80**	**81-150**	**>150**		
205.5 (37-454)	40 (4-175)	26 (20-32)	20.5 (4-43)	28 (11-31)	50 (6-113)	37

Scwabb and Pitt (1991) Moose selection of canopy cover types related to operative temperature, forage and snow depth Northeast of Prince George, BC – Sub Boreal Spruce (SBS)wet cold (wk1) and very wet cold (vk) - * estimated from map					
• **Current annual growth of forage biomass (conifer and deciduous species) based on regression equations for individual species and accounts for snow depth when considering forage availability.** • **Late winter snow depths were 136-163cm across all forest cover types in 1982 compared to 56-75cm in 1983.** • **Amounts are in Kg/ha and are converted by multiplying reported values of grams/m² by 10. Values includes standard deviation (+/-)** • **Each forest cover type is assigned an approximate age (time since disturbance) based on harvest history and reported sampling period for comparisons with other studies.** • **Forest Canopy Cover (CC) estimates are also provided.**					
			Forest Cover Type		
Season	**Mature Forest (~150 yrs old) (77%CC)**	**Diameter limit Logging (~25 yrs. old) (70%CC)**	**Intermediate Utilization Logging (~15-20yrs old) (37%CC)**	**Old Clearcut (~10yrs old) (6%CC)**	**Recent Clearcut (~5yrs old) (4%CC)**
Early winter	9.0+/-3	40 +/- 7	81 +/- 9	119 +/-17	29 +/-5
Late Winter 1982	32 +/- 4	49 +/- 8	99 +/- 7	159 +/- 16	17 +/-4
Late Winter 1983	86 +/- 7	128 +/- 11	193 +/- 12	452 +/-32	74 +/-1.1

Eastmann, D.S. 1977. Habitat selection and use in winter by moose in sub-boreal forests of north-central British Columbia , and relations to forestry. Near Prince George , BC – Sub Boreal Spruce (SBS)wet cold (wk1), moist cold(mk1), very wet cold (vk1) and possibly dry warm (dw3) - * estimated from map										
• **Reported values use estimates of total biomass of shrub (>45cm height) browse species (g/m2: Figure 7.4 and table 7.19) at different age classes of forests.** • **Estimates shown here were derived by multiplying reported values of total plant phtomass by 0.3 to account for current annual twig growth (estimated by author) and then multiplying by 10 to convert to Kg/ha**										
					Forest Age (yrs)					
Substrate	**1**	**5**	**10**	**25**	**45**	**75**	**110**	**135**	**150**	**200**
Till	0.6	24	18	1,084	0.6	6	45	18	60	93
Lacustrine	4.5	19.5	93	738	22.5	0	7.5	0	13.5	0
					Partial Cut Forests					
Till	-	-	-	-	-	-	-	10	84	91
Lacustrine	-	-	-	-	-	-	-	-	60	-

Lord and Keilland (2015) Black Spruce and Aspen forests, Alaska	
Measures were recorded 13 years post-wildfire	
Average	190 kg/ha +/-(104)
High Severity	225 kg/ha +/-(64)
Low Severity	69 kg/ha +/- (48)
Severity Weighted	128 kg/ha +/- (64)

Oldemeyer and Regelin (1987) Kenai peninsula, Alaska				
Postburn age	**3yrs**	**10 yrs**	**30ysr**	**90yrs**
	37	1399	354	4

In central BC between 2005-2011 or so moose density declined by 50-70% in many areas, a time interval coinciding with MPB and salvage. We wanted to know what the effects of increased logging were on moose and more specifically, if the decline in moose was related to logging. But we further reduced those broad questions to more tractable experimental hypotheses. We reasoned that the most likely process was that lambda was inversely related to cow mort [A1] & logging led to higher cow mort (thru.. mechanisms WFR HFR…) [H1].

Because A1 and H1 were based on general ecological relationships, at least for central BC, then we felt could test them in 2014-2018 and make inferences to the 2005-11 decline period. Because we could not manipulate the distribution or amount of logging and because best inferences are made with a big range treatments, we chose study areas with a wide range of existing lt8. our primary research question became:

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How did cow mort differ with lt8 as lt8 varied in space (the SAs) in a specified time (a spatial study - considering our 4 year study was a snapshot in time [Q1]?

Because our study took 4 years, we also analysed the data as a temporal study,
How did cow mort change with lt8 as lt8 varied in time (2014-2018) in the 5 SAs [Q2]?

However because we had no knowledge of if or how lt8 differed over time, and could not be sure that treatments would vary enough to constitute a test of our hypotheses, we were less confident that our Q2 would constitute a reliable test of our hypotheses.

….We chose to study cow mort even though we noted calf mort was a possibility, with wolf and hunter functional responses (WFR and HFR) as the mechanisms… details… we chose lt8 because of Mumma

Analysis Method
To determine if mortality increased with % early serial (lt8%), we regressed mort on lt8, where we considered lt8 the fixed effect, (n=20, 4 years and 5 study areas, where the p-value would be the probability of the slope being 0). To account for the lack of independence of lt8 within SAs, and potential pseudoreplication effects, we considered the yearly mort estimates as fixed effects lt8s nested within SAs with random slopes and intercepts using lmer4 in r (Bates et al. 2015a and b). We did this even though the study areas were not truly repeated measures because, a) the exact area varies within a study area each year because of change in moose HRs (but with variation far less than between SA variation) and, b) landscape change over time as trees aged out of the class (lt8) and logging continued to occur and increased the lt8 area. We could not consider SAs as random factors because they were not randomly distributed across the range of lt8s but specifically chosen to vary ie represent different lt8s. [rerun with new values from Tyler]

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Bates, D., M. Maechler, M. Bolker, and S. Walker. 2015a. Fitting linear mixed-effects models using lme4. Journal of Statistical Software. 67(1) *doi: 10.18637/jss.v067.i01*

Bates D, Maechler M, Bolker B, Walker S (2015b). *lme4: Linear Mixed-Effects Models Using Eigen and S4.* R package version 1.1-10, URL http://CRAN.R-project.org/package= lme4. https://cran.r-project.org/web/packages/lme4/vignettes/lmer.pdf

see also
http://janajarecki.com/blog/2018/09/15/repeated-measures-regression-in-r/

https://stat.ethz.ch/pipermail/r-sig-mixed-models/2011q1/015590.html
https://www.rensvandeschoot.com/tutorials/lme4/

nmle vs lmer:
https://freshbiostats.wordpress.com/2013/07/28/mixed-models-in-r-lme4-nlme-both/
https://online.stat.psu.edu/stat462/node/188/

Results

1. Did logging increase after 2005? This was the whole premise for our study, so we'd better show it to be true and by how much; from x% to y%. lt8 more than 8to15 odd, why? But not the question here anyway. Absolute values 7% vs 5% roughly
2. Cow mortality rate was higher in late winter than at other times of year [see potential bias section below. We removed 2013-14 and ignored the problem after that [table 1] as pctnew had no effect in multiple regression.
3. [Q1] Our study showed cow survival was strongly and inversely related to early seral [sig fixed effect]. Suggesting increased logging did not lead to higher cow mort but lower.. Reject H1. [Fig 1 2] Mechanisms also responded opposite to hypothesis [eg fig 3 4] or not clear effect eg hunting
4. λ did not decrease with increase cow mort so reject A1. [fig 5]
5. given that neither of our research hypotheses appeared to be true then would not expect λ to decline with lt8 and it did not. [fig 5b]
6. [Q2] lt8 decreased slightly in 4 of the 5 SAs but the change over the 4 years was small compared to the difference among SAs [fig 6].
7. With such a small treatment effect (Δlt8) λ & mort changed little but (still to do test) but trends are consistent with Q1. Over time there was slightly less lt8 and slightly higher mort [fig 7 & 8]

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Potential bias

Question of collaring date bias. A) clearly non random distribution of mortality from the 2 figure 28's from the 2019 annual report - late-in-the-biological-year peak of mort (mar apr may).

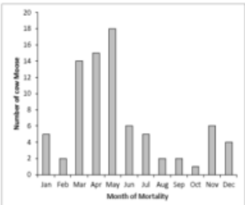


Figure 28. Month of death for radio-collared cow Moose (n = 122) in central B.C. from February 2012–30 April 2019.

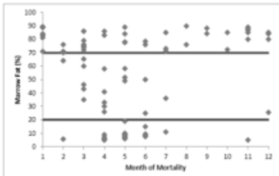


Figure 28. Body condition (as indexed by marrow fat) for each individual collared cow Moose mortality shown by month of mortality (n = 83) in central B.C. from February 2012–30 April 2019. Acute malnutrition is associated with marrow fat <20% (below red line), poor body condition is associated with marrow fat between 21% and 70% (between orange and purple lines), and good body condition is associated with marrow fat >70% (above purple line).

From Mumma & Gillingham

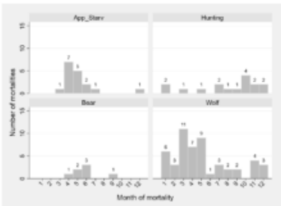


Figure 13. Month of the year when the four most common sources of ultimate mortality of collared cow moose occurred.

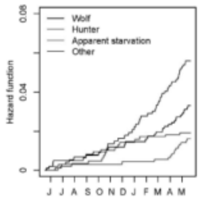
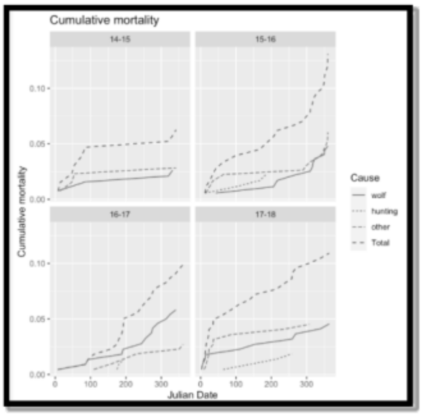
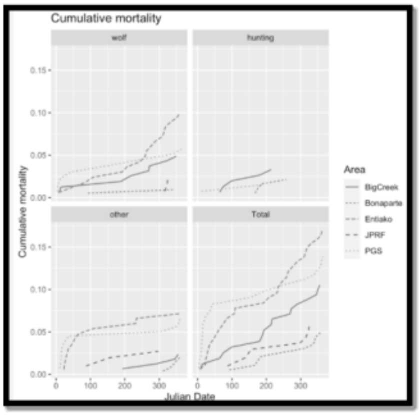


Figure 20. Cox proportional hazard functions for wolf predation, human harvest (hunting), apparent starvation, and other causes for collared cow moose in interior British Columbia.

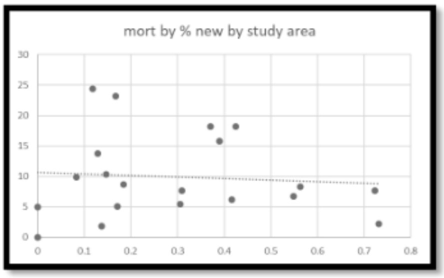
Carl's output seems to tell a less dramatic story but mort does trend up in spring for "other" [which are starvations mostly with some bear pred] especially in 2015-16 and entiako wolf predation.

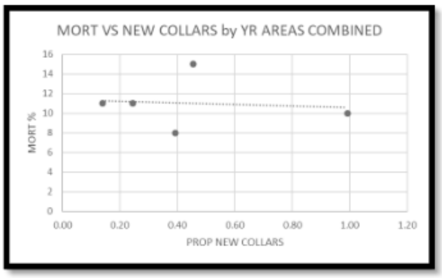
Carl s





MY analysis of rates vs percent new
Percent of newly collared animals seems very high most years (need to check this input data); [from tables in 2019 annual report]. So removing them would be huge deal I think. Overall the mean mort was 10% (study areas combined, right graph) regardless of proportion new even when almost all were new in 2013-14 (99% - the yr most collars were put on). 2013-24 essentially = the long term mean with no obvious study area influence (left graph). In addition when I put in pctnew as covariate in model of total mort vs lt8, pctnew was not significant & had no effect on slope. Table 1





SO? Potential for bias exists but maybe it is small, but it does not look like it is the same bias for all mort causes. I am happy with status quo; omit 2013-14 leave in the rest. ???

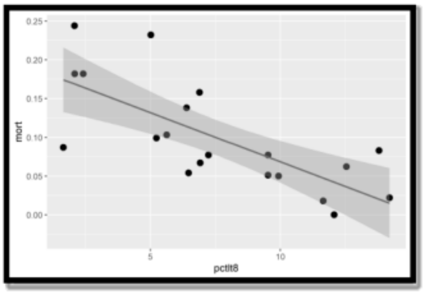


Fig 1

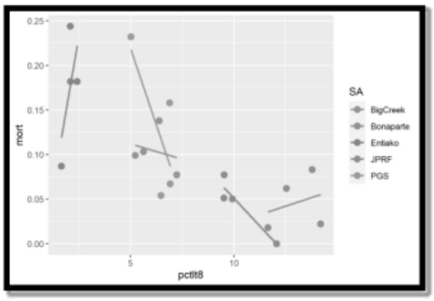


Fig 2

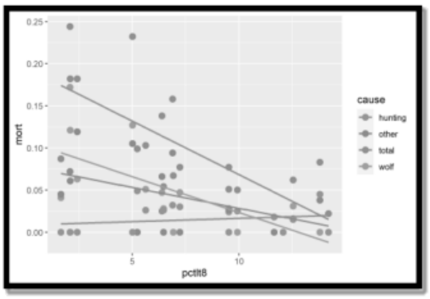


Fig 3

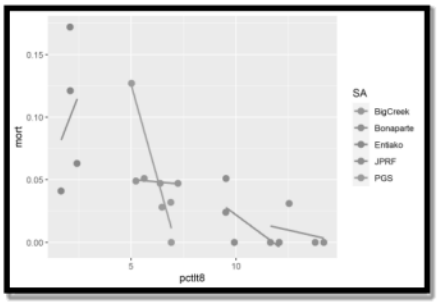
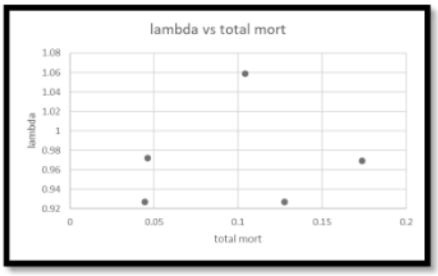


fig 4 wolf mort by SA/yr



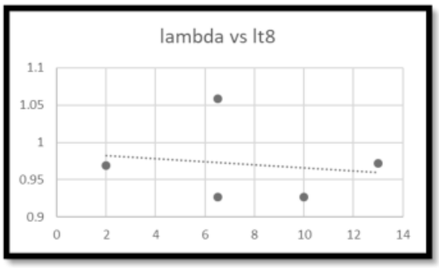


Fig 5 by SA

fig 5b by SA

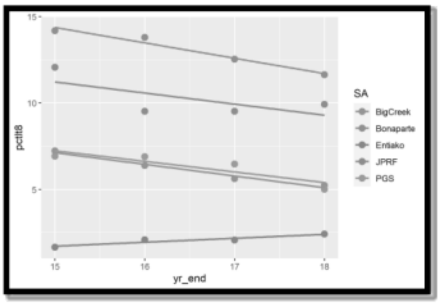
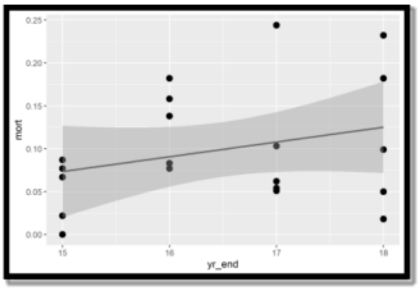


Fig 6 Variation in fraction of landscape logged was much smaller within a SA over time than among study areas



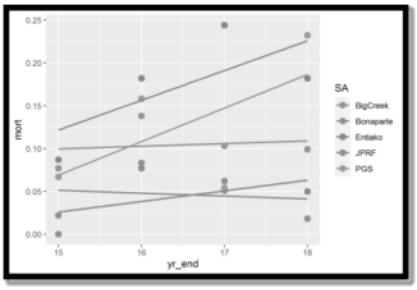


Fig 7 t mort by year and fig 8 by SA Q3

Do fig 5 and 5b by yr (not SA)

Table 1.

```
#try same with pctnew as covariate
> outOnew<-lmer(mort~pctlt8+pctnew +(pctlt8|SA), data=tmort)
boundary (singular) fit: see ?isSingular
>      outOnew
Linear mixed model fit by REML ['lmerModLmerTest']
Formula: mort ~ pctlt8 + pctnew + (pctlt8 | SA)
   Data: tmort
REML criterion at convergence: -36.5458
Random effects:
 Groups   Name        Std.Dev.  Corr
 SA       (Intercept) 0.000e+00
          pctlt8      1.948e-07  NaN
 Residual             4.901e-02
Number of obs: 20, groups:  SA, 5
Fixed Effects:
(Intercept)       pctlt8       pctnew
  0.1879278   -0.0133328    0.0004126
convergence code 0; 1 optimizer warnings; 0 lme4 warnings
>      summary(outOnew)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: mort ~ pctlt8 + pctnew + (pctlt8 | SA)
   Data: tmort

REML criterion at convergence: -36.5

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.7633 -0.4832 -0.2103  0.5213  2.1232

Random effects:
 Groups   Name        Variance  Std.Dev.  Corr
 SA       (Intercept) 0.000e+00 0.000e+00
          pctlt8      3.794e-14 1.948e-07  NaN
 Residual             2.402e-03 4.901e-02
Number of obs: 20, groups:  SA, 5

Fixed effects:
              Estimate Std. Error         df t value Pr(>|t|)
(Intercept)  0.1879278  0.0258697 16.9999991   7.264 1.32e-06 ***
pctlt8      -0.0133328  0.0029575 16.9999942  -4.508  0.00031 ***
pctnew       0.0004126  0.0005311 16.9999998   0.777  0.44785
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
       (Intr) pctlt8
pctlt8 -0.694
pctnew -0.364 -0.282
convergence code: 0
boundary (singular) fit: see ?isSingular
```

Moose Population Reconstruction for the PG West area

Draft technical analyses

Jeffery Werner, Wildlife Ecologist, FLNRORD, Omineca

June 10, 2020

Background

Population counts reveal moose densities have dropped dramatically in recent years, prompting investigations into the role habitat changes play in moose population dynamics. The purpose of this exercise is to support analyses of population trend by linking historic vital rates inferred from density and composition surveys with estimates of concurrent habitat supply.

This is accomplished in three steps. Phase one is to construct a model of past population dynamics (population reconstruction). Step two is to characterise the landscape at key moments in time. Step three is to identify possible thresholds in habitat supply which mark the decline phase in moose numbers. The following is a brief account of the first step in a 'habitat threshold' analysis for the PG West moose survey area (southern Omineca).

We begin with an account of the data on hand. Stratified random block (SRB) surveys provide estimates of moose population size; however, these surveys are costly and conducted infrequently. For the PG West region population estimates are available for the following years: 1991, 1998, 2005, 2011, and 2016. This longitudinal dataset spans 25 years and anchors this population assessment.

Moose composition surveys are less intensive but are designed to provide detailed information on post-hunt sex ratios and calf recruitment. Composition data are available for most years spanning a 50-year period from 1972 to present. As we shall see, combining periodic population counts with annual proportions of sex and age allows us to project moose abundance, growth rate, survivorship and density, for various components of this population through time.

The purposes of models are to explore consequences of our assumptions of the behaviour of complex systems, and to test hypothesized relationships with predicted outcomes. The strength of any model however is also its weakness, and wise use necessitates acknowledgment of all assumptions. To that end, care is taken to address plainly the provisional statements that must hold true for one interpretation or another.

Key Assumptions

The following statements are assumed to be true for the duration of this analysis.

1. The influence of immigration and emigration on yearly estimates of population size are minimal.

2. Geometric growth, whereby successive changes in a population differ by a constant ratio, is appropriate for describing rates of change between empirical estimates of population density.

3. SRB and composition surveys are unbiased. Incorporating sampling error into the population parameters imparts greater realism at the expense of simplicity. Although we encounter on occasion patterns in the data (bias) which defy the most likely circumstances, error in measurements are assumed minimal.

4. Absolute numbers and rates of change are set by, and are a response to, changing environmental conditions. Regardless of the specific form of population limitation, moose numbers are ultimately determined by the quality and quantity of limiting habitat. Comparing trends in the abundance of moose populations with changes in the availability of habitat types is therefore a desirable endeavor.

Questions and Predictions

The contents of this document are but the first of several steps to understanding the cause of moose population declines. However, we benefit at this stage from explicitly identifying our operational questions and their implications. Possible outcomes of this analysis are noted, and some interpretation is given of what each possible result means in terms of basic theory or applied management.

The landscape change hypothesis predicts the moose population as a whole to behave in certain ways. First, because impacts of forest harvest (i.e., fragmentation, road density, reduced interior condition, loss of older age classes) may occur rapidly (e.g. 1 – 10 years) while forest regeneration always proceeds slowly (many decades), we expect changes in the carrying capacity of moose to be irreversible over short time periods. Moose numbers cannot therefore decline and then immediately bounce back. Observing such a pattern compels us to reject our working theory of moose population limitation. In other words, a concave pattern in time series of moose densities are permissible/consistent with our working hypothesis, but a convex pattern is not. During the early phases of our monitoring dataset (pre 1991) the finite rate of increase should be stable or increasing if food was a limiting factor and mature forest remained abundant; in later time periods we expect the supply of mature forest to become limiting, resulting in population decline (post 2000) because of intensified salvage logging (Langin and Eastman 1990). Only some intervention that greatly increases the supply of limiting habitat (e.g., habitat enhancement or ecological restoration) will yield increases in moose numbers.

Different age and sex cohorts rarely contribute equally to population growth. Males for example are often considered surplus, and the tolerable limits of skewed sex ratios that can be maintained in a stable population are considered to vary widely. Regressing annual recruitment and adult cow survival in year N_t respectively against population change at N_{t+1} will clarify the relative contribution of these components to moose trend. The outcomes of this exercise have important implications for subsequent analyses of habitat supply. For example, if population changes are caused by low calf survival, the full impact on population declines may phase in (be delayed) by up to 15 years corresponding to the natural mortality rate of the adult component. On the other hand, if the rate of increase is driven by cow survival, minimal delays are expected between the crossing of a critical habitat threshold and a shift in moose numbers from one stable state to another.

Lastly, where the limiting role of predation is acute, we expect changes in rate of change in the prey population to reflect the *total response* of the predator (i.e., the combination of functional and numerical responses). Graphical analysis of **r** against **N** will reveal the pattern of predator-mediated density dependence in the PG West moose population. This pattern may indicate a) the nature of the predator response, b) specific moose densities under which positive or negative population growth can be expected, and c) the potential for stable equilibria and unstable thresholds in moose numbers.

Methods of Analysis

Our aim is to reconstruct the historic dynamics of the PG West population over the period prior, during, and after its decline using SRB data to anchor interpolation of Calf:Cow:Bull ratios. Harmonising periodic estimates of abundance with annual surveys of population structure enable us to infer population composition through time. Some of the more common calculations described in this report are defined in Table 1.

Moose counts and ratio of calves and bulls to cows obtained from the survey reports (listed in the references) were entered into an excel database. D. Heard generously supplemented data from reports for historic composition for the southern Omineca region. A standardized survey-year was applied to each entry to account for mid-winter aerial surveys occurring in December of one year versus January of the next. Surveys were assigned the earliest possible winter-year, such that reports from January or February of year t were assigned to the previous year (t-1). Consistency in the year assigned to a count mitigates errors in the calculated annual rates of change.

Where population compositions are reported by management unit (MU) I determined overall Calf:Cow and Bull:Cow ratios (hereafter CC and BC) via weighted average based on the area of a MU proportional to its contribution to the PG West study area.

Population size was first converted to density. Although boundaries of the PG West survey region have changed little over time, standardizing moose abundance per km^2 minimises bias associated with changes to study area. This is relevant should the approach described here be expanded to other moose populations. Rates of change calculated from density estimates are identical to those using total population size.

Finite rates of increase were calculated for the entire population for the periods 1991-1997, 1998-2004, 2005-2011, and 2012-2016 and subsequently used to compute population density for each year between reference periods. CC and BC ratios were standardized from number-per-100 cows to number-per-1 cow and combined into a single ratio of adult females to everything else.

This ratio was applied to the population size to obtain a density for adult cows, and then individual CC and BC ratios were multiplied by cow density to get calf and bull density for each year. Proportional contributions of each cohort to the total population were calculated as a percentage, whose components must sum to one.

Having decomposed the population into cow, calf, and bull segments I determined lambda (λ) for each cohort. In rare cases where some or all composition data for a particular year were missing, I projected lambda across the missing interval to obtain annual density in keeping with the assumed pattern of geometric growth. Imputed densities were then used to complete the missing composition data. These imputations were rare and occurred in 5 of 47 years. The coefficient of variation (the ratio of the standard deviation to the mean) in the annual rate of increase of cows was determined for each of the key time periods to test for trends in the stability in annual population growth rate before and after the initial population decline.

To estimate annual adult female survival, I used the R-M (Recruitment – Mortality) equation (Hatter & Bergerud 1991; Table 1) to solve for **S**, using lambda for the adult female component of the population instead of lambda derived from the population as a whole. The R-M relationship assumes contribution of the sexes to overall numbers are balanced and, most importantly, stable over time. Inspection of CC and BC revealed high annual variation in population composition, warranting the calculation of population growth for the adult female component separately. Recruitment, here interpreted as the female calf component of the entire female population, was set to 50% the calf:cow ratio by presuming sex of calves were balanced.

By using the R-M equation in combination with mid-winter survey data we must assume that CC ratios approximate annual recruitment, and that calf survival is equivalent to adult survival for the remaining months of the year. This is almost certainly not the case: calf survival through the winter is not likely to be very high. Inflated recruitment values (because calves are counted with 4-6 months left in the year) algebraically deflates cow survivorship. To account for this, I adjust the CC ratio by projecting calf survival from mid-winter to the following spring (i.e., a calf's year-one birth date). Recent survival estimates of collared calves 8 months to 1 year range from 45% to 80%. I applied a mean calf survivorship for the months 8-12 of 0.7 (n=3 years) reported for PG South (See Table 7 Kuzyk et al. 2019) to attain more realistic estimates of annual recruitment and, therefore, of adult cow survival.

I calculated instantaneous rates of increase (r) of the entire population for the four time periods and graphed them against population density to evaluate the density dependent relationship. Patterns of per capita increase were evaluated against those predicted by predator-prey theory.

Accurate surveys of moose population size began in 1990. Prior to this moose harvest management was based on yearly aerial survey data aimed at monitoring population composition. I took advantage of the population data obtained from 1972-1990 to model expected adult female survival using an arbitrary but stable lambda of 1.02. Discussion with moose biologists working during this time period and/or familiar with this historic data indicate that the PG West population was considered stable or increasing during that time. The chosen rate of increase is conservative and reflects this assumption.

Results

Inspection of the density and of the finite annual rate of increase of the moose population reveal important trends in abundance (Figure 1). To the extent that changes in habitat supply are ultimately responsible for changes in moose numbers, the observed convex curve indicates a breach in the supply of limiting habitat. An analysis linking abundance with the habitat of this species must therefore rationalise and account for this important shift.

If the principal driver of landscape change is industrial forestry, we conclude that logging activities historically benefited moose through provision of a specific type of limiting habitat, but that another form of habitat became limiting as its supply was diminished with forest harvest. If this parabolic curve is to be explained by landscape change, we acknowledge that conditions responsible for the increase of moose numbers are different from the conditions responsible for their decline. It is our task therefore to identify thresholds in habitat supply which may be responsible for such a pattern. Such logic underpins the validity of this analytical exercise.

Using the calf and sex ratios from 1972—present (Figure 2) population reconstruction is possible for each cohort (Figure 3). The most dramatic changes in abundance during the increase and decline phases are observed for the adult female component. Indeed, the overall proportion of the population composed of adult females has steadily increased throughout the study period (Figure 4). This observation warrants further investigation because it determines which analytical approach should be applied to the habitat assessment. If population declines are most sensitive to adult mortality, habitat supply can be assessed concurrent to population change. However, if recruitment dynamics (calf component) are driving observed patterns we must consider applying time lags to account for the delayed impact of calf survival on population size. Regression of per capita rate of increase (r) and mean adult cow survival reveals near perfect correspondence ($r2=0.98$; Figure 5a). This constitutes strong support for annual adult cow survival being the principle driver of per capita population growth. However, calf recruitment also correlates significantly to rate of increase (Figure 5b). With only four time periods (estimates of r) with which to associate these two variables, we cannot easily separate the importance of one versus the other. Multiple linear regression indicates that both independent variables are likely to influence population trend (Table 2). Introducing 4-5-year time lags effectively breaks the relationship, and yields non-significant regression models.

Factors such as amount or quality of available habitat may drive fluctuations in both strength of competition among individuals and their vulnerability to predation. Because the degree of fluctuation in population change often reflects fluctuation in the strength of population regulation, I determined the CV associated with lambda for adult females over the relevant time periods. The extent of inter-annual variability in cow ƛ in relation to the mean of each census period has dropped steadily since 1990. In addition to the observed decline in annual rate of change, the PG West population has shifted to a low-variance state characterised by compressed interannual variability (Figure 6a). This compression is visible in time series (Figure 6b). There is no statistical explanation for this pattern; unless the accuracy of composition surveys has improved drastically after 2005, we must conclude that this low variation is linked to mechanisms limiting population size. Quantitative analyses exist to decompose variance associated with annual population growth into environmental and demographic forms of stochasticity. However, this is outside the present scope of work.

Trends in adult female survival were variable throughout the 47 years but generally exhibited a hump-shaped trend over time (Figure 7) consistent with the period of increase and decline in moose numbers (Figure 3). The calculation of survival is sensitive to the form of population increase (Figure 7) used in the R-M calculations. Based on the variable contribution of calves and bulls between years (Figure 2) I advocate using lambda for cows only. This requires access to sex and age ratios for population reconstruction. The highest and most realistic adult cow survival rates were achieved using an adjusted estimate of recruitment which incorporated projected losses of calves during late winter (8 to 12 months of age).

By summarising cow survival between SRB survey intervals we observe an abrupt shift in the mean annual rate of mortality from 2005 onwards (Figure 8). Our analysis confirms that changes to PG West moose abundance are most sensitive to a combination of adult cow survival and calf recruitment coinciding with the time intervals used to calculate r between SRB surveys; linking habitat supply to moose abundance is therefore best accomplished with minimal time lags.

The relationship between cow survival and calf recruitment with population change could be further understood using a matrix population model to explore proportional changes in r resulting from a 10% change in each demographic parameter. Analyses of *sensitivity* and *elasticity* remain useful options once the habitat variables have been defined. An alternative is to apportion r to the female component of the population, and then use regression analysis to estimate the relative importance of survival vs. recruitment to the adult female rate of increase. This increases the number population points from 5 SRB estimates to 26 partial imputations. Because these imputations are based on yearly surveys of composition, I see no reason why this type of analysis would breach statistical assumptions of independence.

As density dependent processes are generally believed to account for population behaviour, I analysed the pattern of instantaneous increase (r) in relation to population density. Moreover, because increased levels of predation are suspected to have caused population declines, I compared these data to patterns predicted by predator-prey theory (Figure 9). Patterns of increase across a range of historic moose densities are reminiscent of the Type III predator response, whereby prey increase is held low by predators at low prey density (Figure 10). A lower stable equilibrium point may prevent local extirpation. However, positive population growth is unlikely to achieve abundances associated with historic carrying capacity. This so called ‘predator pit’ hypothesis predicts that moose recovery will be slow and may even require habitat modification to supplement the supply of refuge habitat. Ecological restoration may shift the pattern in Figure 9 upwards by improving the ability of moose to avoid predator encounters. I consider the contents of this paragraph to be highly uncertain. Until analysis of other local populations corroborate this pattern of density dependence, these results are not addressed further.

Conclusion and Next steps

Present efforts to test the landscape change hypothesis with contemporary GPS collar data suffer a major challenge: the collapse in moose abundance has already happened. We have no clear way of knowing if post-decline survival hazard functions are similar to those that drove moose from one apparently stable state to another. It is for this reason that population reconstruction has value. This report provides a method by which to quantify habitat-abundance relationships before, during, and after the critical decline in the PG West population. Reconstructing numerical density for separate components of the population enables us to test hypotheses regarding demographic sensitivity to vital rates, proximate drivers of population change, potential predator-prey dynamics, and the ultimate response of this important herbivore to anthropogenic stressors. As an exercise in proof-of-concept we succeed in demonstrating that population reconstruction can be accomplished with data derived from routine monitoring.

Two tasks remain. The first is to proceed with phase two of the habitat threshold analysis (as described at the outset). Completing this will clarify the extent to which loss of limiting habitat has resulted in the depression of moose numbers. By quantifying change in habitat coinciding with the population collapse we better understand what limits moose numbers today while deriving an explicit recovery target for those wishing to restore numbers to former densities through habitat enhancement.

The second task is to expand population reconstruction to other survey regions in BCs central interior. This will help corroborate findings from PG West and clarify whether observed density-dependent relationships reported here are part of a larger regional phenomenon.

Tables & Figures

Table 1: Common calculations used in the modelling and reconstruction of the PG West study population.

Measure	**Symbol**	**Calculation**	**variables**
Lambda (finite rate of increase) from census data	λ	$=(N_{t+1}/Nt)^{(1/t)}$	**N**=population density (#/km^2) **t**=years between measurement
Lambda from recruitment & survivorship data	λ	=S/(1-R)	**S**=survival **R**=recruitment
Instantaneous rate of increase	***r***	$=Log_e(\lambda)$	**Log_e**=natural log, to the base of the constant 2.71828
Female recruitment (proportion of the female calves in the female population)	**R_f**	=(CC/2)/(100+CC/2)	CC=number calves per 100 cows
Density of adult cows from SRB & composition data	**N_c**	$=N_p/(1+C:C+B:C)$	N_p=density of total population (#/km^2) C:C=number calves per single cow B:C=number bulls per single cow
Annual adult female survival	**S_f**	$=\lambda_f^{1/(1-C:C/2)}$	**λ_f**=annual rate of increase for the adult female component of the population
Population density calculated from lambda & density of earlier time period	**N_{t+1}**	$=N_t(\lambda)^t$	Nt=moose density from an earlier time period t=number of years between estimates

Table 2: Descriptive statistics and multiple linear regression of calf recruitment and adult cow survival on per capita instantaneous rate of increase of the PG West moose population 1990 to present. Positive linear correlation is found between combined cow survival and recruitment with the overall rate of increase. Sample sizes do not permit separating the significance of these two variables.

Descriptive Statistics

Variable	Mean	Std Dev.	N
r	-0.022	0.113	4
Cow Survival	0.860	0.075	4
calf:cow	0.359	0.073	4

Pearson Correlations

	r	Cow Survival	calf:cow
r	1.000	0.988	0.993
Cow Survival	0.988	1.000	0.968
calf:cow	0.993	0.968	1.000

Significance for Correlations

	r	Cow Survival	calf:cow
r	-	0.012	0.007
Cow Survival	0.012	-	0.032
calf:cow	0.007	0.032	-

Summary

R^2	R	Adj. R^2	S.E. of Estimate
0.998	0.999	0.993	0.010

ANOVA

Source	Sum Sq.	D.F.	Mean Sq.	F	Prob.
Regression	0.038	2	0.019	204.384	0.049
Residual	0.000	1	0.000		
Total	0.038	3			

Regression Coefficients

Source	Coefficient	Std Error	Std Beta	-95% C.I.	+95% C.I.
Intercept	-0.905	0.151		-2.828	1.017
Cow Survival	0.661	0.295	0.438	-3.086	4.407
calf:cow	0.878	0.302	0.569	-2.959	4.716

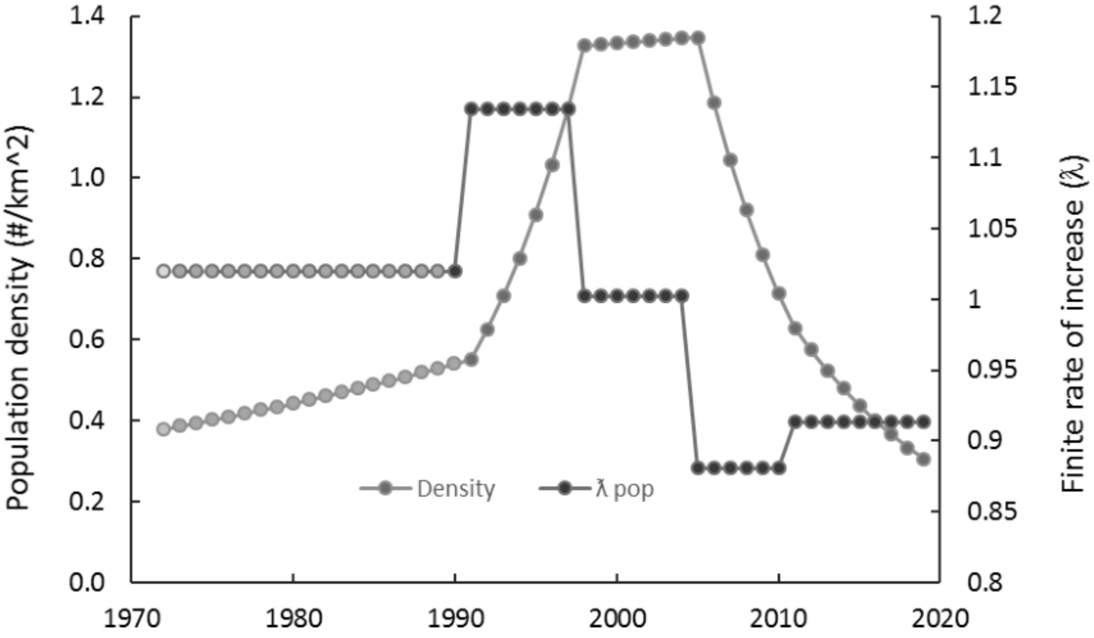


Figure 1: Density projection & rate of population change (all ages & sex combined) for the period 1991-2019 (dark circles) based on SRB survey data; Light circles (1972-1990) are the back-casted density estimates assuming constant lambda of 1.02.

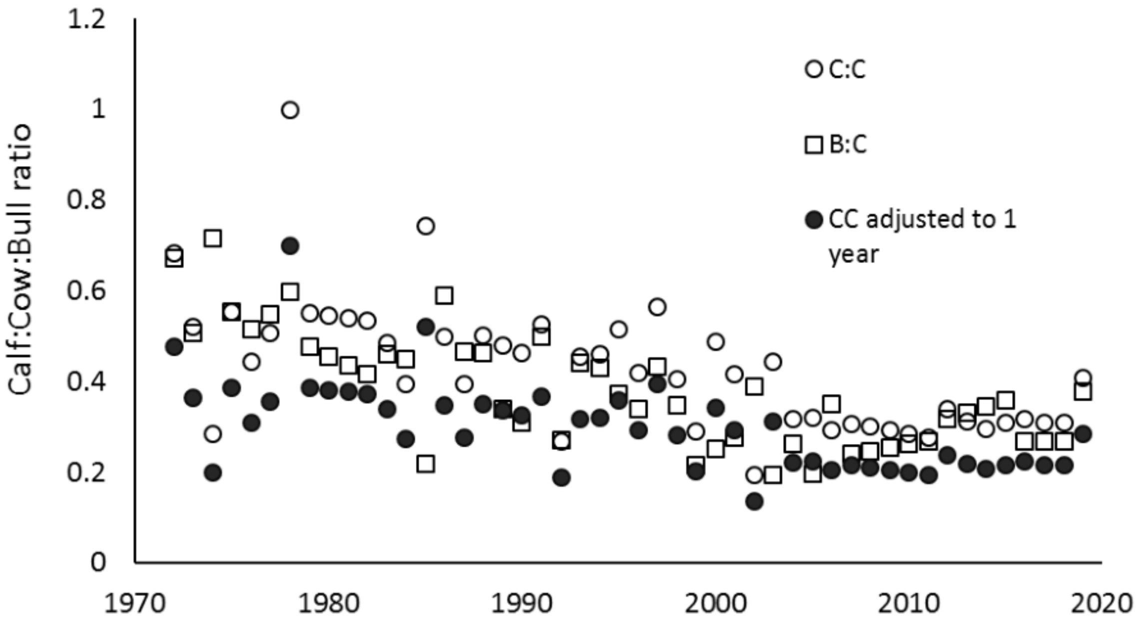


Figure 2: Calf:cow (open circles) and bull:cow (squares) ratios from mid-winter composition surveys, and calf:cow estimates adjusted to one year (black circles; incorporating late winter mortality of 0.3).

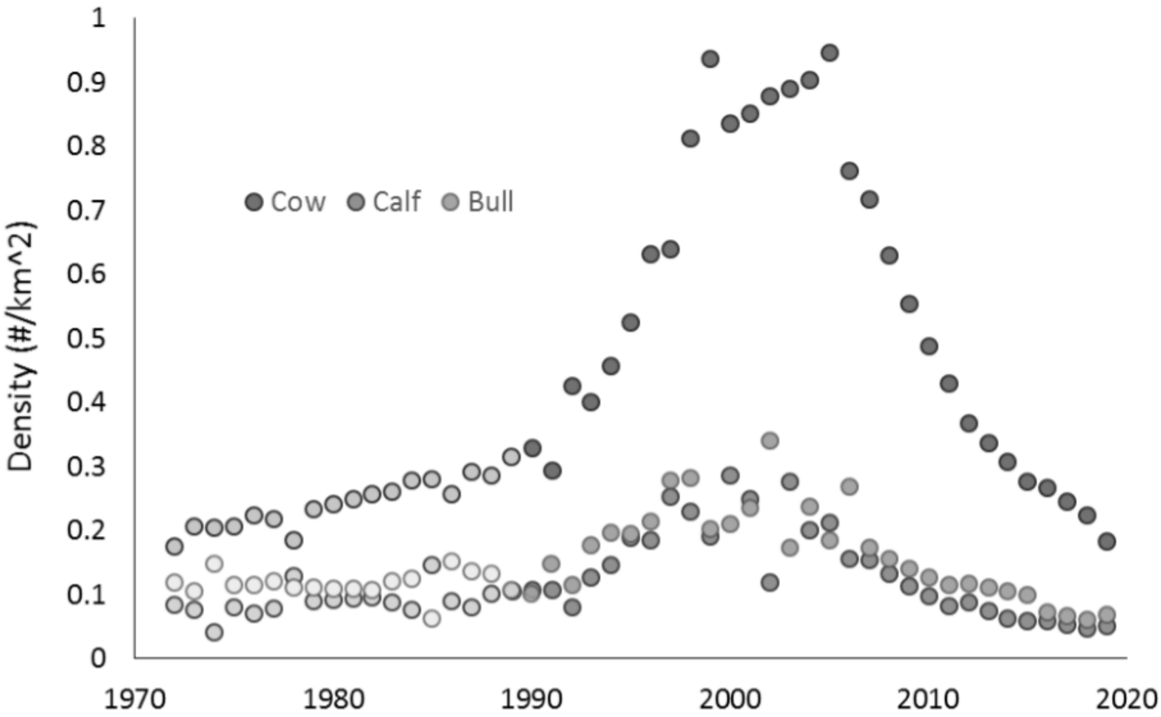


Figure 3: Density estimates for each component of the population. Light circles (1972-1990) are based on an arbitrary stable lambda of 1.02 in combination with historic composition survey data. Dark circles represent lambdas calculated from SRB count data and annual calf:cow:bull ratios.

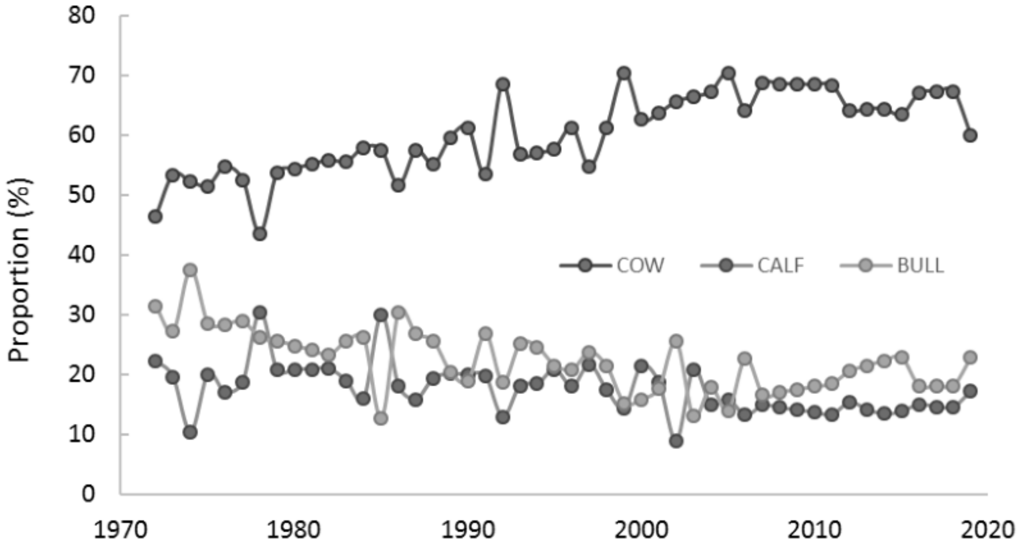


Figure 4: The composition of the population over time as a percentage of total density. Proportions are adjusted for annual recruitment of calves to one year. All three estimates sum to 1 for a given year.

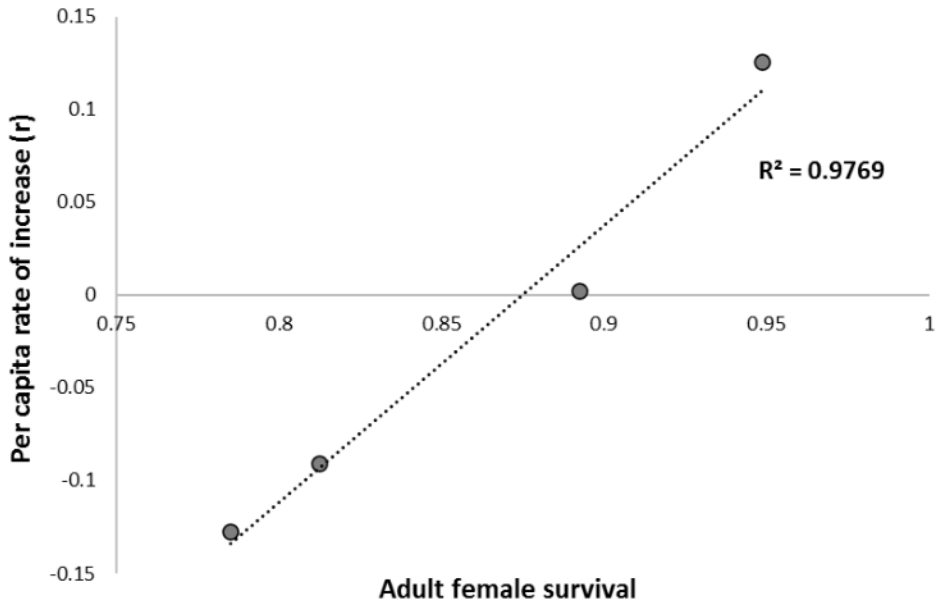


Figure 5a-b: Correlation of the annual population growth rate (r) and mean annual adult female survival (above) versus annual mean calf recruitment (CC; below) for the PG West population for the period 1991 to present.

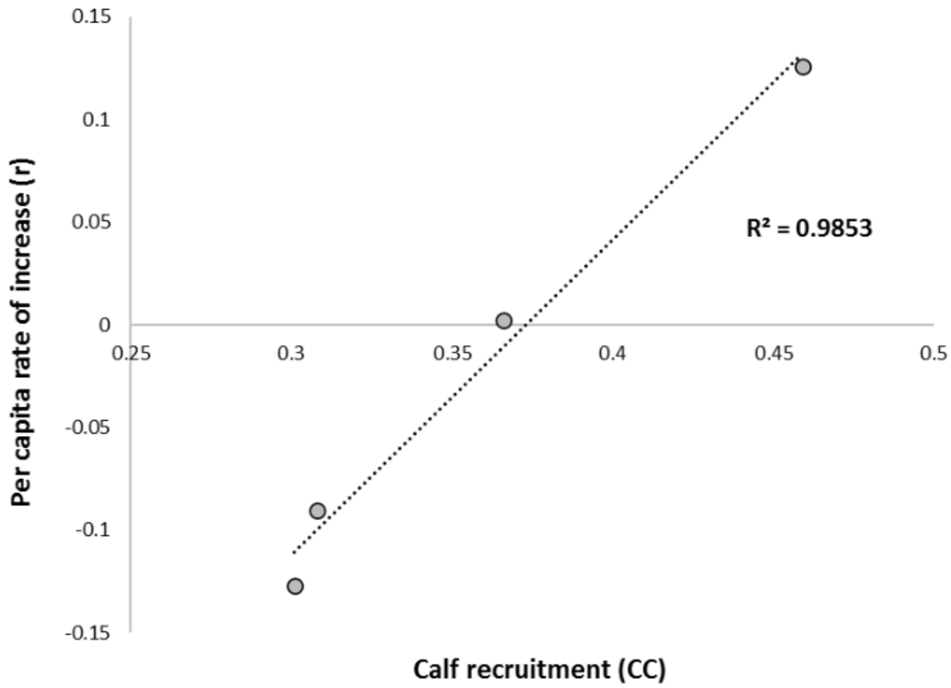


Figure 6a: A declining trend in the coefficient of variation (relative standard deviation) of the finite rate of increase (ƛ) for the adult female component of the PG West moose population over time between census intervals. The first data point (1972-1990) should be interpreted with caution as annual rates of population change are assumed an arbitrary mean of 1.02.

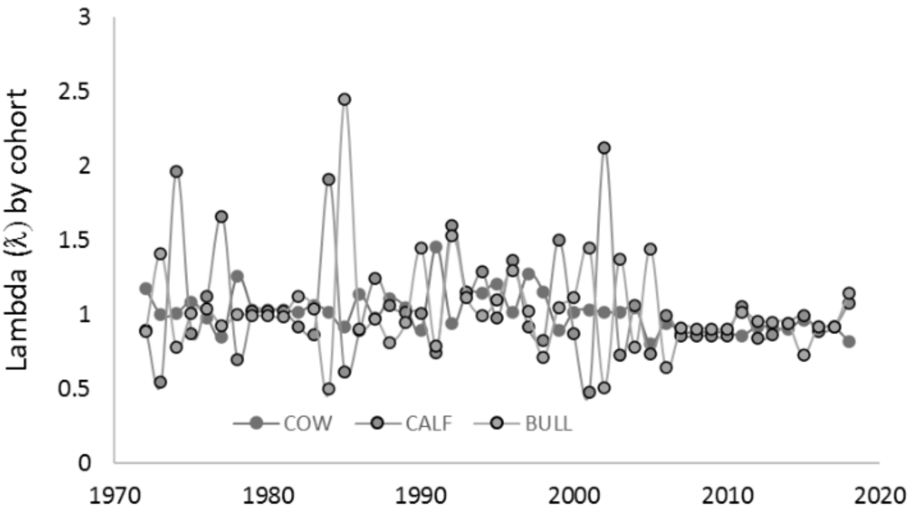


Figure 6b: The finite rate of increase (ƛ) different components of the PG West moose population over time. Data for the period 1972-1990 are modelled using an arbitrary total population lambda of 1.02, while those from 1991-present are based on lambda calculated using empirical SRB information.

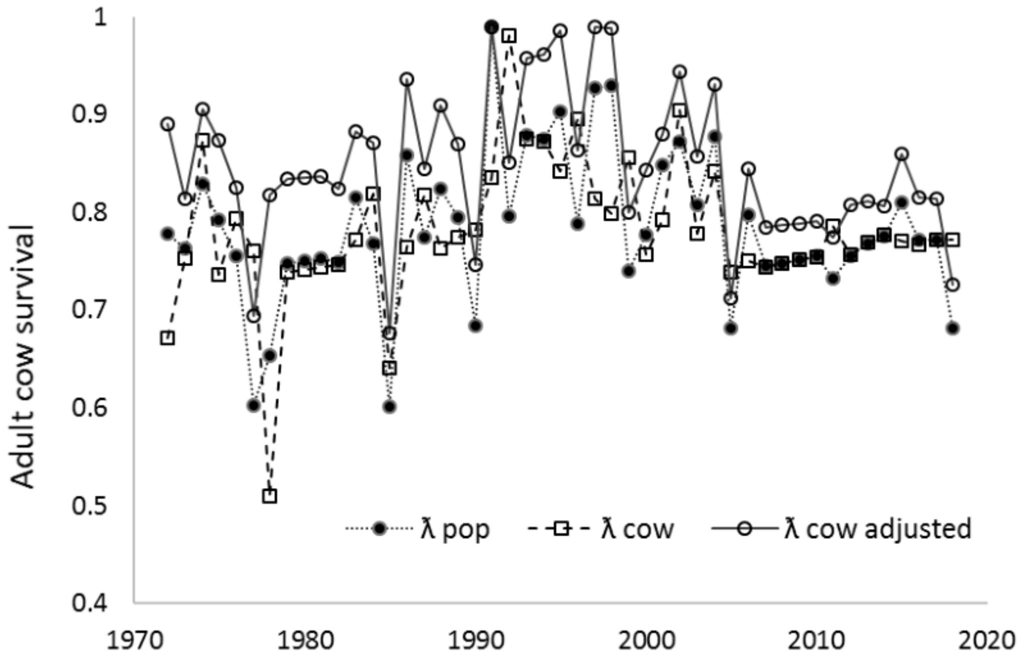


Figure 7: Comparison of adult cow survival calculations using lambda for the entire population (dark circles), lambda derived for the female component only (open squares), and from adult female lambda with female recruitment adjusted to account for late winter losses (female cc ratio x 0.7).

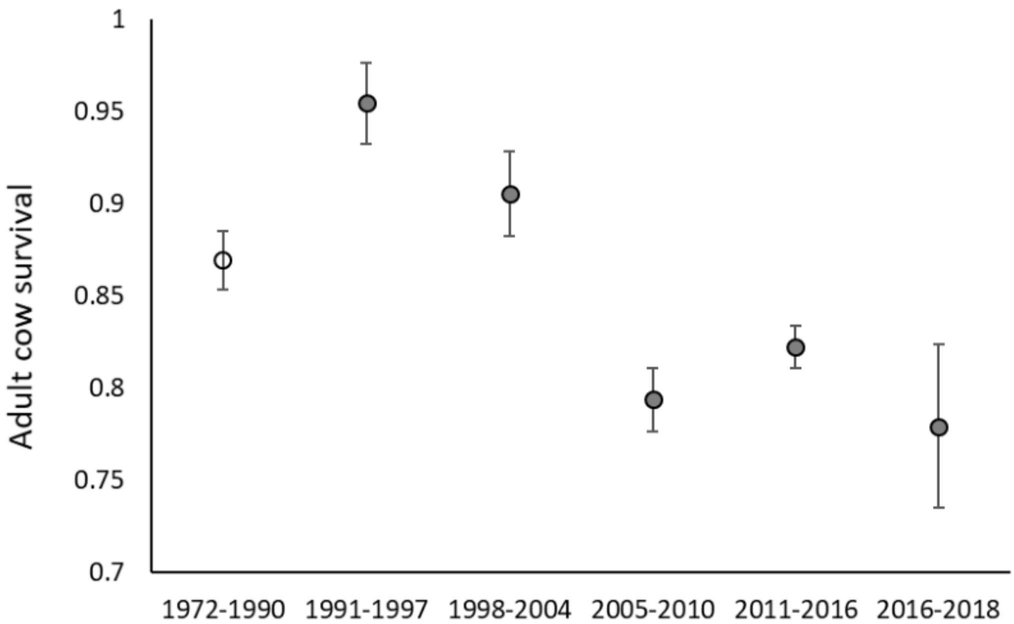


Figure 8: Annual adult cow survival rates calculated using R-M equation where Survival= ƛ(1-R). R=recruitment=proportion of female calves in the female population. ƛ=finite rate of increase for the adult female component of the population. Survival for the period 1972-1990 (open circle far left) is uncertain and was calculated using an arbitrary population growth rate (all sexes, ages combined) of 1.02.

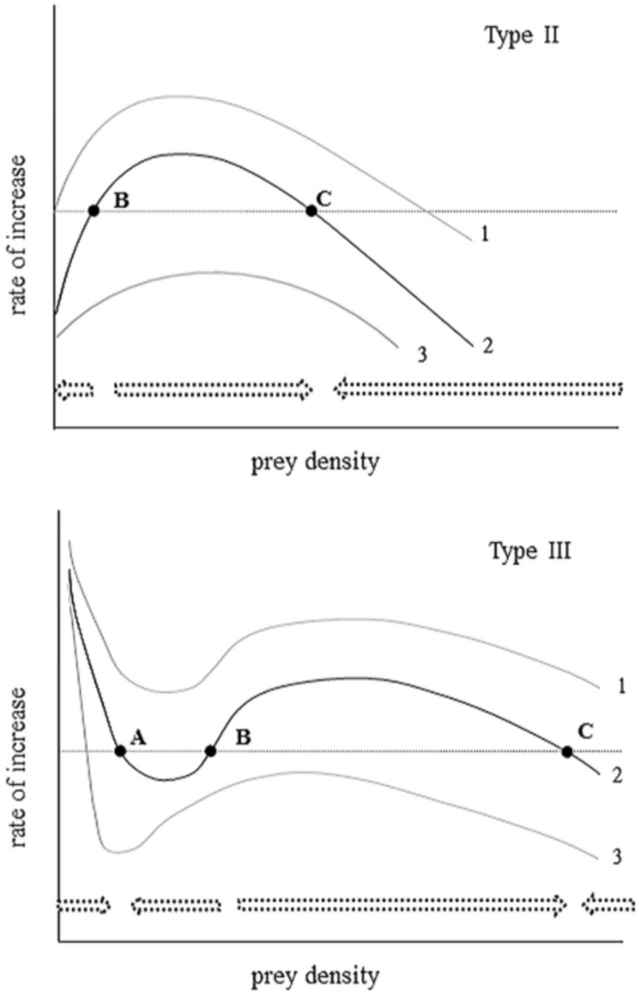


Figure 9: An illustration of the instantaneous rate of change for a prey population experiencing varying levels of Type II and Type III predation. Arrows represent direction of projected population change relative to stable equilibria (A, C) and an unstable boundary threshold (B). Curves 1 and 3 represent different levels of predation rate (1 = lowest; 3 = highest). Key distinguishing features for a Type II is for declining prey population growth at low prey density, but for Type III a lower stable equilibrium results from positive population growth at low numbers.

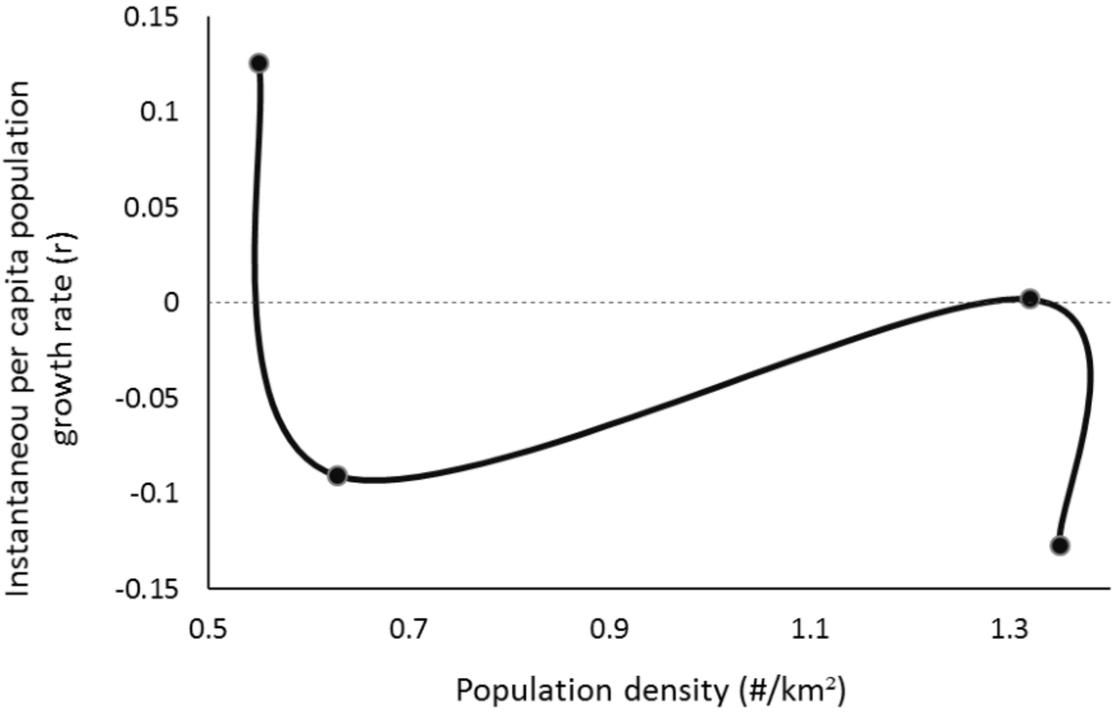


Figure 10: The instantaneous rates of population increase for PG West moose plotted against spring population density. This relationship is consistent with a 'predator pit' whereby type III predation depresses density dependence at low to moderate population size. Habitat loss or modification is predicted to reduce refuge from predation, thereby exacerbating declines and inhibiting recovery.

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An Approach for Estimating Moose Carrying Capacity based on Browse Forage

Doug Lewis – July 14, 2020

Goals/Objectives

1. Estimate moose carrying capacity by WMU based on available browse
    - Difference between expected and observed moose #'s gives us an indication of relative impact of population-related factors (predation, hunting) and habitat change.
    - Improve how we communicate and manage user expectations (hunters/guide-outfitters) and manage with First Nations
    - Consider how different management options alter moose numbers (GAR Orders, Mtn caribou mgmt, TSR)
2. Incorporate effects of climate change on moose distribution and available browse.
3. Reduce subjectivity and improve transparency compared to expert-based habitat capability/suitability ratings schemes.

Calculating Moose Carrying Capacity from Available Browse Estimates

Area Capable Winter Range	**Browse Yield**	**Available Browse**	**Total Moose Days**	**Moose Carrying Capacity (# Moose)**	**Carrying Capacity Density (#/Km^2)**
Riparian Wetland Deciduous Cutblocks & openings	50Kg/Ha 100Kg/Ha 100Kg/Ha Varies by age and climate	Multiply by 0.5 assuming 50% browse utilization	Divide by 5, assuming moose require 5Kg/ha/day	Divide by 210 – assumes moose use browse forage for 210 days/Yr.	Divide by Km^2

Telfer, E.S., 1995. Moose range under pre-settlement fire cycles and forest management regimes in the boreal forest of Western Canada, Alces, Vol 3: 153-165

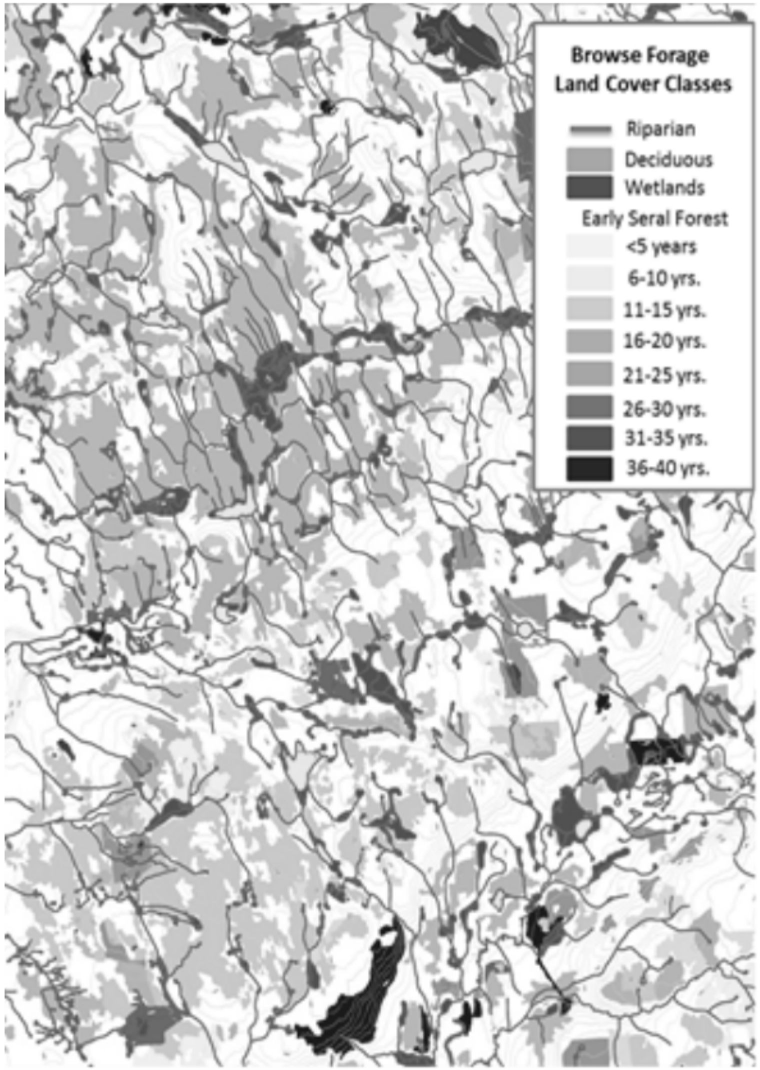
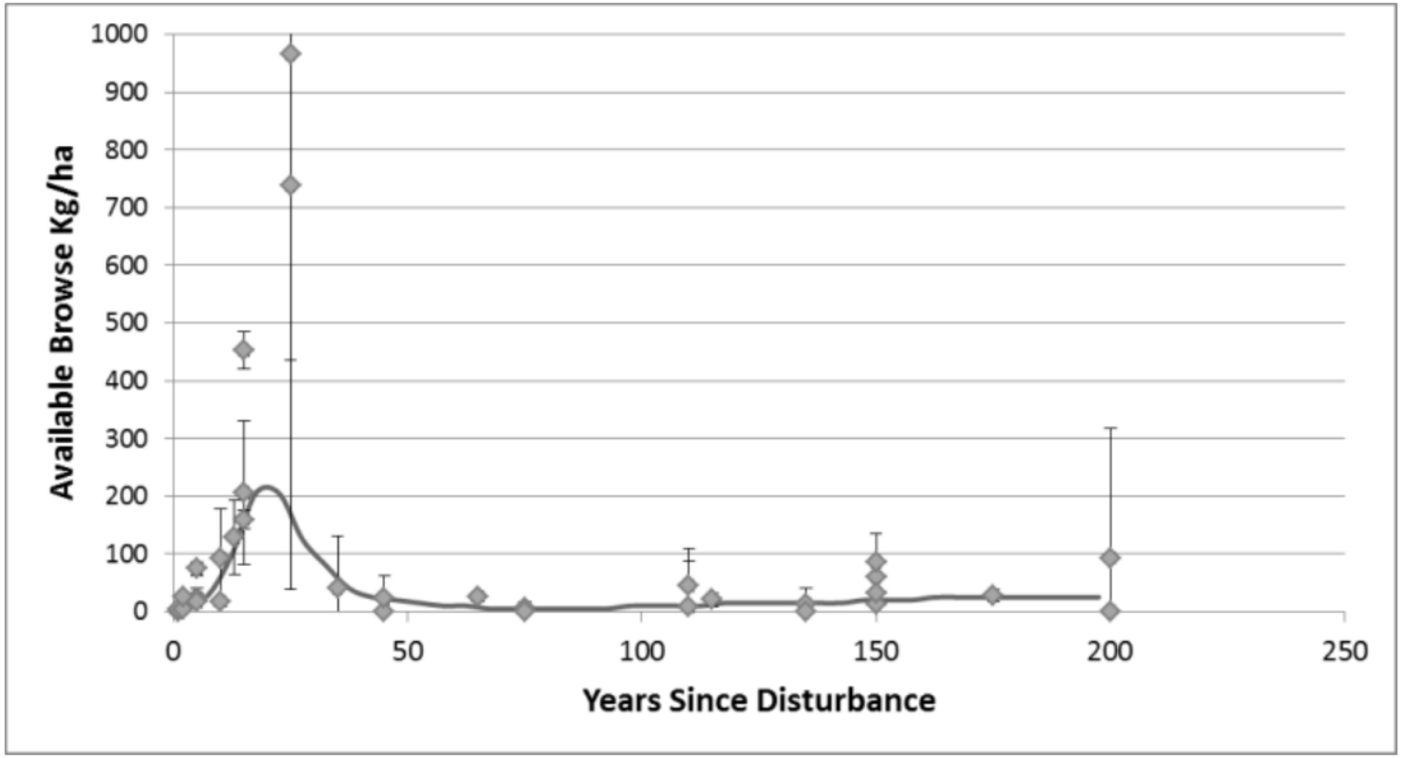


Figure 7. Land Cover Classes used to characterize moose browse forage sources.

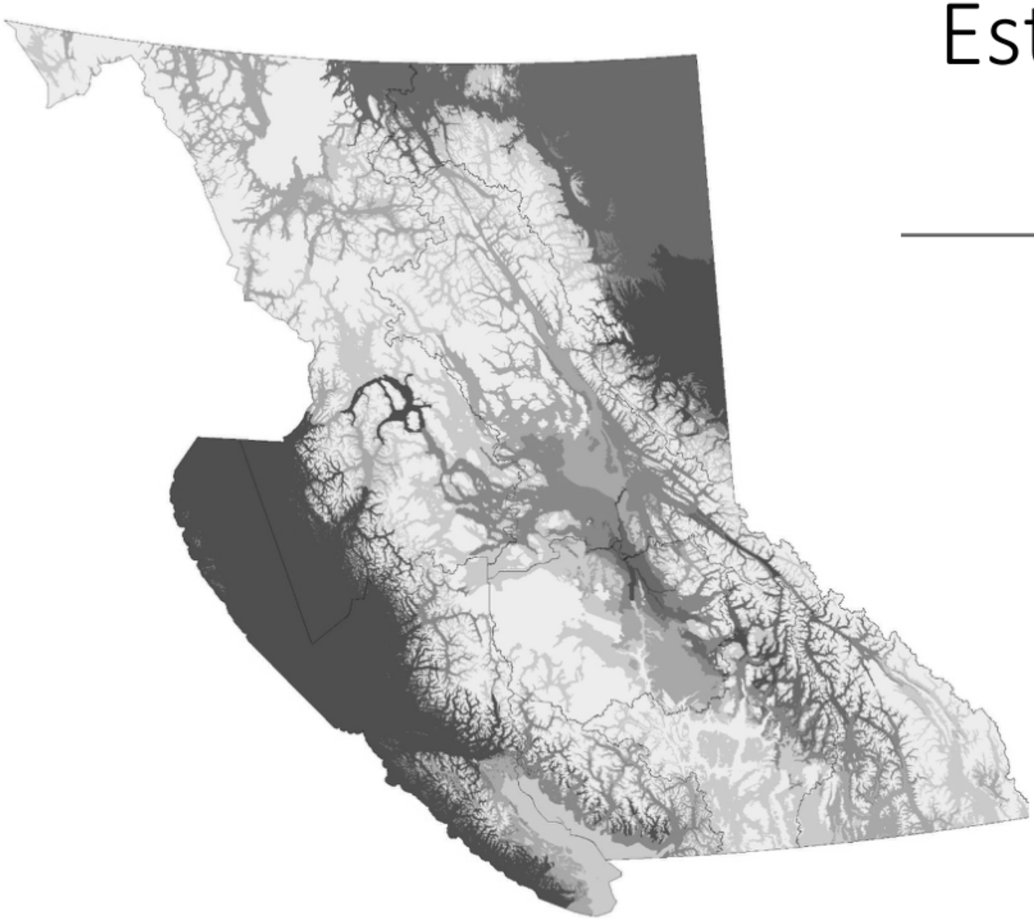
Different Forage Sources

- 'Static' Habitats – riparian, self-sustaining deciduous forest >30% deciduous) and wetland habitats
- 'Dynamic' habitats - disturbed sites (harvested areas, wildfires) browse availability varies spatially and temporally

Browse Production and Time Since Disturbance in Conifer Stands



- Standard relationship based on studies of moose browse biomass in ecosystems that are highly productive for moose
- Curve represents 'optimal' browse levels in disturbed stands.
- Biomass will vary considerably based on ecosystem productivity and will need to be adjusted accordingly



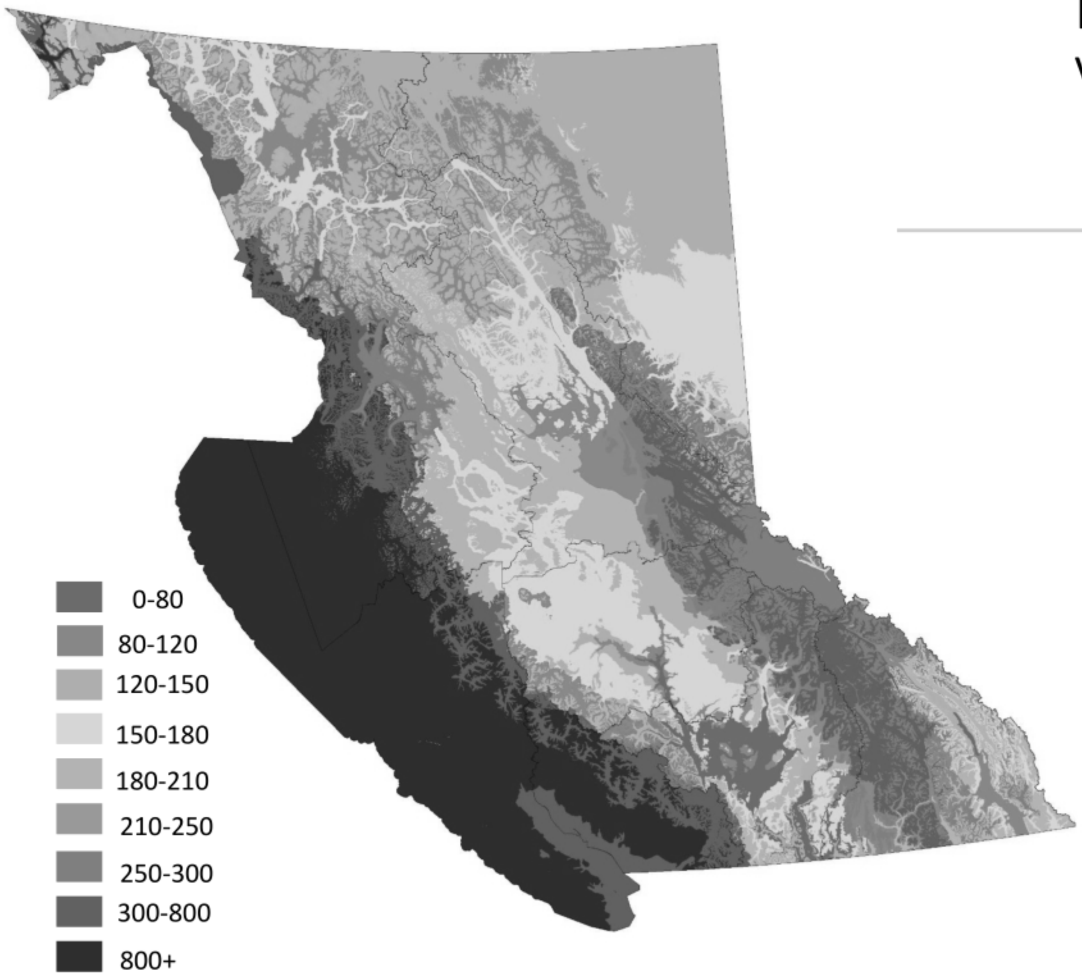
Estimating Deciduous Browse Productivity

Browse Productivity Index (BPI)- an index of the potential to produce deciduous moose browse biomass on disturbed sites

BPI= Productivity x Occurrence

Productivity - describes the potential for <u>mesic</u> sites to produce deciduous browse biomass

Occurrence – refers to how likely a browse species assemblage will occur



Patterson's (1956) Climate Vegetation Productivity (CVP) Index

$$CVP = \frac{Tv \times P \times G \times E}{Ta * 12}$$

Tv = maximum monthly (July) temperature (°C)

P = mean annual precipitation (mm)

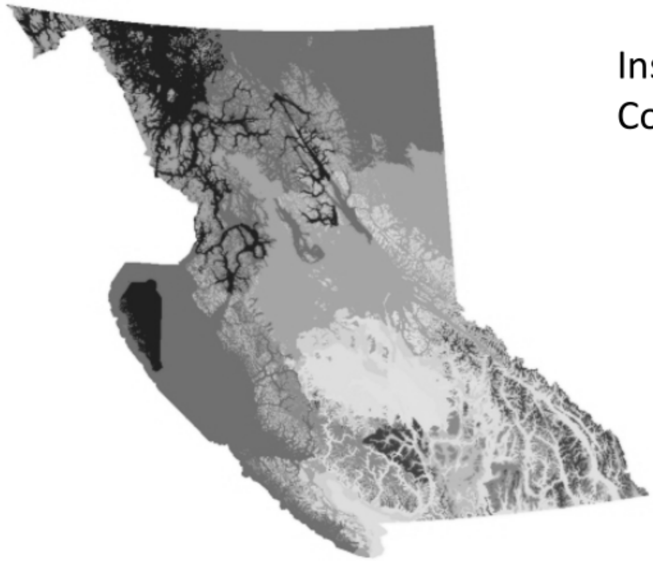
G= Growing Months (>6°C and monthly precipitation >2x temperature)

E = Insolation coefficient (mean annual solar radiation at the pole expressed as percent of area in question)

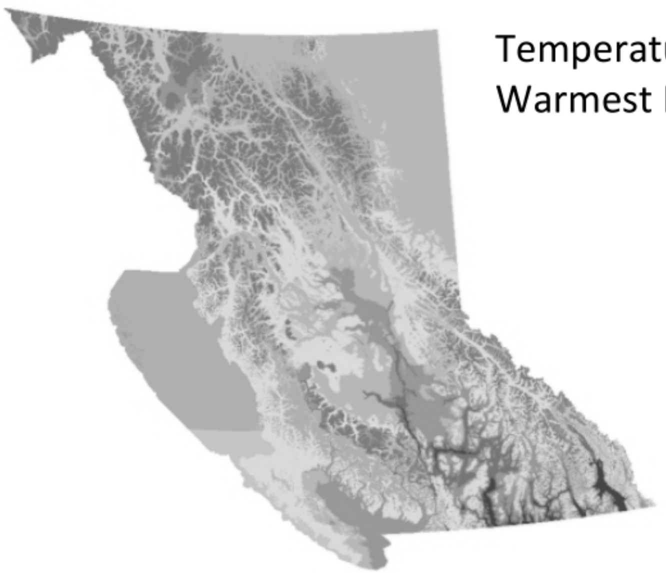
Ta = temperature differential (difference between warmest and coldest month

Derived based on ClimateBC data for average period 1980 -2010 summarized at random locations by Biogeoclimatic subzone

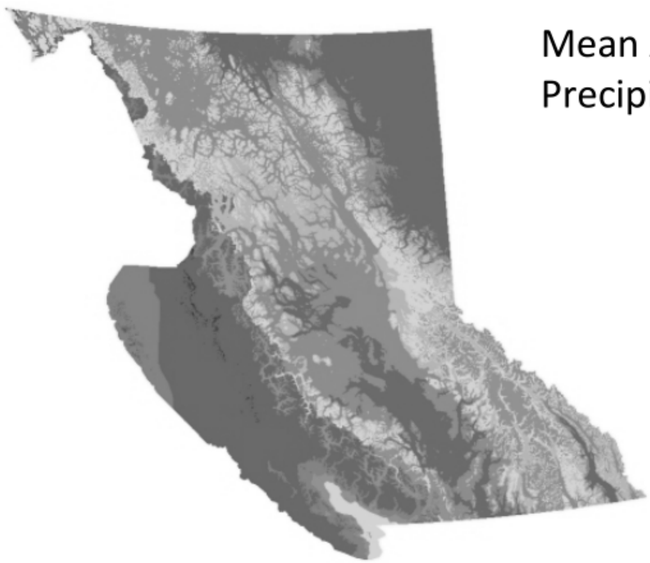
Growing Months



Insolation Co-efficient

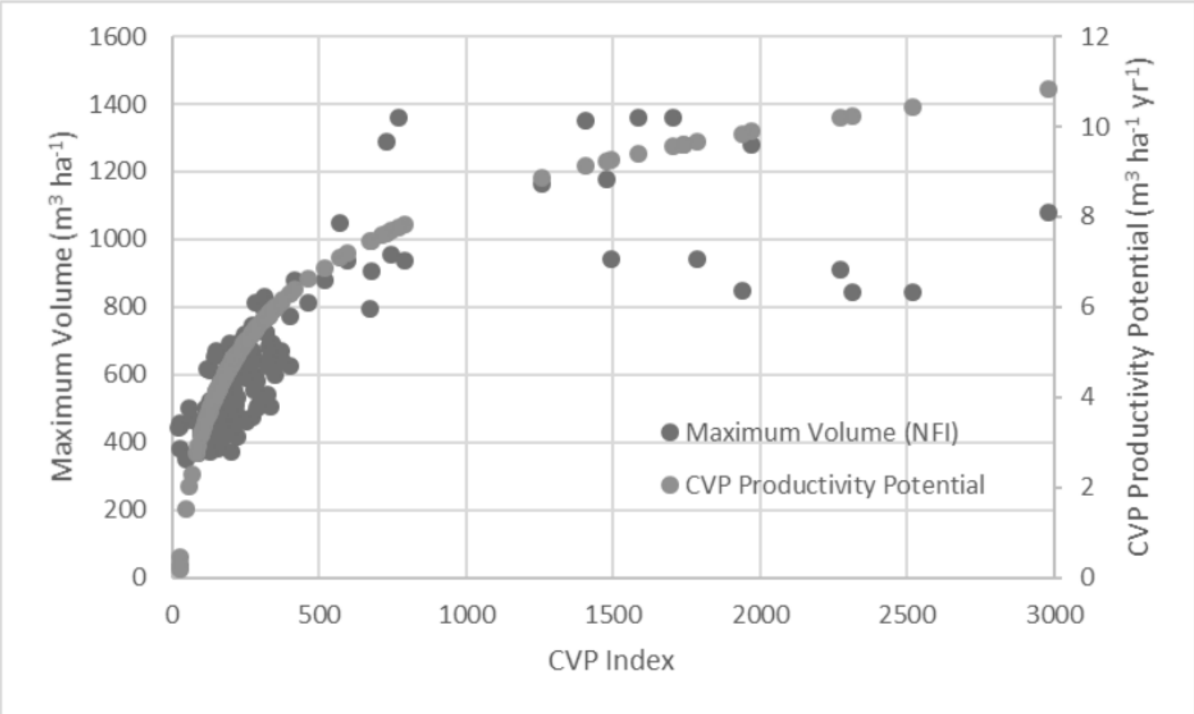


Temperature of Warmest Month



Mean Annual Precipitation

Productivity Potential (PP)

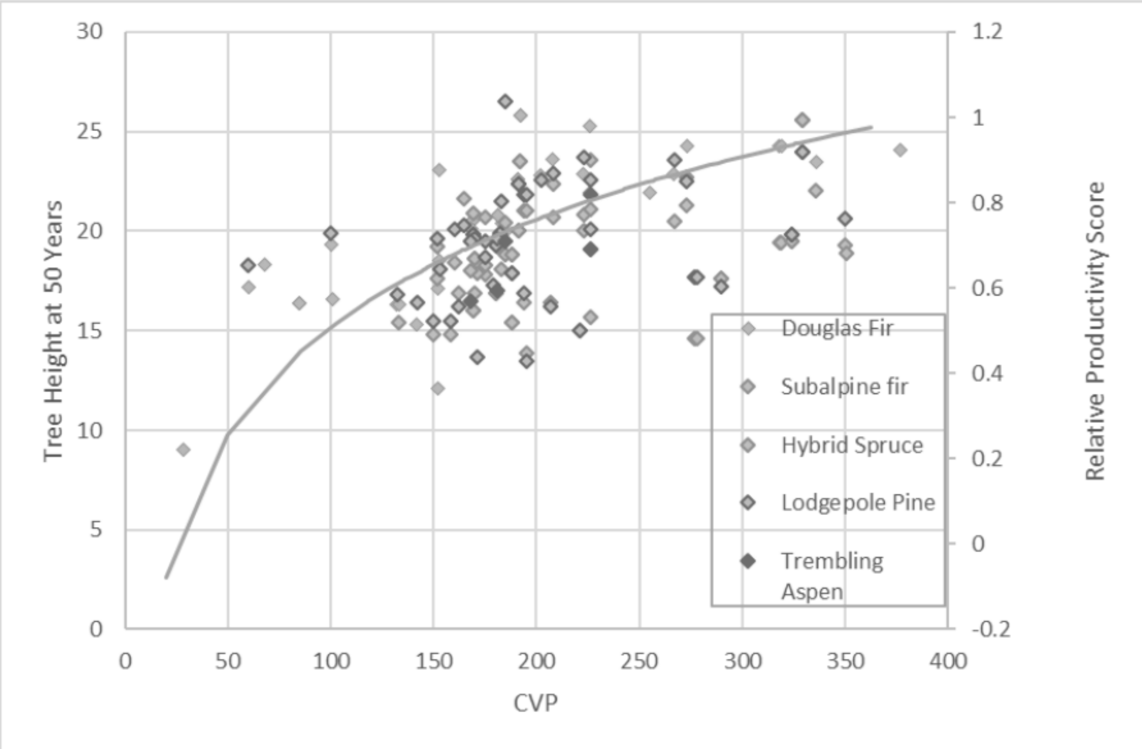


- Based on CVP – a standard relationship is applied to estimate potential productivity (m³/ha/yr)

$$PP=5.20\ Log(CVP)-7.25$$

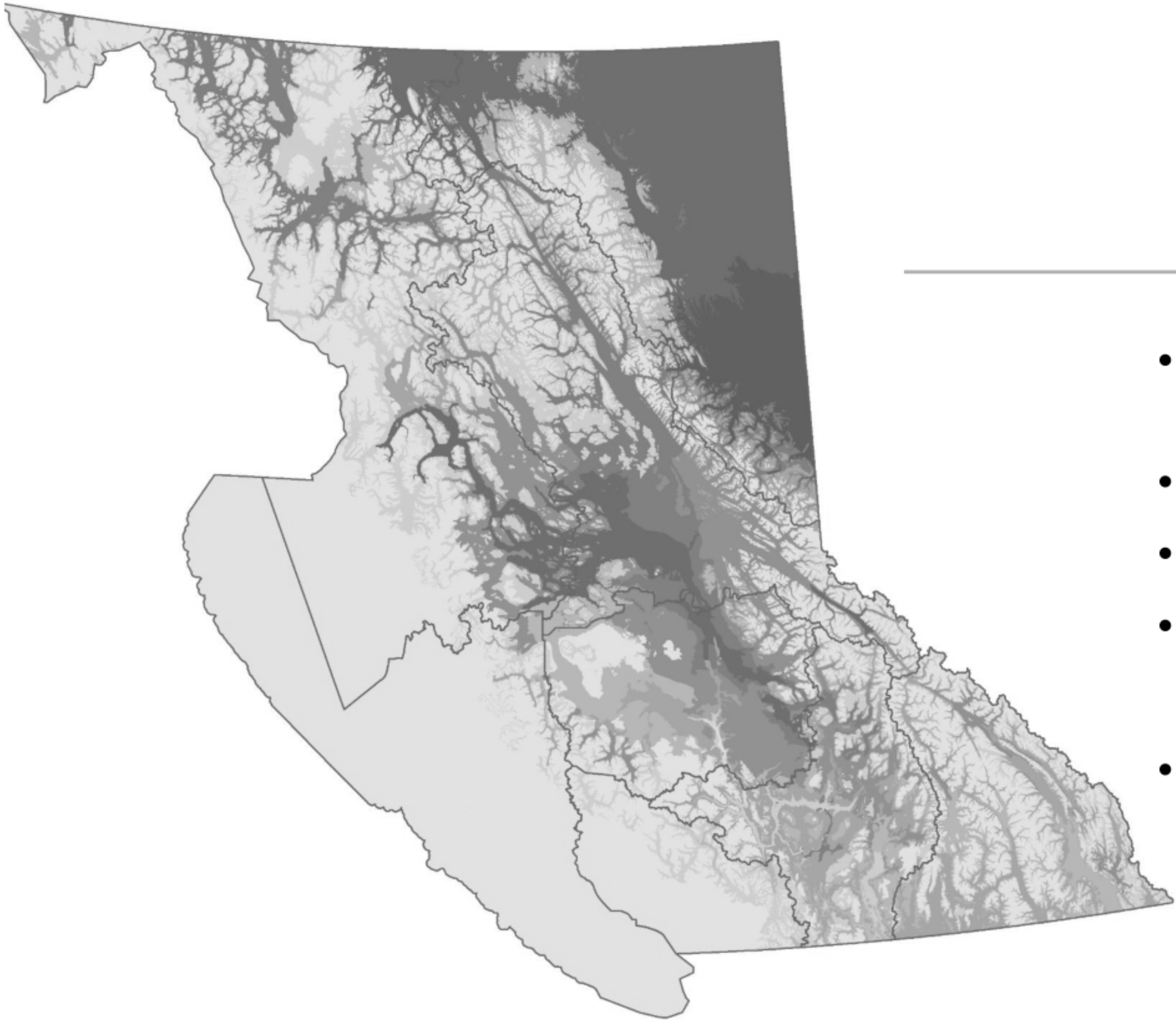
- Aligns well with estimates of actual maximum forest volume from inventory data for forested Biogeoclimatic subzones
- CVP values <500 generally found through most of BC (except Coast)
- Standardized score (0-1) used based on PP=6, CVP up to 500

Relationship to Site Index



Comparison of average Site Index estimates for different tree species on zonal sites to CVP Index values for that Biogeoclimatic subzone.

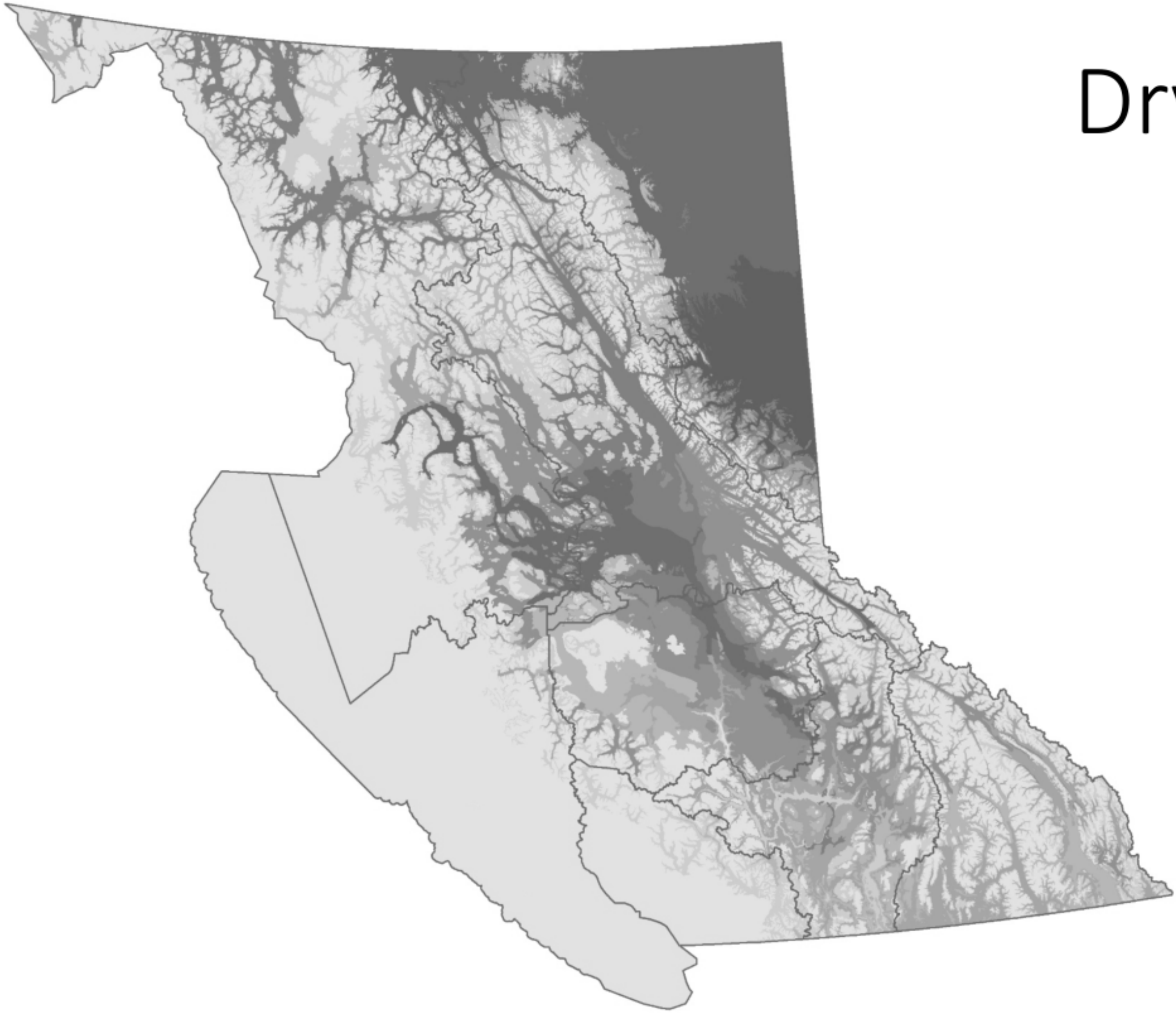
- Site Index primarily based on height of conifer tree species
- Generally aligns with CVP
- Deciduous largely associated with excess of precipitation over potential evaporation- Site Index may overestimate productivity for deciduous in drier BGC subzones where conifers grow.



Browse Species Occurrence

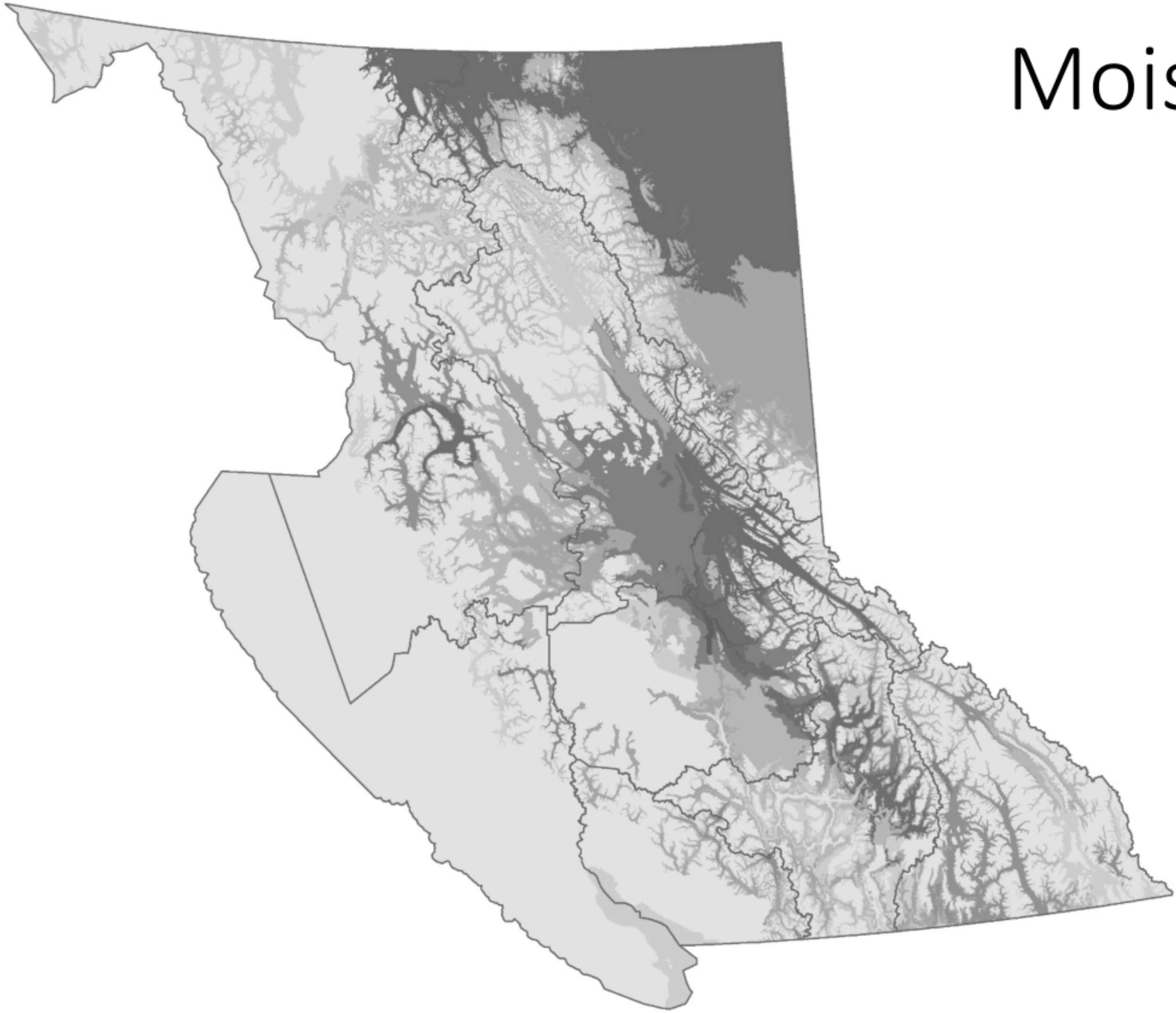
- Used three tree species to represent assemblages of browse species
- Dry/Cold – Aspen
- Moist/Cold- Birch
- Wet- Cool – Cedar

- Used National Forest Inventory (NFI) – 400x400m pixel files that estimate tree species composition



Dry Cold assemblage

- Used aspen (*Populus Tremuloides*) to represent the occurrence of the Dry-Cold assemblage.
- Other species include:
  - Saskatoon (*Amelanchier alnifolia*)



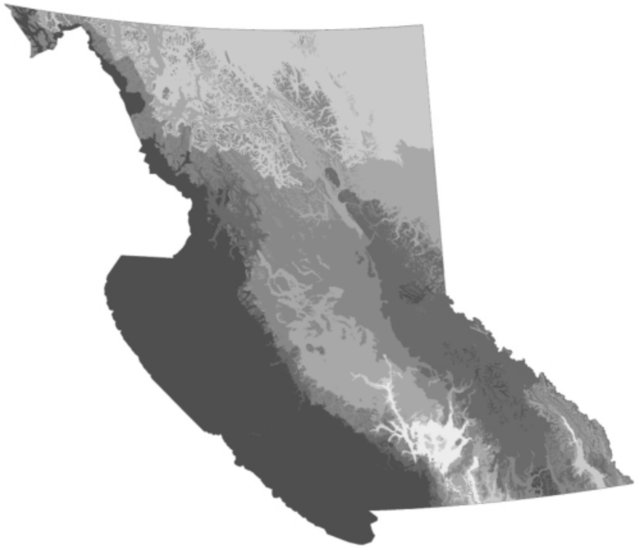
Moist Cool Assemblage

- Used paper Birch (*Betula papyrifera*) to represent the occurrence of the Moist-Cool assemblage
- Other species Include:
  - Red-Osier Dogwood (*Cornus Stolinifera*)
  - High-brush cranberry (*Viburnum edule*)

Wet Cold Assemblage

- Used Cedar (*Thuja plicata*) to represent occurrence of wet-Cool assemblages
- Other Species Include:
  - Willow (Salix spp.)
  - Douglas Maple (*Acer Glabrum*)
  - Beaked hazelnut (*Corylus cornuta*)
  - Cottonwood (*Populus*)

Standardized Productivity Score



Standardized score 0-1 to highest productivity ecosystem

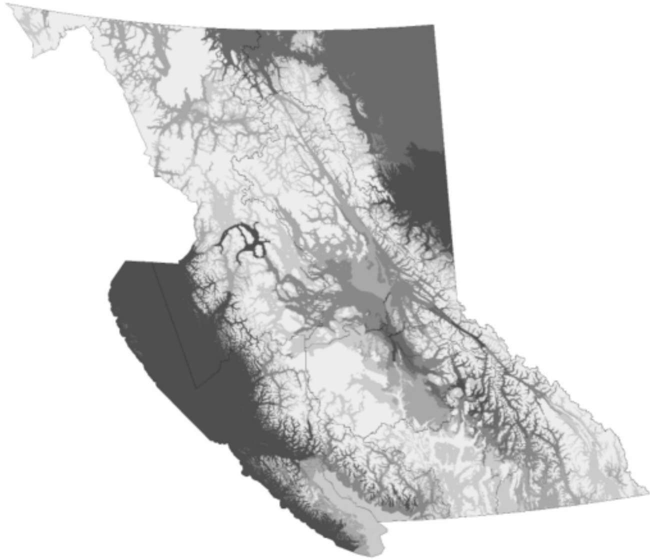
X

Standardized Composition Score

Mean composition of all 3 species assemblages standardized to highest value

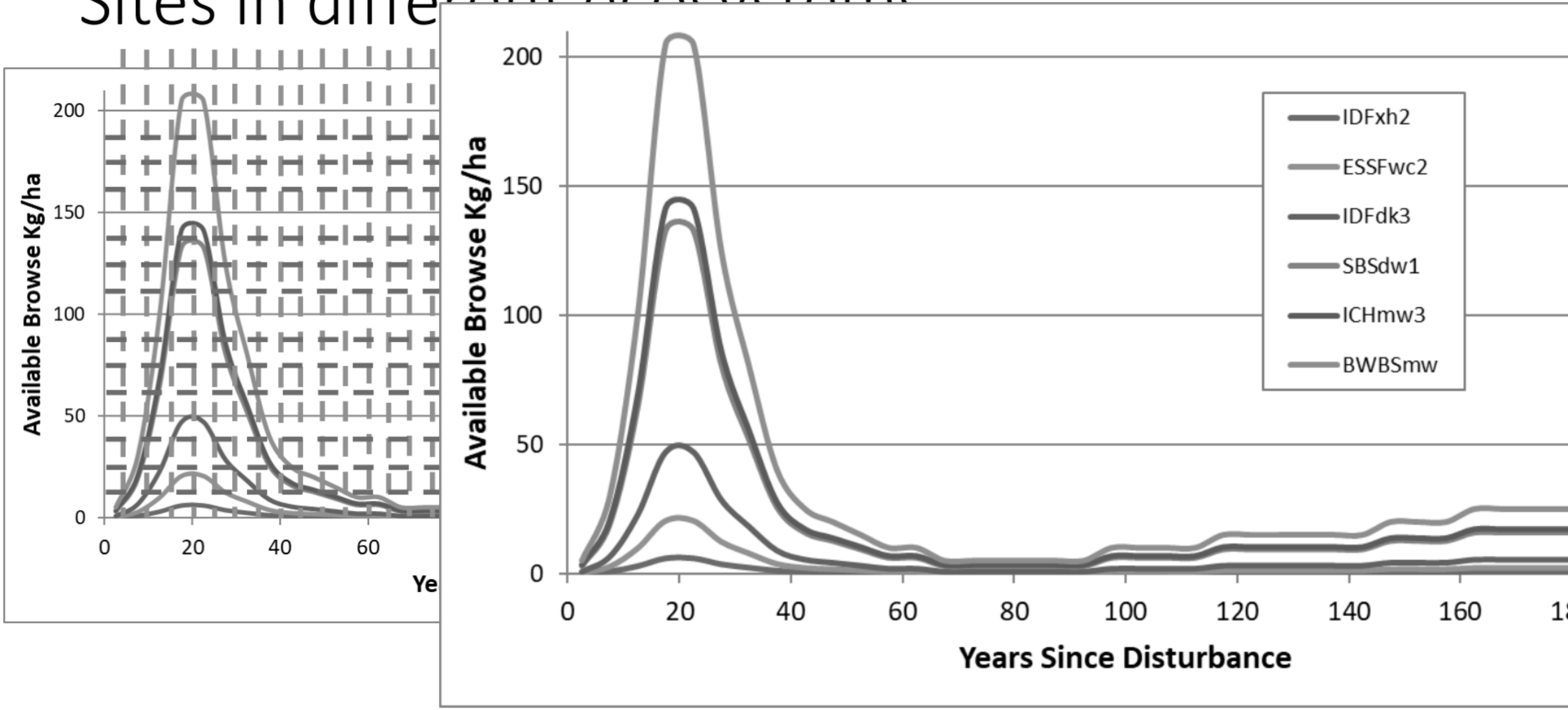
=

Browse Productivity Index

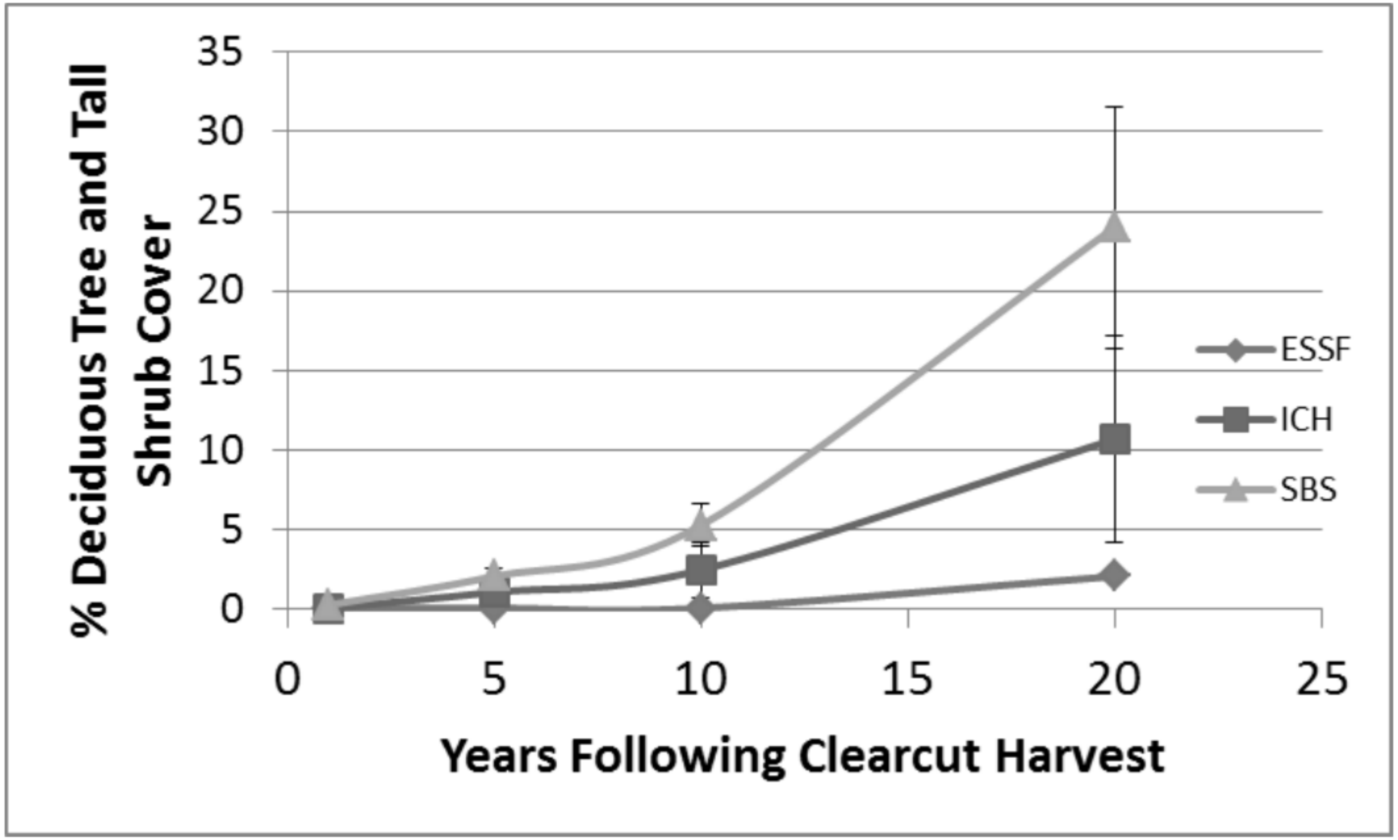


Score 0-1

Estimating Browse Production on Disturbed Sites in different ecosystems

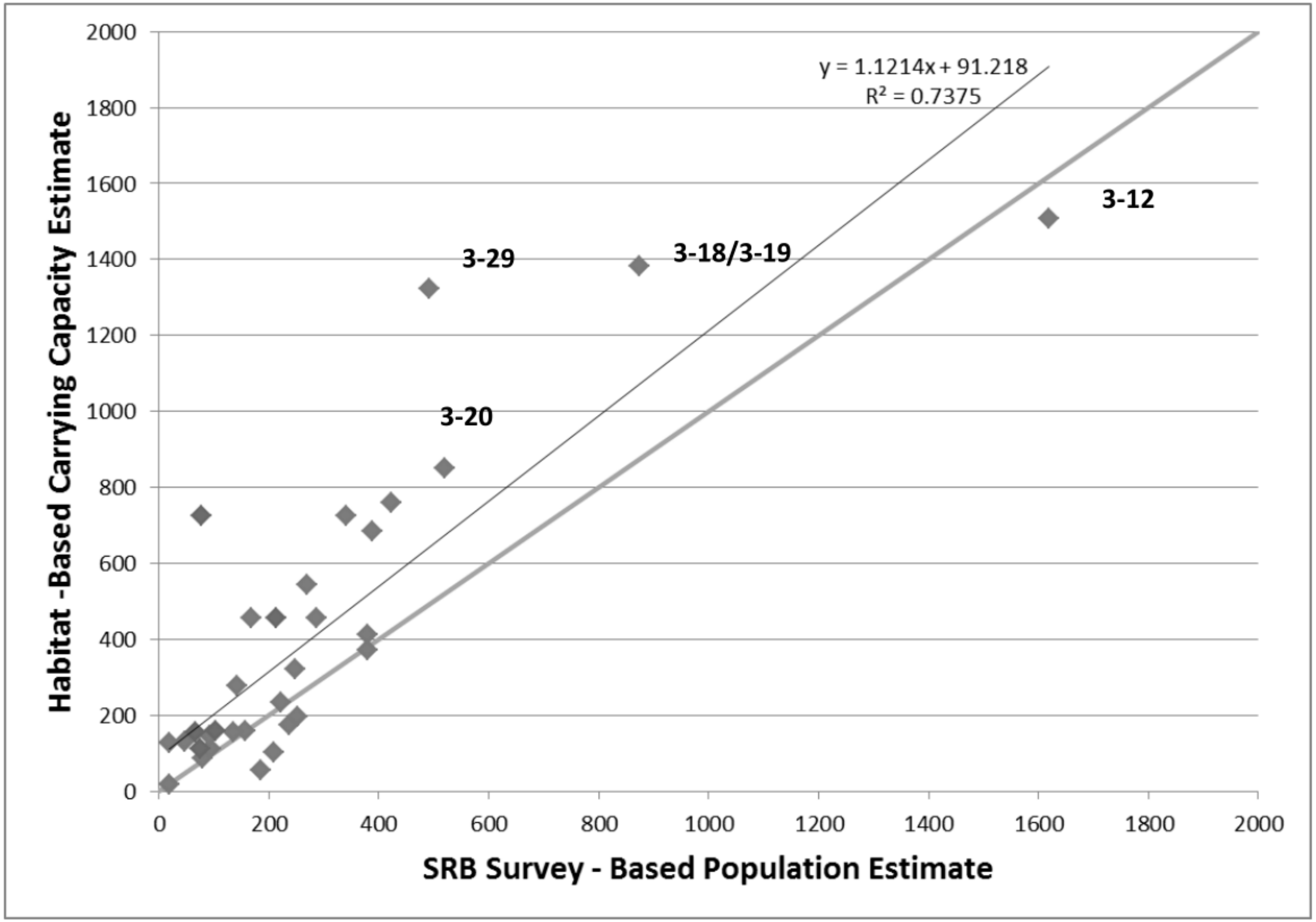


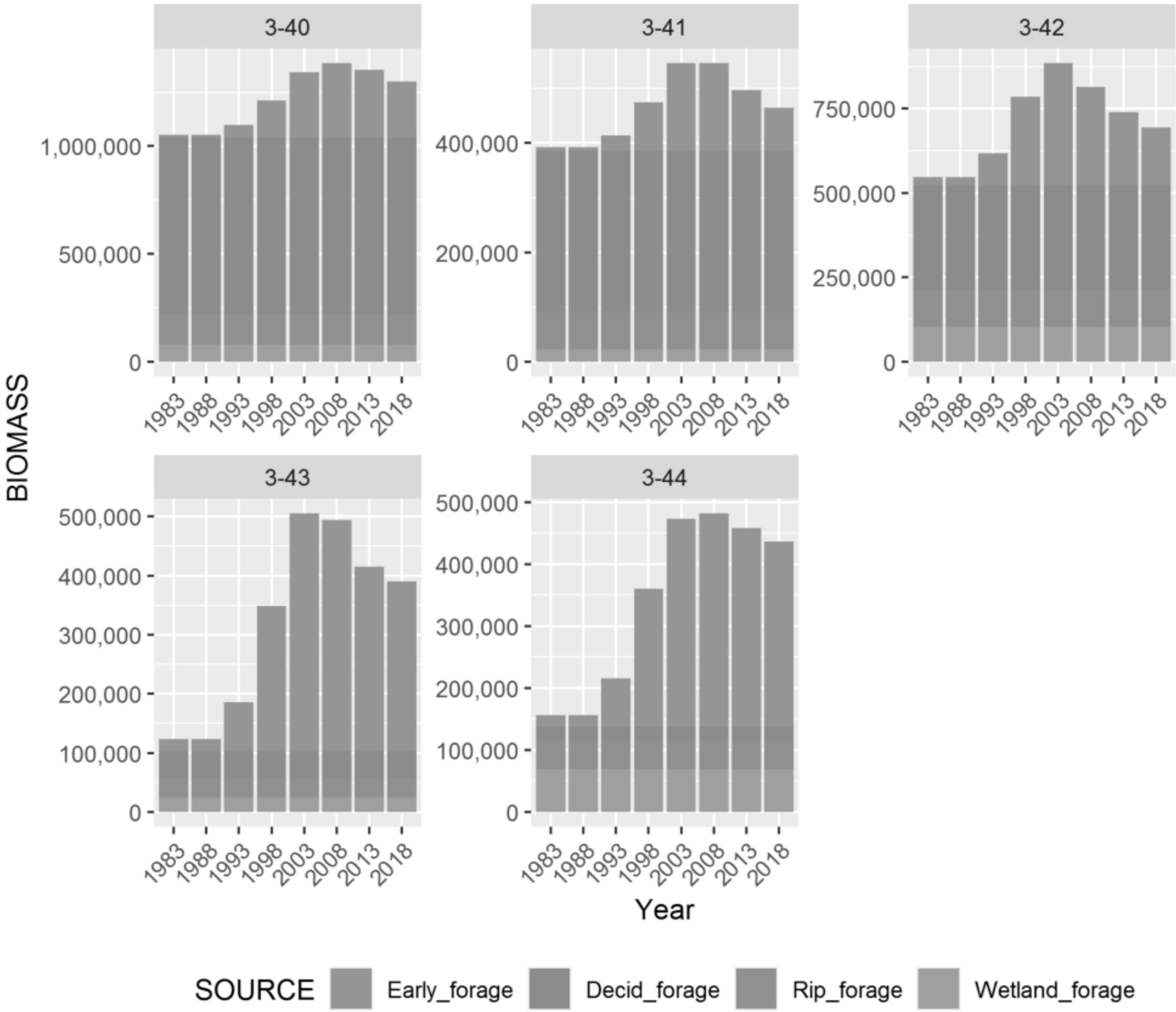
Comparison to Field data



Chandler et al. 2017. Twenty years of ecosystem response after clearcutting and slashburning in conifer forests of British Columbia, Plos ONE 12(2)

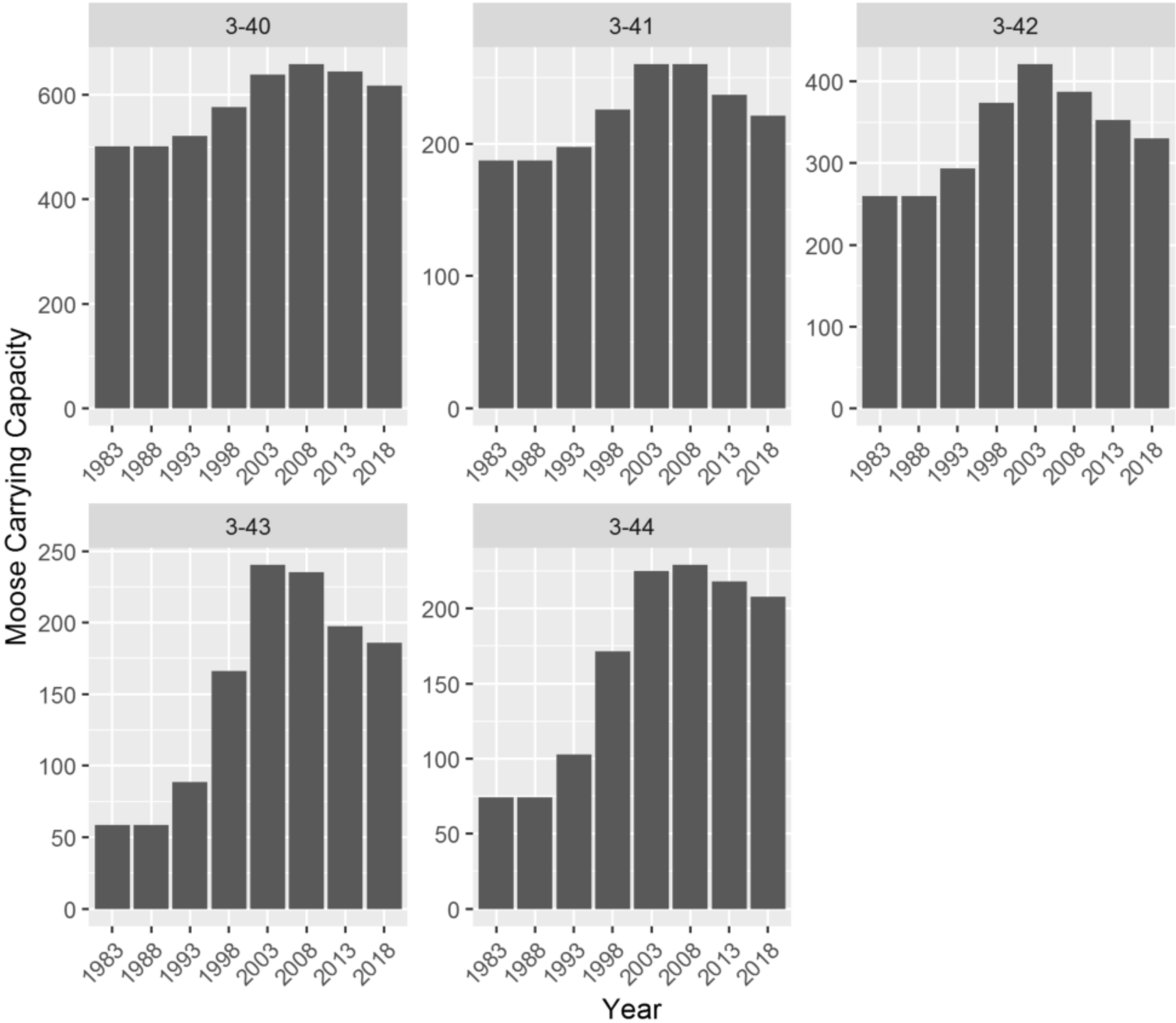
- Estimates of relative increases and relative differences in available biomass (% cover) are consistent with published studies.
- Additional field-based information necessary to calibrate and validate the Browse productivity Index.


y = 1.1214x + 91.218
R² = 0.7375
3-12
3-29
3-18/3-19
3-20
Habitat -Based Carrying Capacity Estimate
SRB Survey - Based Population Estimate
0
200
400
600
800
1000
1200
1400
1600
1800
2000



Estimating Available Browse Biomass

- Underlying ‘static’ forage sources a large determinant of carrying capacity
- Dynamic sources can contribute significantly



Estimating Carrying Capacity

- Carrying capacity closely follows available forage
- # of moose on winter range impact density and predator response

Uncertainties

1. Actual amount of browse (Kg/ha) in deciduous, wetland and riparian habitats.
   - Data from Alberta – local information?
2. BPI is a relative index – how well does it relate to actual browse species biomass- need ground estimates.
   - Available plot data locally to calibrate results?
3. How does browse production vary with silviculture systems.
   - Retention levels/shading

Thompson-Okanagan Moose Assessment Model v6.6

Model Structure and Logic

Updated

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December 2019

Structure and Application

The Thompson-Okanagan moose assessment model is a testable, causal Bayesian Belief model that evaluates currently available information to estimate population trend of moose populations at the scale of Wildlife Management Units. Although designed for the Thompson-Okanagan, the model is suitable for general applicability throughout British Columbia.

The model can be used to estimate the effect of different factors on moose populations. Factors can be natural or human-caused stressors, as well as individual management actions or policies (i.e., groups of actions). The model captures interactions among factors and can assess the independent effect of each.

The model is structured as a Bayesian network, illustrating the system as a directed acyclic graph and representing relationships probabilistically (Marcot et al. 2006). Structurally, Bayesian networks are composed of:

- *Nodes,* which are the boxes of the model diagram and represent random variables. For the purposes of the moose model, nodes are categorized as:
  - inputs (yellow): measurable factors that are hypothesized to have a relationship with moose population trend (output node in green);
  - indicators (orange): derived factors that can be compared to field data for validation and calibration purposes; and,
  - latent factors (beige): these are derived factors that are not directly observable.
- *Directed edges* are the arrows linking nodes and the direction of the arrows indicate an hypothesized, causal relationship.
- *Marginal and conditional probability tables* define the relationships among nodes linked by edges. Each node has a table. A node without *parents* (i.e., no incoming links from other nodes) have marginal tables that define a probability distribution for an input. The probability distributions are discretized into *states* that represent discrete conditions, or for continuous inputs, ranges of conditions. *Child* nodes (i.e., with one or more incoming links from other nodes) have conditional probability tables, so called because the probability distribution of the child node is conditional on the probability distributions of the parent nodes.

The model topology (i.e., structure of *nodes* and *directed edges*; Figure 1) is based on the expert opinion of biologists and managers from the Thompson-Okanagan Region who contributed iteratively to the model through a series of workshops and meetings. The quantitative relationships between factors (i.e., instantiation of the *conditional probability tables*) was based on data, where available, derived relationships based on data, or on expert opinion where little or no data were available. The model can continue to be refined as theory evolves and as data become more available.

Model Inputs

The following sections list the inputs accepted by the model. The model will still run if one or more of the inputs is missing, but greater uncertainty will be expressed in the output node. Moose capability and habitat variables were summarized by Wildlife Management Unit (WMU) based on provincial data accessed in raster format via HectaresBC.org, current as of February 2017.

Population Estimate (Carrying Capacity)

The population estimate for a Management unit is an input to the Bayesian model and was derived for this iteration of the model from a deterministic algorithm based on the provincial Broad Ecosystem Inventory (BEI; see RIC 1998) coverages for the three subspecies of moose occurring in B.C. (*Alces americana* americanus *ssp. andersoni, gigas, shirasi*; Shackleton 2013). It is meant to estimate the maximum expected population, or carrying capacity, of a WMU based on the current suitability of the habitat.

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FIGURE 1. MODEL TOPOLOGY (NODES AND DIRECTED EDGES) OF THE BAYESIAN NETWORK USED TO ESTIMATE THE EFFECT OF DIFFERENT FACTORS ON MOOSE POPULATIONS.

To develop this estimate, the highest rating among the three subspecies models was first assigned to each BEI polygon. Then the habitat suitability rating for polygons was adjusted by "stepping down" the capability rating (excluding class 6 or "nil") by 1-3 classes (RIC 1999), depending on forest age class, as reported by Vegetation Resources Inventory (VRI) data. Note that VRI was available only for TSAs, so there are gaps in the habitat suitability ratings for TFLs and private land. Wetland or riparian habitat was not stepped down. This resultant was then overlaid on WMU boundaries and the areas of each suitability class falling within each WMU was summed and multiplied by an estimated moose density to generate a maximum, current carrying capacity population estimate for each WMU (Figure 2). The estimate was most sensitive to the density assumption for a suitability rating of 5 because this was the largest area.

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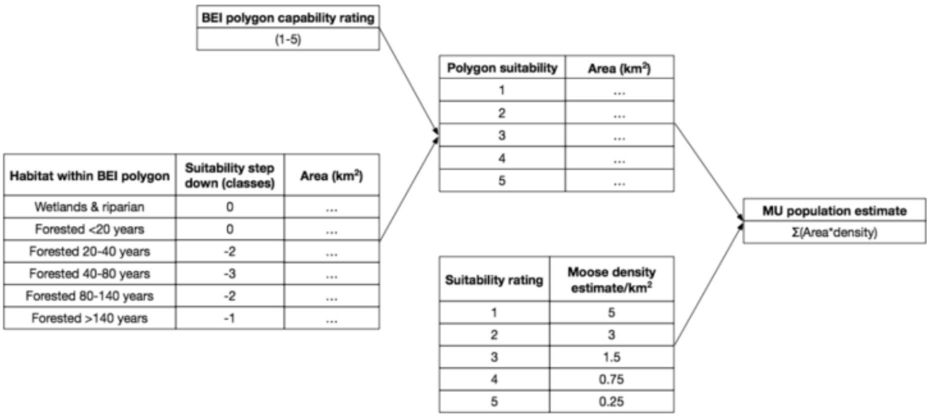

FIGURE 2. SUMMARY OF LOGIC FOR ALGORITHM USED TO ESTIMATE MOOSE POPULATION BY WILDLIFE MANAGEMENT UNITS (WMUS) FROM PROVINCIALLY AVAILABLE DATA.

Population estimates derived from this algorithm were compared against survey data from Region 8 to test overall performance (Figure 3).

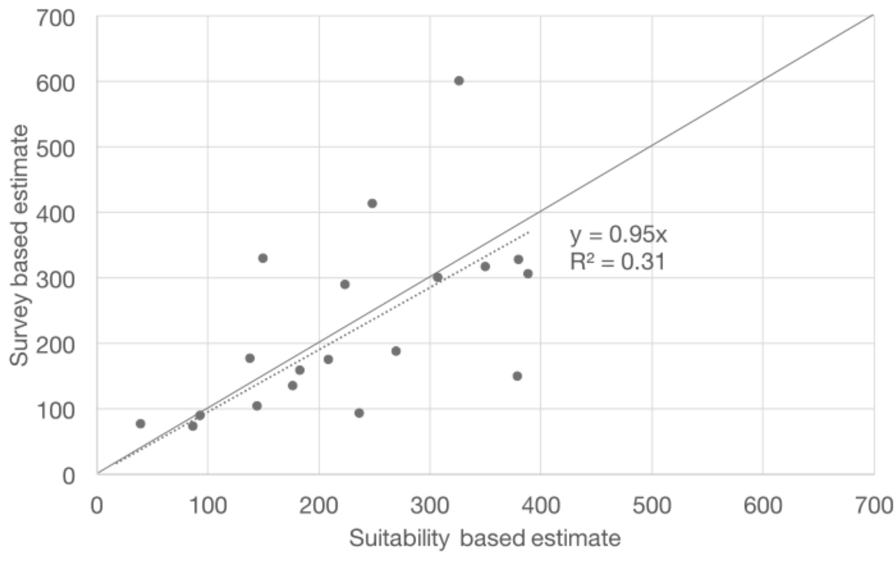

FIGURE 3. CORRELATION BETWEEN SURVEY-BASED MOOSE POPULATION ESTIMATES AND MODEL-BASED (“SUITABILITY”) ESTIMATES FOR REGION 8. SURVEY-BASED ESTIMATES ARE BASED ON MOST RECENT SRB DATA FOR EACH WILDLIFE MANAGEMENT UNIT.

As noted above, population estimates can be derived from different source data by different methods. This maximizes the flexibility of the model and allows for regional and subregional derivation of estimates based on best available information. These estimates can be used as direct inputs associated with the population estimate node.

The carrying capacity *Population_estimate* input node is discretized into three classes (<1500, 1500-4000, >4000). s.13

Early Seral

The proportion of each planning cell in early seral condition is a key determinant of forest suitability because early seral forested habitats provide abundant moose forage (Peek et al. 1976) but also removes cover that can provide important thermal cover during warm conditions (i.e., ambient temperatures >-5º C; Renecker and Hudson 1986).

Early_seral is the percentage of the gross area of moose habitat within a WMU composed of forest <20 years old, based on VRI data. The factor is discretized into 3 classes (<5%, 5-10%, >10%). s.13

Road Density

Roads are hypothesized to increase the vulnerability of moose to hunting by providing greater access to hunters (Kuzyk et al. 2016). Road density was calculated for each WMU based on the provincial Digital Road Atlas data and the *Road_density* variable was discretized into 3 classes per km^2 (<1, 1-2, >2).

Licensed Hunter Days

Licensed hunter days are one of the main drivers of harvest, and therefore moose mortality rates and population size. *Licensed_hunter_days* is a 5-year average (2010-2014) of the number of resident and non-resident hunter days reported in hunter survey data, by WMU. The factor is discretized into 3 classes (<1500, 1500-4000, >4000).

Wolf Density

Wolves are one of the main predators of moose in BC (Shackleton 2013, Kuzyk et al. 2016) and can play a regulating role in their populations (Messier 1994). *Wolf_density* was calculated for each Management Unit based on an area-weighted averages of intersecting ecosections, based on estimates in BC Ministry of Forests, Lands and Natural Resource Operations (2014). The node is discretized into three classes per 1000 km^2 (<2, 2-6, >6).

Other Adult Male, Female and Juvenile Mortality

In addition to hunting and wolf predation, there are other sources of mortality that are captured in the model as separate, additive constants that can be set by users for each sex/age class. "Low" is set at 0-10% (default for adult males and adult females, "Moderate" 10-20% (default for juveniles) and "High" (20-30%).

Latent Factors

Latent factors result from intermediate calculations in the model and their conditional probability tables are based on either equations or estimates.

Unlicensed Harvest

For the purposes of this model, unlicensed harvest was assumed to be proportional to the moose population estimate for each WMU according to the following probabilities:

	Unlicensed_harvest		
Population_estimate	**Low (0.5)**	**Moderate (1)**	**High (2)**
<1500	50	30	20
1500-4000	70	20	10
>4000	90	10	0

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So WMUs with an estimated maximum population of <1500 moose were assumed to have a 50% chance of a *Low* rate of unlicensed harvest, a 30% chance of a *Moderate* harvest, and a 20% chance of a *High* harvest rate. These estimates reflect the assumptions that the absolute harvest of moose by unlicensed hunters is higher where moose are more abundant, but that unlicensed harvest comprises a smaller proportion of larger moose populations.

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Constants associated with low (0.5), moderate (1) and high (2) classes are used in equations in nodes that are children of *Unlicensed_harvest*. For example, *Unlicensed_harvest* is an input to the *Adult_male_survival_rate* node, and the factor is weighted by 2 where the rate of unlicensed harvest is considered *High*.

Adult Male, Female and Juvenile Harvest

Harvest nodes accept as input: *Population_estimate, Hunting_vulnerability* (see below for details), and *Licensed_hunter_days.* The conditional probability tables were populated via maximum likelihood estimation (Conrady and Jouffe 2015) from provincial moose harvest statistics, averaged over the last five years for which data were available (2010-2014) by WMUs where moose harvest occurred. The nodes are expressed as harvested animals rather than rates to align with provincial databases and are discretized into 3 classes (adult males: <50, 50-100, >100; adult females (0, 0-10, >10) and juveniles (0, 0-5, >5). The following tables present the conditional probability tables:

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			Adult_male_harvest		
Hunting_ vulnerability	***Population_ estimate***	***Licensed_ Hunter_days***	**<50**	**50-100**	**>100**
Low	<1500	Low	89.024	10.976	0
Low	<1500	Moderate	69.231	30.769	0
Low	<1500	High	33.3333	33.3333	33.3333
Low	1500-4000	Low	100	0	0
Low	1500-4000	Moderate	25	50	25
Low	1500-4000	High	100	0	0
Low	>4000	Low	100	0	0
Low	>4000	Moderate	0	100	0
Low	>4000	High	0	0	100
Mod	<1500	Low	100	0	0

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			Adult_male_harvest		
Hunting_ vulnerability	***Population_ estimate***	***Licensed_ Hunter_days***	**<50**	**50-100**	**>100**
Mod	<1500	Moderate	66.667	33.333	0
Mod	<1500	High	33.3333	33.3333	33.3333
Mod	1500-4000	Low	0	100	0
Mod	1500-4000	Moderate	50	50	0
Mod	1500-4000	High	0	0	100
Mod	>4000	Low	33.3333	33.3333	33.3333
Mod	>4000	Moderate	0	0	100
Mod	>4000	High	50	0	50
High	<1500	Low	100	0	0
High	<1500	Moderate	33.333	66.667	0
High	<1500	High	0	0	100
High	1500-4000	Low	33.3333	33.3333	33.3333
High	1500-4000	Moderate	50	0	50
High	1500-4000	High	0	0	100
High	>4000	Low	33.3333	33.3333	33.3333
High	>4000	Moderate	50	0	50
~~Mod~~High	>4000	High	25	0	75

			Adult_female_harvest		
Hunting_ vulnerability	***Population_ estimate***	***Licensed_ Hunter_days***	**<50**	**50-100**	**>100**
Low	<1500	Low	89.024	10.976	0
Low	<1500	Moderate	69.231	23.077	7.692
Low	<1500	High	100	0	0
Low	1500-4000	Low	100	0	0
Low	1500-4000	Moderate	37.5	37.5	25
Low	1500-4000	High	100	0	0
Low	>4000	Low	100	0	0
Low	>4000	Moderate	50	50	0
Low	>4000	High	0	100	0
Mod	<1500	Low	66.667	33.333	0
Mod	<1500	Moderate	33.333	66.667	0
Mod	<1500	High	33.3333	33.3333	33.3333
Mod	1500-4000	Low	100	0	0
Mod	1500-4000	Moderate	50	50	0

			Adult_female_harvest		
Hunting_ vulnerability	***Population_ estimate***	***Licensed_ Hunter_days***	**<50**	**50-100**	**>100**
Mod	1500-4000	High	0	0	100
Mod	>4000	Low	33.3333	33.3333	33.3333
Mod	>4000	Moderate	0	0	100
Mod	>4000	High	100	0	0
High	<1500	Low	93.333	6.667	0
High	<1500	Moderate	0	100	0
High	<1500	High	0	0	100
High	1500-4000	Low	33.3333	33.3333	33.3333
High	1500-4000	Moderate	0	50	50
High	1500-4000	High	0	50	50
High	>4000	Low	33.3333	33.3333	33.3333
High	>4000	Moderate	50	0	50
~~Mod~~High	>4000	High	25	25	50

			Juvenile_harvest		
Hunting_ vulnerability	***Population_ estimate***	***Licensed_ Hunter_days***	**<50**	**50-100**	**>100**
Low	<1500	Low	89.024	10.976	0
Low	<1500	Moderate	69.231	30.769	0
Low	<1500	High	33.3333	33.3333	33.3333
Low	1500-4000	Low	100	0	0
Low	1500-4000	Moderate	25	50	25
Low	1500-4000	High	100	0	0
Low	>4000	Low	100	0	0
Low	>4000	Moderate	0	100	0
Low	>4000	High	0	0	100
Mod	<1500	Low	100	0	0
Mod	<1500	Moderate	66.667	33.333	0
Mod	<1500	High	33.3333	33.3333	33.3333
Mod	1500-4000	Low	0	100	0
Mod	1500-4000	Moderate	50	50	0
Mod	1500-4000	High	0	0	100
Mod	>4000	Low	33.3333	33.3333	33.3333
Mod	>4000	Moderate	0	0	100
Mod	>4000	High	50	0	50

			Juvenile_harvest		
Hunting_ vulnerability	***Population_ estimate***	***Licensed_ Hunter_days***	**<50**	**50-100**	**>100**
High	<1500	Low	100	0	0
High	<1500	Moderate	33.333	66.667	0
High	<1500	High	0	0	100
High	1500-4000	Low	33.3333	33.3333	33.3333
High	1500-4000	Moderate	50	0	50
High	1500-4000	High	0	0	100
High	>4000	Low	33.3333	33.3333	33.3333
High	>4000	Moderate	50	0	50
Mod	>4000	High	25	0	75

s.13

Adult Male Survival Rate

Adult male survival rate is estimated by the model but does not serve as an indicator because it does not directly influence the output note of *Population_trend,* which by convention is calculated from only the female component of the population. The *Adult_male_survival_rate* node accepts as inputs: *Population_estimate, Unlicensed_harvest, Adult_male_harvest, Wolf_predation* and *Other_adult_male_mortality.* The conditional probability table is populated from the following equation that estimates the interaction of the input variables on adult survival:

s.13

Adult_male_survival_rate (Population_estimate, Adult_male_harvest, Wolf_predation, Unlicensed_harvest, Other_adult_male_mortality) = (1-(Wolf_predation/5+Unlicensed_harvest+Other_adult_male_mortality)/5)-(Adult_male_harvest/Population_estimate.25)*

s.13

This equation assumes that harvest, predation and other mortality sources are additive. Adult males are assumed to comprise 25% of the population.

Wolf Predation

Wolf predation accepts as input *Wolf_density* and *Road_density* and the interactions of these variables in driving the intensity of wolf predation is estimated in the following table:

		Wolf_predation		
***Wolf_density* (/1000 km^2)**	***Road_density* (/km^2)**	**Low (0.5)**	**Moderate (1)**	**High (2)**
<2	<1	90	10	0
<2	1-2	45	45	10
<2	>2	5	90	5
2-6	<1	5	90	5
2-6	1-2	10	45	45
2-6	>2	0	10	90
>6	<1	0	10	90
>6	1-2	0	10	90

s.13

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		Wolf_predation		
***Wolf_density* (/1000 km²)**	***Road_density* (/km²)**	**Low (0.5)**	**Moderate (1)**	**High (2)**
>6	>2	0	10	90

Constants associated with low, moderate and high classes are used in equations in nodes that are children of *Wolf_predation.*

Bear Predation

Bear predation is assumed to be proportional to the bear population, and since bear population estimates are not routinely available, bear populations are assumed to be proportional to the proportion of early seral habitat. This recognizes that bear populations are known to respond to the abundance of suitable forage, which is generally most abundant in early seral conditions (e.g., Nielson et al. 2004, Brodeur et al. 2008).

The scaling of the probabilities in the following table were calibrated using the correlation between black bear harvest (2010-2014) and proportions of early seral habitat,[1] by Management Unit:

	Unlicensed_harvest		
***Early_seral* (%)**	**Low (0.79)**	**Moderate (1)**	**High (1.42)**
<5	95	5	0
5-10	25	50	25
>10	0	5	95

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Constants associated with low, moderate and high classes are used in equations in the equation for *Juvenile_recruitment_index.*

Indicators

Hunting Vulnerability

Because of the hypothesized importance of hunting vulnerability as function of landscape condition (road density and early seral habitat; Kuzyk et al. 2016), this factor was included in the model as an indicator. The *Hunting_vulnerability* node was discretized into three classes and the conditional probability table was populated by back-calculating values via maximum likelihood estimation using harvest data, *Early_seral* and *Road_density* estimates for all provincial Management Units where moose harvest occurs.

Adult Female Survival Rate

Adult_female_survival_rate is considered an indicator rather than a latent variable because it can be verified from field data (i.e., survival rate estimates from the fates of radio-collared moose) and it an important management indicator of population trend. Population trends of

[1] Note that this correlation explained only a small proportion of variation in the data (r^2 = 0.05)

ungulates are generally more sensitive to adult female survival than to recruitment (Gaillard et al. 1998). Survival rates of >90% are generally consistent with an increasing population.

The conditional probability table is estimated using the same inputs and equation as *Adult_male_survival_rate,* but the parameter controlling the influence of unlicensed harvest is adjusted to reflect the estimated sex ratio of harvest observed in the Thompson from First Nations hunters (2.8:1 adult males to females; C. Procter, *pers. comm.*):

Adult_female_survival_rate (Adult_female_harvest, Wolf_predation, Population_estimate, Unlicenced_harvest, Other_adult_female_mortality) = (1-(Wolf_predation/5+Unlicenced_harvest/3+Other_adult_female_mortality)/5)-(Adult_female_harvest/Population_estimate.5)*

Adult females are assumed to comprise 50% of the population.

Juvenile Recruitment Index

Juvenile recruitment is an important indicator of population trend and is routinely collected during aerial surveys. The equation used to populate the conditional probability table for juvenile recruitment is analogous to the equations for adult male and adult female survival rate, but also includes bear predation as a factor:

Juvenile_recruitment_index (Juvenile_harvest, Population_estimate, Wolf_predation, Unlicenced_harvest, Bear_predation, Other_juvenile_mortality) = ((1-(Wolf_predation/2+Unlicenced_harvest/3+Bear_predation/2+Other_juvenile_mortality)/5)-(Juvenile_harvest/Population_estimate.25))*60*

Juvenile recruitment is considered to be an index because it is measured months before females are actually recruited into the breeding population. Recruitment >30 calves:100 cows is generally consistent with an increasing population.

The maximum calf:100 cow ratio in the absence of predation, hunting and other risks is assumed to be 60. The effect of unlicensed hunting on juveniles is assumed to be the same as that of adult females.

Output - Population Trend

Population_trend accepts *Adult_female_survival_rate* and *juvenile_recruitment_index* as inputs and calculates lambda according to the equation developed by Hatter and Bergerud (1991):

Population_trend (Adult_female_survival_rate, Juvenile_recruitment_index) = Adult_female_survival_rate/(1-((Juvenile_recruitment_index/2)/(100+(Juvenile_recruitment_index/2))))

Model Sensitivity

Model sensitivity was assessed to rank the importance of input factors according to their influence on model output (Figure 4).

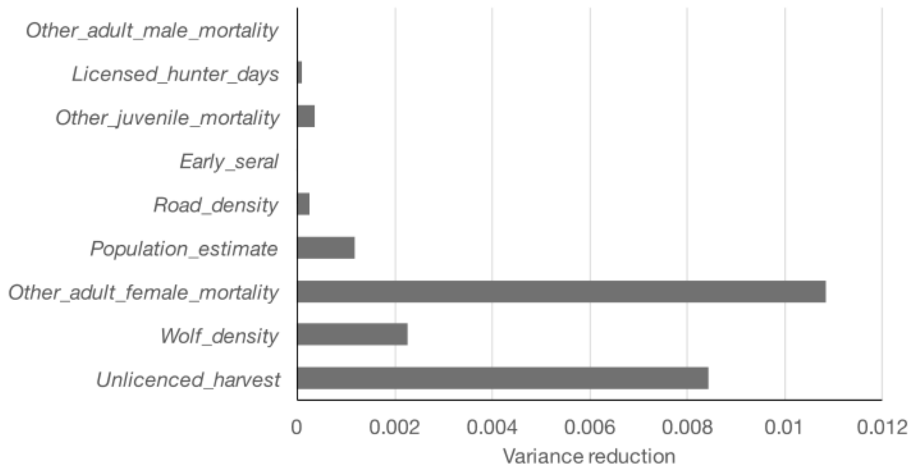

FIGURE 4. SENSITIVITY OF THE OUTPUT NODE (POPULATION TREND) TO MODEL INPUTS.

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Results suggest that moose population trend was most affected by other adult female mortality, unlicensed harvest, wolf density and moose population estimate.

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Moose Analysis for the Kispiox Timber Supply Review

Tyler Muhly, Forest Analysis and Inventory Branch

25/11/2021

Background

Moose (*Alces alces*) are the largest ungulate species in British Columbia, and are widely distributed throughout the interior of the province (see Moose In British Columbia). They are a highly valued wildlife species across North America for a variety of cultural and economic reasons (Timmermann and Rogers 2005).

Importance to the Canadian Government

Moose are not legally listed by the Canadian government and their conservation status has not been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Across North America, moose abundance was recently estimated at approximately 1,000,000 animals, with approximately 1/3 of jurisdictions with increasing populations, 1/3 with decreasing populations and 1/3 with stable populations (Timmermann and Rodgers 2017).

Importance to the British Columbian Government

In British Columbia, moose are *yellow listed*, meaning they are apparently secure and not at risk of extinction. They have an S5 conservation status, meaning they are demonstrably widespread, abundant, and secure.

In the early 2010's it became apparent that moose populations were declining in central portions of the province. In response, a provincial moose management strategy was created to provide provincial direction for moose management and establish a scientific basis for making moose management decisions (FLNRORD 2015). In addition, in 2013 the provincial government initiated a provincial research program focused on improving understanding of factors driving moose populations.

Importance to First Nations Governments

Moose are a highly valued wildlife species to many First Nations communities in British Columbia. Prior to European colonization, moose were used extensively by Indigenous peoples for food, clothing and shelter (see Moose In British Columbia). In the last 100 years, moose have become an important, nutritious, staple food of many interior and coastal First Nations communities in British Columbia (First Nations Health Authority fact sheet). The Gitanyow community has identified moose (*Ha daa*) as the most important wildlife species in terms of consumptive demand, as they provide important sustenance during the winter months (see Hamelin, 2003. Seasonal Movements and Distribution Patterns of Moose (*Alces alces*) within the Kitwanga Watershed).

Relationship to Forestry

Historically, some amount of forest harvest has generally been viewed as positive for moose habitat and populations, by creating open, young (less than 40 year old) forest stands that provide forage (e.g., shrubs such as willow and red osier dogwood) for moose. Moose also require older stands with closed canopies to provide shelter from snow in winter and heat in summer, and thus a mix of young and old forest provides forage and cover that moose need for survival (Eastman 1974; Schwab 1985; Proulx and Karix 2005; Poole and Stuart-Smith 2006).

Recent moose population declines in parts of central British Columbia coincided with the last mountain pine beetle outbreak and salvage harvest, potentially implicating large-scale harvest and road building as a cause of population decline. The Provincial Moose Research Project has been investigating whether landscape change, including from forestry activities, is related to moose mortality and population trends. Initial results of this research has shown that the relationship between moose and forestry is perhaps more variable and complex than previously believed, depending on ecosystem productivity and abundance of predators (both human and non-human, such as wolves) in a region.

Roads

Recent research from interior British Columbia has shown that moose in areas with higher road densities have a higher risk of mortality from human hunters and starvation, but a lower risk or mortality from wolves (Mumma and Gillingham 2019). Thus, road development from forestry could both potentially positively and negatively affect moose populations, depending on predator densities and forage quality in the area.

Forestry road density within a landscape unit can be used as an indicator of mortality risk to moose from hunter harvest, starvation and wolves. There are no clear thresholds for road density that clearly increase or decrease mortality risk for moose, but road density indicators can be considered in the context of other information.

Forest Stand Characteristics

As indicated above, forestry can indirectly influence moose by directly influencing the composition of vegetation in forest stands in an area. Recent research has shown that region-specific differences in vegetation composition and regrowth after forest harvest can influence habitat quality for moose (Mumma et al. 2021), and thus local habitat conditions and context are important to evaluating impacts of forestry on moose. In some cases, moose avoid very young

(1 to 8 year old) cutblocks, and moose mortality from starvation is higher in areas with more cutblocks (Mumma and Gillingham 2019), perhaps due to poorer forage quality in large cutblocks (J. Werner, pers. comm.). Therefore, “uplifts”, or significant increases in forest harvest over a short period of time, particularly in low productivity ecosystems, may negatively affect moose.

The percentage of forested area within a landscape unit that is 5 to 30 year old cutblocks is a useful indicator of forage availability for moose, where very low or high proportions could indicate poor habitat conditions for moose due to a lack of forage or forest cover, respectively. This indicator should be considered in the context of forest productivity and early seral forest vegetation community composition in the area.

Current Conditions

Below provides a summary of current and recent conditions of moose population and habitat indicators in the Kispiox TSA.

Population Status and Trend

The total population of moose in the Skeena region was estimated at 25,000 to 45,000 animals in 2017. Current and recent moose population estimates for the Kispiox TSA were obtained from the BC government’s species inventory web explorer (SIWE) by searching for ‘moose’ inventory data collected in the Skeena region. Any data on moose density, populations, bull:cow ratios and calf:cow ratios was compiled.

Moose surveys were completed in the Nass Wildlife Area (NWA), which overlaps western portions of the Kispiox TSA and portions of wildlife management units (WMUs) 6-15 and 6-30, in 2001, 2007, 2011 and 2017. Surveys were also completed in the Kispiox Valley, which overlaps much of the Kipsiox TSA, including the majority of WMU 6-30, and portions of WMUs 6-08, 6-09 and 6-15.

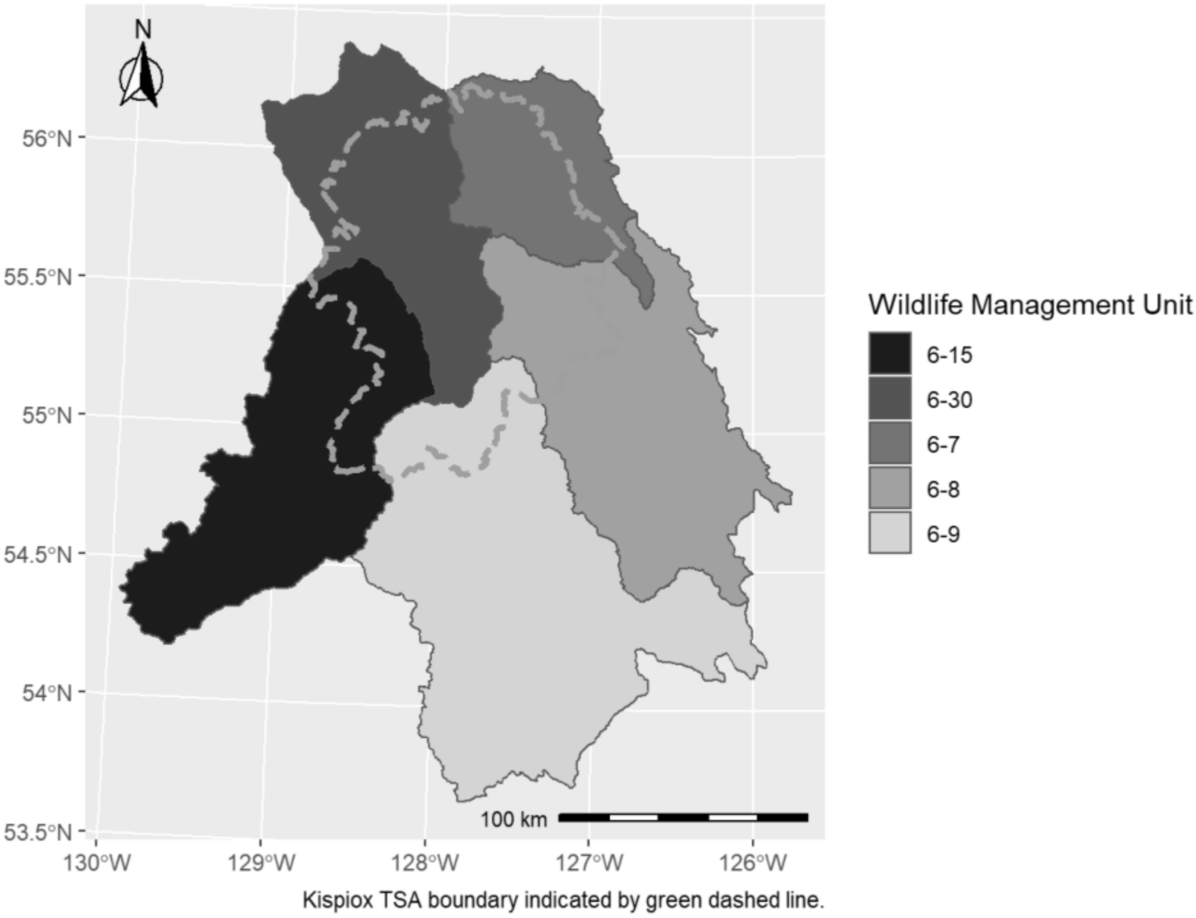


Figure 1. Wildlife management units in the Kipsiox Timber Supply Area.

Moose abundance in the NWA has shown an overall decreasing trend since 2000, although with a decrease from 2001 to 2011, and increase from 2011 to 2017. Moose abundance in the Kispiox Valley has a slightly decreasing trend between 1999 and 2020, however, estimates are within 90% confidence intervals with each other, indicating the population may be stable.

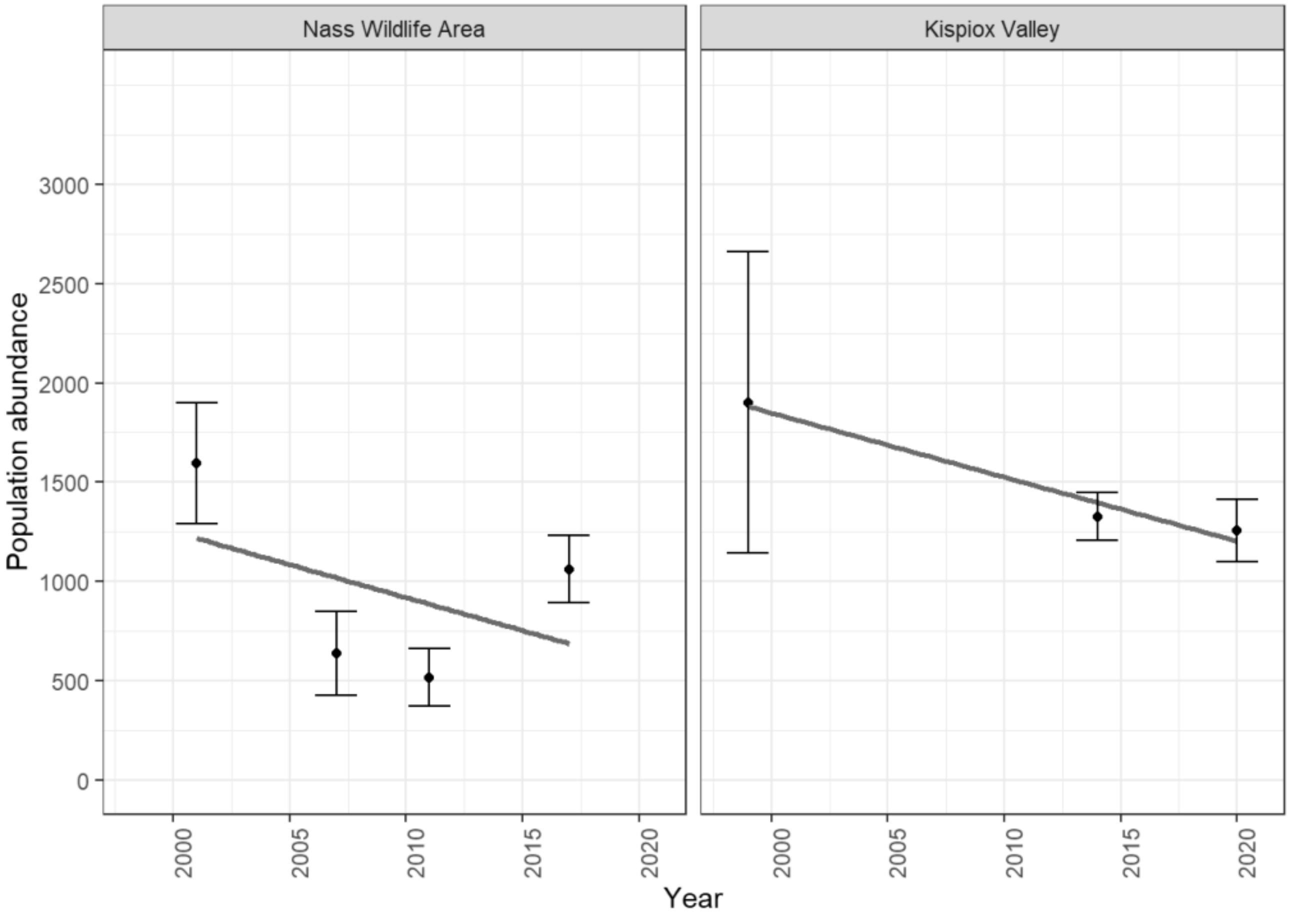


Figure 2. Moose population estimates (with 90% confidence intervals) for the Nass Wildlife Area and Kispiox Valley in the Kispiox Timber Supply Area.

The ratio of calves to cow moose is often used as an indicator of moose population trend, where ratios of 25 to 30 calves per 100 cows indicate a stable population, and ratios greater than 30 indicate an increasing population (FLNRORD 2019). Cow:calf ratios in the NWA and Kispiox Valley declined slightly from the early 2000's to now, but remained well above 30 calves per 100 cows.

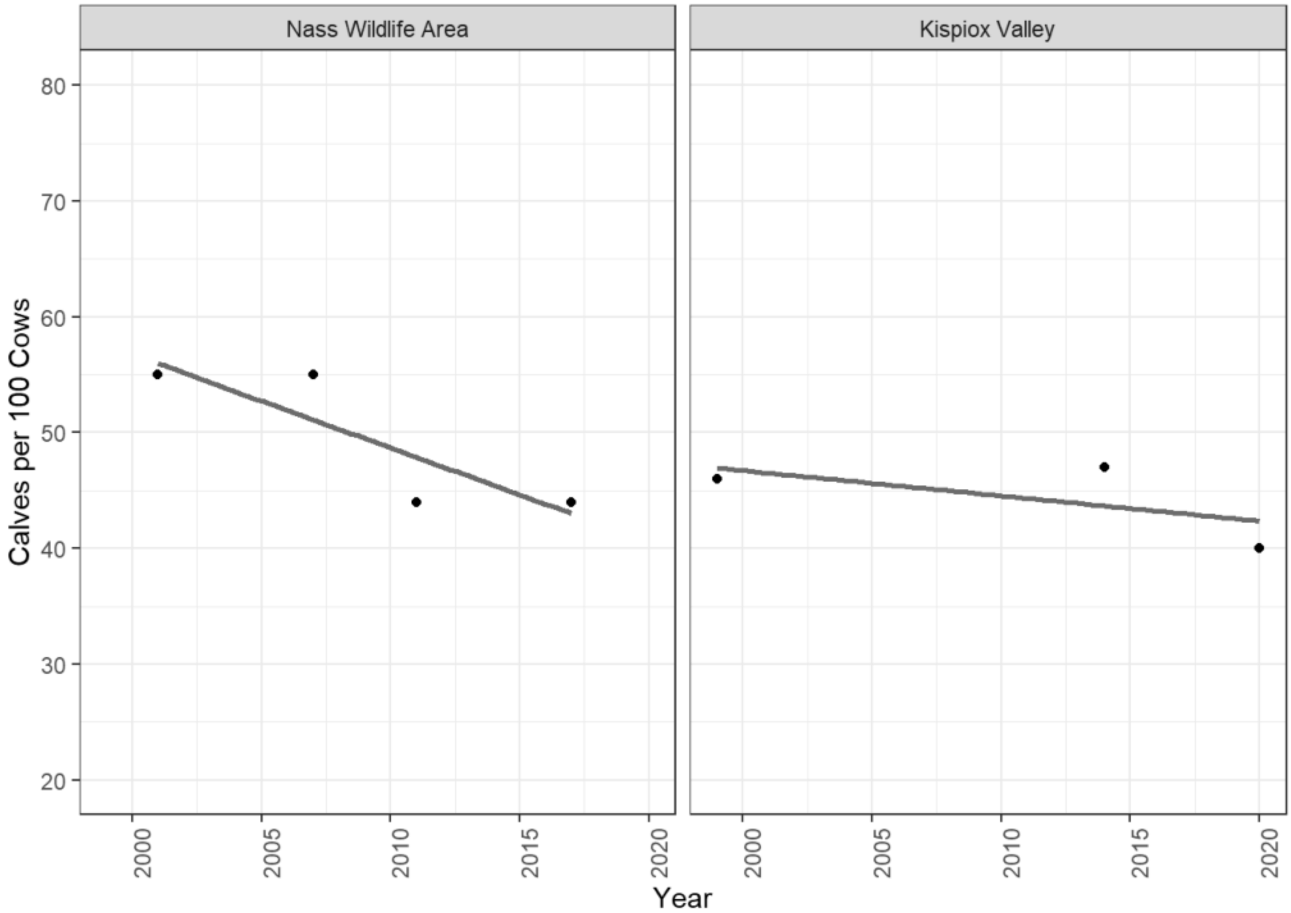


Figure 3. Moose calf:cow ratios for the Nass Wildlife Area and Kispiox Valley in the Kispiox Timber Supply Area.

Hunter harvest total and effort can sometimes be used as indicators of moose population trends, where low harvest totals and high efforts indicate low moose population abundance. In the Skeena region, hunter harvest totals declined from the 1990's to 2010, but were generally correlated with the number of resident hunters, indicating the harvest decline wasn't due to moose population declines but due to a decline in hunter participation (Thiessen, 2014. Skeena Region moose harvest overview: 1976 – 2011. BC Ministry of Forests, Lands and Natural Resource Operations. Smithers, BC. 57 pp.). Hunter effort increased from 2005 (~30 days/kill) to 2011 (~80 days/kill), but this increase may be due to decreasing amount of young, open forest (i.e., open sightlines), due to decreasing forest harvest in the region (H. Schindler, pers. comm.).

The ratio of bull moose to cow moose can sometimes be used to indicate hunting pressure on moose populations, and a ratio of greater than 30 bulls to 100 cows is a typical management target, where populations below that indicate a heavily hunted, and potentially unstable population (Young and Boertje 2008; Walker et al. 2017). The bull:cow ratio has consistently been above this target in the NWA and Kispiox Valley, increasing slightly in both areas from the 2000's to now.

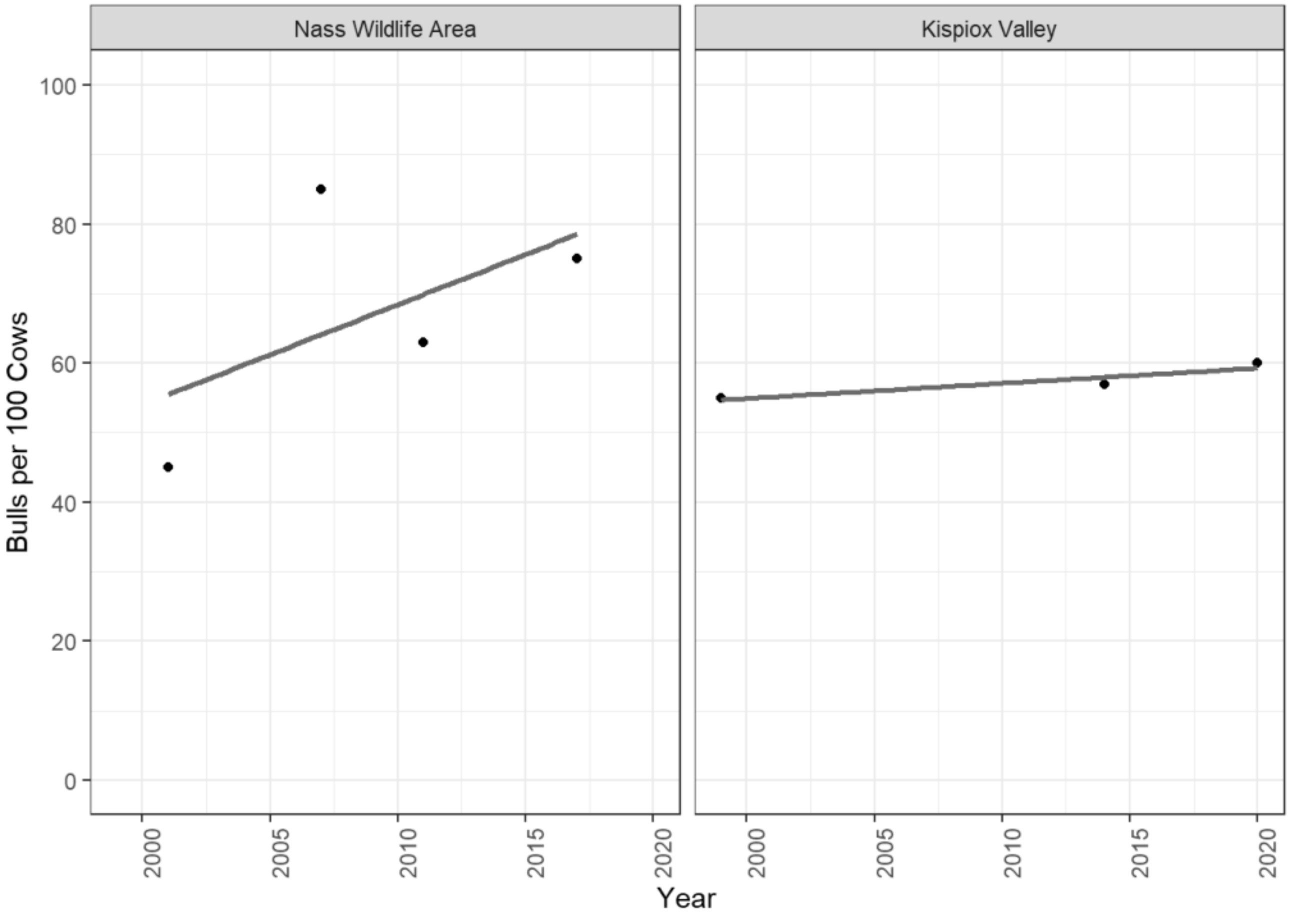
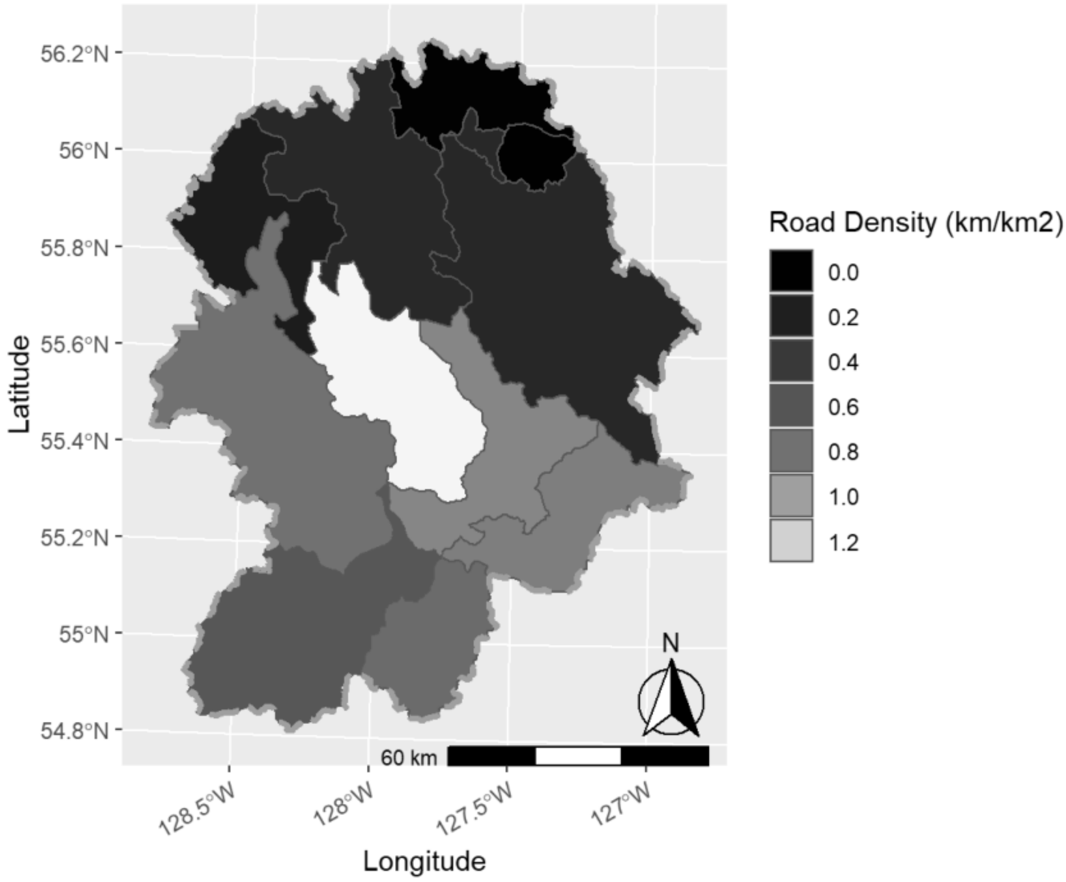


Figure 4. Moose bull:cow ratios for the Nass Wildlife Area and Kispiox Valley in the Kispiox Timber Supply Area.

Overall, the moose population indicators suggest that the moose population in the Kispiox TSA has been stable between 2000 to 2020.

Roads

Road densities are relatively high in the Kispiox TSA, with 6 of the 10 landscape untis havign road densitives greater than 0.6 km/km^2. Higher densities occurred in the central and southeast portions of the TSA. The Kispiox South landscape unit had the highest road density (1.34 km/km2), and the Suskwa, Middle Skeena South, Cranberry, Gitsegukla and Lower Skeena landscape units had road densities greater than 0.60 km/km2. Thus, road densities in the central and southern portions of the Kispiox TSA potentially present a risk for moose, and roads may be having their greatest influence in east-central portions of the TSA.



Kispiox TSA boundary indicated by green dashed line.

Figure 5. Current road density in landscape units in the Kispiox Timber Supply Area.

Forest Stand Characteristics

The percentage of forested area within a landscape unit that is 5 to 30 year old cutblocks is a useful indicator of forage availability for moose, where very low or very high proportions could indicate too little forage or too little forest cover, respectively, and thus poor habitat conditions for moose.

The southern and west-central portions of the Kispiox TSA had the highest percentage of forested area as cutblocks 5 to 30 year old. The Kispiox South landscape unit had 8% of forested area as cutblocks 5 to 30 year old and the Cranberry and Middle Skeena South landscape units had 5% forested area as cutblocks 5 to 30 year old. The northern and southern portions of the Kispiox TSA had a low percentage of forested area as cutblocks 5 to 30 year old.

It does not appear that forest harvest is occurring at high enough rates to cause a lack of older forest stands that provide cover for moose. Forestry may provide some forage habitat for moose in central portions of the Kispiox TSA, but not in northern portions of the TSA. However, these results should be considered with road density estimates, as potentially high forage value areas correspond with high road density areas.

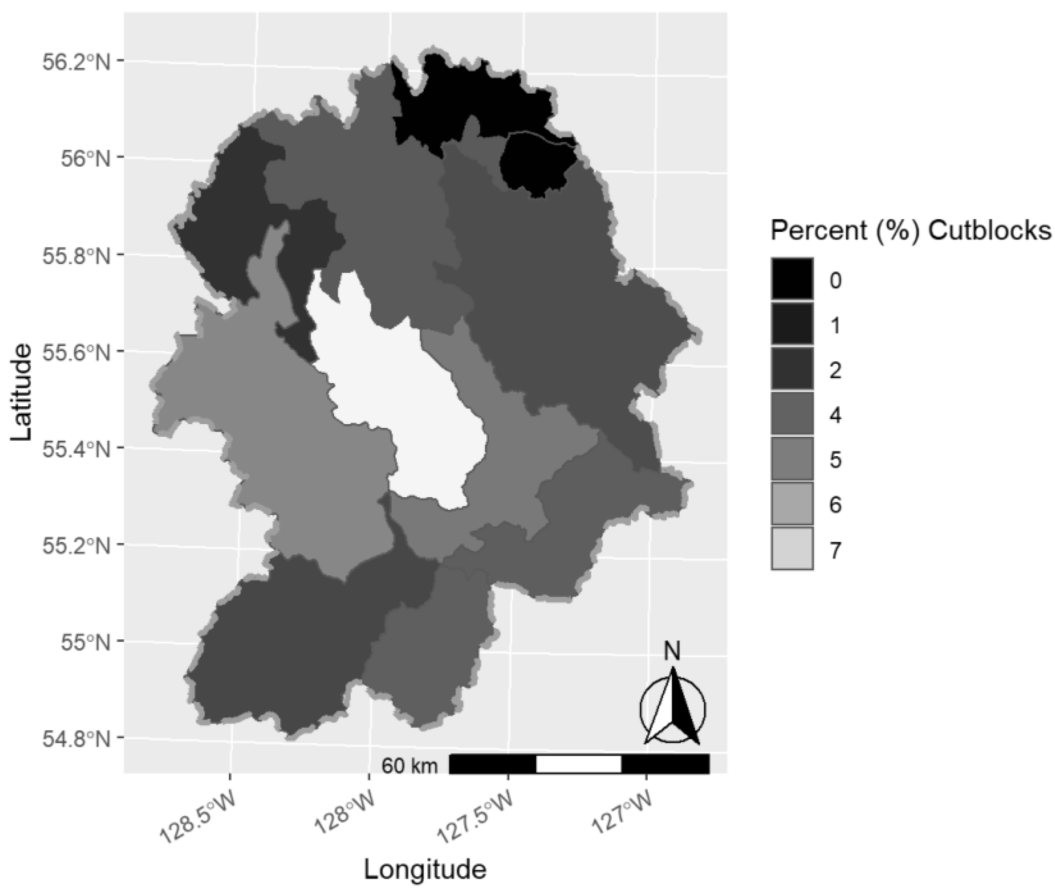


Figure 6. Current percentage of landscape units that are cutblocks 5 to 30 years old in the Kispiox Timber Supply Area.

Future Conditions

- analyze outputs from timber supply models, if/when available

Alternate Forest Management Regimes for Moose

- scenario that includes proposed draft moose UWR and general wildlife measures

Roads

- future road densities, at 10 years intervals

Forest Stand Characteristics

- future proportion of 5 to 30 year old cutblocks

Timber Supply

- comparison of timber supply between base case and 'moose case'

Mitigating Potential Impacts of Forest Harvest to Moose

Impacts to moose from forestry may be mitigated by limiting road building and deactivating and restoring roads that are built, and maintaining a rate of forest harvest that sustains a steady proportion of age 5 to 30 year old cutblocks in the forested area. It's not known what road density is too high, or what proportion of age 5 to 30 year old stands is ideal for moose populations in the region. However, it appears that recent levels of forest harvest and road density have not been significantly limiting moose populations across the TSA. Forest management regimes that may cause a significant deviation from current conditions could be risky for moose population sustainability and should be evaluated with careful monitoring of moose habitat and populations. In addition, localized concentratations of forest harvest activities

Uncertainties and Limitations

The relationship between road density, young forest and moose population dynamics is not clear. These relationships vary across BC, and there are no known habitat thresholds defined for the Skeena region. Within the region, it's not known how road density or vegetation composition (particularly moose forage) post-forest harvest influences moose survival and abundance. Additional research and monitoring of moose populations in response to forestry would significantly improve our understanding of how forestry influences moose in the region.