Moose Habitat and Populations in Alberta

Boreal and Foothills Regions

fRI | fRI Research
Informing Land & Resource Management

ABOUT THE AUTHORS

fRI Research is a unique community of Partners joined by a common concern for the welfare of the land, its resources, and the people who value and use them. fRI Research connects managers and researchers to effectively collaborate in achieving our vision and mission.

Learn more at fRIresearch.ca

The fRI Research Caribou Program carries out applied research, in partnership with industry and the Government of Alberta, to help maintain caribou herds in Alberta into the future.

Learn more at fRIresearch.ca/program/caribou-program

Prepared by:

Karina Lamy, Caribou Program Wildlife Biologist, fRI Research

Dr. Laura Finnegan, Caribou Program Lead, fRI Research

DISCLAIMER

This is a draft report. Any opinions expressed in this report are those of the authors, and do not necessarily reflect those of the organizations for which they work, or fRI Research.

November 1, 2019

ABOUT OUR PARTNERS

A leading diversified wood products company, West Fraser Mills Ltd. operates more than 45 manufacturing facilities in Western Canada and the southern United States. Today, the company is one of North America's largest lumber manufacturers and an established leader in sustainable forestry, high-efficiency wood product production and innovation in manufacturing.

Learn more at westfraser.com

FRIAA serves the people of Alberta and is accountable to the Minister responsible for Forestry. Over nearly two decades, FRIAA has helped Alberta continue to develop world-class forest management practices and a sophisticated understanding of the relationships between things like human activity, forest resources, species at risk, and wildfire

Learn more at friaa.ab.ca

ACKNOWLEDGEMENTS

Cover photograph: Karina Lamy

EXECUTIVE SUMMARY

Moose occur across the northern Boreal and Foothills of Alberta (*Alces alces*). Their core range is in mid- and west-central Alberta and supports the highest densities of moose in the province. The most recent provincial population estimate from 2014 is 115,000. However, in northern Alberta and British Columbia, local populations are thought to be in decline, and concern has been voiced about local population declines by First Nations and land managers.

Changes in the distribution of moose are driven by climate change, predation pressure, habitat change, recreational harvest, and disease. In British Columbia, although population limiting factors are known to be contributing to moose population declines, the specific mechanisms driving these declines are unknown. In the Boreal and Foothills of Alberta, there is less available knowledge of limiting factors and mechanisms that may be contributing to local declines.

Wildlife managers regulate moose populations through harvest and predator management, and to a lesser extent through habitat management. Although forestry does not regulate moose populations, forestry activities do change moose population dynamics through changes in habitat. Forestry is one of the dominant anthropogenic landscape driver changing habitats by design in Alberta's Boreal forests, and there is potential to enhance moose-forestry co-management through improved forest planning and management practices.

This document reviews the current literature on moose, with a specific focus on the Foothills and Boreal regions of northern Alberta, specifically with a goal of identifying gaps in our knowledge in: Ecology, Monitoring Methods, and Response to Disturbance. These gaps were used to develop Future Directions that are meant to facilitate consultations and tabletop sessions with stakeholders, organizations, and individuals with the goal of identifying next steps and gathering local knowledge. Based on these knowledge gaps, we provide ten Future Directions with several recommendations to support forest planning and best management practices to benefit moose through the development of future research, partnerships, plans, and guidelines. Based on this literature review it is likely that moose could benefit most from future research informing the following **topic areas**:

  i. researching moose population sizes and trends;
  ii. researching moose response to mountain pine beetle;
  iii. developing industrial access management plans;
  iv. improving herbicide BMP application strategies;
  v. enhancing the government Open Data Portal;
  vi. partnering in observational winter tick surveillance;
  vii. planning for climate resilient and connected forests;
  viii. researching moose and moose browse response to operational and forest planning practices;
  ix. considering landscape scale criteria in cumulative effects assessments; and
  x. innovating moose monitoring methods.

TABLE OF CONTENTS

TABLE OF TABLES

1. BACKGROUND

1.1 OVERVIEW

Moose (*Alces alces*) in Alberta primarily reside in the Boreal and Foothills Natural Regions, but over the last 40 years they have spread south into the Parkland and Grasslands Natural Regions (Bjorge et al. 2018). These changes in the distribution of moose are driven by climate change, predation pressure, habitat change, recreational harvest, and disease (Rippin 2001). Recently, there has been renewed concern from First Nations and stakeholders that moose are in decline in northern Alberta (T8FN Team 2012; Alexis 2010); L. Trout pers. comm. 2019). Adjacent populations in British Columbia are in general decline, and although population limiting factors have been identified and are known to be contributing to this decline, the specific mechanisms driving moose decline in British Columbia are unknown (Kuzyk, Hatter, et al. 2018; Kuzyk, Marshall, et al. 2018). It is currently unclear whether moose in the Boreal and Foothills of Alberta are declining.

This document reviews the current literature on moose, with a specific focus on the Foothills and Boreal regions of northern Alberta, in order to identify key gaps in our knowledge in: **Ecology (Section 2)**, **Monitoring Methods (Section 3)**, and **Response to Disturbance (Section 4)**. These key gaps could be used to guide **Future Directions (Section 5)**, and to facilitate consultations and tabletop sessions with stakeholders, organizations, and individuals with the goal of identifying next steps and gathering local knowledge.

1.2 BOREAL AND FOOTHILLS REGIONS

The economy in northern Alberta is primarily driven by industrial development (i.e. forestry and oil and gas) on forested Public Lands in the Boreal and Foothills regions (Hebblewhite 2017; AEDT 2019). Agriculture in the Boreal and Foothills of northern Alberta is less prevalent than in the Parkland and Grasslands, since cultivation is limited by shorter growing seasons (Natural Regions Committee 2006). In addition to public lands, northern Alberta has large areas of federally and provincially protected land.

1.2.1 VEGETATION AND CLIMATE

The Boreal is the dominant ecosystem in Alberta (58% of the province), with the Foothills, considered to be sub-Boreal, representing a smaller area (10%). Boreal and Foothills topography is mostly even or gently undulating, excepting at higher elevations in the Foothills, where it transitions into more steeply sloping terrain (Natural Regions Committee 2006).

The Boreal is predominantly a mix of wetlands and deciduous, mixedwood, and coniferous forests. The southern Boreal is dominated by aspen (*Populus tremuloides*) interspersed with white spruce (*Picea glauca*), and wetlands. The northern Boreal is mixedwood, dominated by aspen, white spruce, and balsam poplar (*Populus balsamifera*) interspersed with fens. Wetlands have black spruce (*Picea mariana*), shrub, or sedge fens, while dry, well-drained areas can have stands of jack pine (*Pinkus banksiana*). The climate in the Boreal is moist and cool, with short summers (Daily Avg. Temp. ≤15°C) and long cold winters (Daily Avg. Temp. < -10°C; Natural Regions Committee 2006).

The Foothills are dominated by deciduous and mixedwood forests of aspen, white spruce, balsam poplar, white birch (*Betula papyrifera*), lodgepole pine (*Pinus contorta*), and black spruce at lower elevations. There are also some wetland areas with stunted black spruce and tamarack (*Larix laricina*) or shrub communities. At higher elevations, coniferous forests of lodgepole pine are dominant. The climate is moist and cool with short summers and cold winters (Natural Regions Committee 2006).

1.2.2 CULTURE

First Nation communities in northern Alberta are predominantly Woodland Cree and Dene, and are both members of the Treaty 8 First Nations (T8FN). Moose are particularly important for subsistence hunting, since they are the traditional staple for many First Nation communities (Schramm and Krogman 2001; Nelson 2003; Alexis 2010; T8FN 2012) because they are large and widespread (Alexis 2010).

Although, traditionally bison, where present, were the culturally preferred species, but as they became scarce in the 1830s, caribou and moose were hunted instead (Broomfield in T8FN 2012). More recently, as caribou have become scarce, moose became the most important food source. However, as moose are also now scarce in some areas like Peace River country, some T8FN members have switched to hunting elk (T8FN 2012). However, elk skin is thin and cannot be used for many traditional purposes (e.g., moccasins, shelters, clothing; T8FN 2012). Therefore, although there is great concern over the loss of caribou and moose, there is also concern over the loss of culture, values, and way of life (T8FN 2012).

2. Moose Ecology

2.1 Distribution and Description

There are seven recognized subspecies of moose and four occur in Canada (Peterson 1955; Rippin 2001). In Alberta, Northwestern moose (*A.a. andersoni*) occur in the Boreal and Foothills, and Shira's moose (*A.a. shirasi*) occur in the south; both are listed as 'secure' under the Alberta Wildlife Act (AEP 2017).

Moose are the largest ungulate (Cervidae), weighing up to 771kg (Rodgers 2001) and standing 2m tall at the shoulders (Rippin 2001). However, the average weight of the Northwestern moose in Alberta is 441kg for males and 400kg for females (Lynch et al. 1995). Moose are considered senior at 10-12 years of age (Rodgers 2001), and rarely live more than 16 years (Rausch, Gasaway, and Schwartz 2008).

During the snow-free season (May to late-November), moose are typically solitary or occur in cow-calf pairs until the rut (early-September to late-November), when they can be found in groups of three to six (RISC 1998). During the rut, bull moose breed with several females and afterwards disperse, shedding their antlers from late-November to December. During spring (late-May to early-June), cow moose commonly produce only one calf per year, but can have up to three calves (Rausch, Gasaway, and Schwartz 2008). Higher twinning rates are a sign of a productive population (e.g. Lynch 2006).

2.2 Population Sizes and Trends

In North America, the most recent moose population estimate (2014-2015) was approximately 1,000,000 individuals with approximately 115,000 in Alberta (provincial data based on hunting records; subspecies data not available; Timmermann and Rodgers 2017).

In Alberta, the highest moose densities are in the mid-boreal and boreal-cordilleran mixed-wood forests in the west and central parts of the province. The provincial population estimate was 92,000 in 2001, increasing to 115,000 in 2014 (Timmermann and Rodgers 2017). However, in Alberta and British Columbia populations are presently in decline (R. Corrigan pers. comm. In Timmermann and Rodgers 2017; Kuzyk, Hatter, et al. 2018).

Historically, moose were abundant in Alberta prior to the 1940s (Rippin 2001). However, population limiting factors – like wolf predation, non-licensed and recreational harvests, agricultural land conversion, wildfire, and winter tick outbreaks (*Dermacentor albipictus*) contributed to general population decline into the late 1940s (Rippin 2001). In the 1950s, wolf control and better harvest management practices contributed to moose populations rebounding into the 1960s. But in the late 1970s, moose populations again began to gradually decline, and this decline continued into the 1980s. Overharvesting, predation, and significant winter tick outbreaks were the primary drivers of this decline, but fire suppression and agricultural and industrial land conversion were also contributing factors.

Moose harvest management evolved in response to these declines, becoming more adaptive by employing limited-entry systems and by designating Wildlife Management Units (WMU), with management actions specific to each WMU. In the 1990s, recreational and First Nation hunters became concerned about low numbers of bulls. These

concerns drove further change in moose management towards planning by moose population structure and density, while also accounting for different limiting factors (Rippin 2001).

In 1999, a strong El Niño year providing favourable conditions for winter tick survival and reproduction (i.e., limited snowfall, mild winter, hot dry summer) resulted in a major winter tick outbreak, causing significant moose mortality (Pybus 1999). Since then, there was another strong El Niño year from 2015-2016, but weaker than the 1999 El Niño event (GOC 2016; Huang et al. 2017). However, we could not find information indicating that this El Niño event caused any significant winter tick outbreaks, nor could we find records of significant moose mortality in Alberta during this time.

Between 2000 and 2014, moose populations gradually returned to numbers previously observed in the early 1980s (Timmermann and Rodgers 2017). However more recently, moose populations have been trending towards decline (R. Corrigan pers. comm. 2015 In Timmermann and Rodgers 2017). In 2010, several First Nations in the Boreal (i.e., Beaver Lake Cree, Aseniwuche Winewak, Bigstone Cree) noted moose populations in their areas were declining, and expressed concerns related to population health and the number of sick and thin looking animals on the landscape (Alexis 2010). Conversely, Alexis Nakota Sioux Nation noted increases in the moose population in their homelands adjacent to the Parkland region and expanses of cultivated land (Alexis 2010). Between 2015 and 2019, there is a gap in the literature describing moose population trends, sizes, and their fluctuations with limiting factors. However, results compiled from individual WMU aerial inventory reports (1978-2018) indicate that during that time some local moose populations have been in decline, while others are stable or increasing. Overall, in the Boreal and Foothills, moose populations have been declining since the 1980s (1978-2018 WMU reports), whereas in the Grassland and Parklands, populations have been increasing (Bjorge et al. 2018; see **Section 2.5.2** Range Expansion and Shifts).

Historically, fluctuations in moose populations have been related to synergistic limiting factors, many of which managers cannot directly control like parasites, disease (e.g. winter tick), insects (e.g. MPB), and weather. However, current moose populations are likely being influenced by additional limiting factors which differ across populations, but which could be managed. For example, differential intensities of mountain pine beetle infestation, industrial development, and human and predator access may all impact moose populations (e.g. Kuzyk 2016). These factors, combined with climate change and increasing human disturbance, mean that management of habitat and harvests to manage moose populations will become increasingly important (Timmermann and Rodgers 2017).

2.3 MOVEMENT BEHAVIOUR

For many species, movement occurs at two different scales: the home range and the landscape. The home range scale encompasses local movements and daily activity patterns. The landscape scale describes large scale movements like juvenile dispersal, seasonal range shifts, and migratory movements (see **Section 4.5** Habitat Connectivity). At the daily scale, moose are active during the day and night, with peak activity periods at dawn and dusk to forage (Klassen and Rea 2008). At the seasonal scale, moose migrate and disperse from summer ranges to winter ranges by latitudinal or elevation gradients (Demarchi 2003).

2.3.1 MIGRATORY MOVEMENTS

Not all moose in a population will migrate from winter to summer ranges (e.g. Stenhouse et al. 1994; Ball, Nordengren, and Wallin 2001). Older moose in Sweden, for example, became non-migratory in areas with high road density or high hunting pressure (Singh et al. 2012), and in Ontario, female moose migration and movements are restricted by roads (Finnegan et al. 2012).

Considering moose that migrate, moose migration is influenced by snow pack depth (Demarchi 2003), and seasonal green-up of herbaceous vegetation (Allen et al. 2016). Before calving (April to June), as the snowpack decreases moose move from winter to summer ranges, returning to winter ranges when snowpack increases (December to January; Demarchi 2003). During these seasonal migrations moose can travel distances of up to 75km (i.e. *A.a. gigas*; Demarchi 2003). Moose ranges may be separated by elevation or latitudinal gradients; e.g., moose in the mountains spend the summers at high elevation (e.g. 1500m), and move to lower elevations during the winter (e.g. 200m; Demarchi 2003).

Cows teach migratory movements and routes to their calves. However if calves are orphaned prior to migration, they may fail to migrate and stay on their summer range throughout the winter, or they may establish a different winter range than their mother (Sweanor and Sandegren 1989). Reintroduced moose can take decades to accumulate knowledge through generations to re-establish reliable migration corridors (Jesmer et al. 2018). Additionally, moose migratory corridors may not necessarily be a well-defined route taken by the entire population, but can consist of multiple routes taken by different individuals.

2.3.2 DISPERSAL MOVEMENTS

Yearling moose are the primary dispersers in moose populations. While on the summer range, their mothers drive them away prior to birthing young of year (Altmann 1958; Stringham 1974). Dispersers have variable dispersal patterns (Labonte et al. 1998; Hoffman, Genoways, and Choate 2006) and typically disperse short distances (< 15.2km; Labonte et al. 1998), but dispersal distances as high as 1,511 km have been reported (Hoffman, Genoways, and Choate 2006). In some cases, moose have high inter-seasonal fidelity to their natal range (Göran Cederlund, Sandegren, and Larsson 1987), and can retain winter or summer ranges in common with their mothers (i.e. partial dispersal; Göran Cederlund, Sandegren, and Larsson 1987; Labonte et al. 1998). Yearling males also disperse farther than females (Labonte et al. 1998), and females retain more overlap in their established home ranges with their mothers than males (Göran Cederlund, Sandegren, and Larsson 1987).

2.4 HABITAT

Moose are primarily associated with shrublands and deciduous cover (Stewart, Komers, and Bender 2010), which can be considered "permanent" moose habitats (Geist 1971). Moose are also dependent on early seral habitats generated by major disturbances that are dynamic (e.g., fire, forestry; Geist 1971).

2.4.1 HABITAT USE

Moose habitat use is driven by foraging requirements and co-occurring factors like wildfire, mountain pine beetle (*Dendroctonus ponderosae*), predation risk, heat stress, and human disturbance (e.g. Snaith and Beazley 2004). Moose

are habitat generalists occupying a range of habitats during different stages of their life cycle – including boreal forest, mixedwood forest, subalpine shrub, tundra, flood plains, and riparian areas (Secretariat 2014). Generally, moose browse on aspen, willow, and birch, but from mid-June to July they also browse on aquatic vegetation (Timmermann and McNicol 1988).

As generalists, moose interact with a mosaic of habitat types (Stewart, Komers, and Bender 2010), adjusting their habitat preferences with changes in resource availability (Osko et al. 2004). In northeastern Alberta, moose habitat preferences changed with changes in abundance of available habitat, even though similar habitats were available (Osko et al. 2004). However, moose primary habitat associations are with shrubland communities and deciduous forests (Stewart, Komers, and Bender 2010), and low elevations where these shrubland communities and deciduous tree cover are more prevalent. To a lesser extent, moose are also associated with wetlands (Serrouya et al. 2011; Toews 2016).

2.4.1.1 WINTER RANGE

Lamy, K.

Moose winter range (Photo: Lamy, K).

Moose winter ranges are smaller than their summer ranges (winter: 110.7km^2, summer: 237.9km^2; Peters 2010b), and they adapt the size of their home range to changes in forage quality, availability of suitable habitat types (Bjørneraas et al. 2011), and snow depth (Telfer 1970). Generally, moose winter range includes areas with less snow that allow good mobility, and have higher habitat suitability (Demarchi 2000) and browse production (Telfer 1970). During periods of deep snow, moose will reduce their movements and select areas with dense coniferous stands or select coniferous patches within mixed stands (Telfer 1970; Rehaume Courtois et al. 2002). But when snow depth is not limiting, moose select shrublands and open deciduous or coniferous forests (Telfer 1970), and avoid avalanche chutes (Serrouya et al. 2011) and grasslands (Stewart, Komers, and Bender 2010). Grasslands are thought to have a fragmentary effect on moose populations and are avoided during winter due to deeper snow, reduced mobility (Telfer 1970), and reduced escape cover (Stewart, Komers, and Bender 2010). Even in open stands snow depth can be up to 70% greater than adjacent closed canopy forests (Rolley and Keith 1980).

In years with long periods of deep snow (>70cm; Sweanor and Sandegren 1989) winter habitat is limited, and moose are concentrated (60-90cm) on or even confined (>90cm) to critical winter range (Telfer 1970), causing intense browsing damage in these areas (Sweanor and Sandegren 1989). During winter, moose primarily browse on trembling aspen, willow, white birch, balsam poplar, balsam fir (*Abies balsamea*), red-osier dogwood (*Cornus stolonifera*), beaked hazel (*Corylus cornuta*), pin cherry (*Prunus pensylvanica*), Saskatoon berry (*Amelanchier stolonifera*), and green alder (*Alnus crispa*; Timmermann and McNicol 1988).

2.4.1.2 SUMMER RANGE

During summer, habitat heterogeneity is important for moose; a mix of older and younger forest age classes with non-forest cover types optimizes cover and forage from predation and heat stress, while also providing access to forage (Olsson, Brown, and Smith 2002; Olav Hjeljord, Hövik, and Pedersen 1990). If moose summer home ranges are within highly productive habitats, they are smaller than those within unproductive habitats (e.g. Bjørneraas et al. 2012). During summer, moose browse the same species as in winter, although they do not consume balsam poplar and balsam fir (Timmermann and McNicol 1988). They also consume aquatic plants including emergent aquatic species (pond lilies (*Nuphar spp.*)), and submergent aquatic species (pond weeds (*Potomegeton spp.*), macroscopic algae (*Niteila spp*. and *Chara spp*.), bladderwort (*Unicularia vulgaris*), and water milfoil (*Myrophyllum verticillatum*; (Timmermann and McNicol 1988). During calving, cows select refugial habitats or sites for birthing, in isolation from other cow-calf pairs (e.g. islands; (T8FN 2012), that reduce predation risk and increase calf survival (White et al. 2014).

2.5 ENVIRONMENTAL CHANGE

Climate is a known population distribution driver for moose as well as for other ungulates. It is predicted that winters will continue to warm and have increased precipitation, and spring will continue to arrive earlier, reducing soil moisture and resulting in longer growing seasons (Cerezke 2009). Half of the western Boreal is predicted to have a drier climate similar to the Aspen Parkland Zone by the 2050's (Schneider et al. 2009; Cerezke 2009).

With climate change, forest fires are also predicted to be larger, more frequent, and more severe (Hanes et al. 2018). As forests are burned, succession will shift to forests with younger age class structures, which is likely to impact moose distribution and abundance (e.g. Eastman 1974; Lord and Kielland 2015). Extreme weather events are also predicted to be more frequent with climate change, resulting in more severe storms, periods of drought, and tree mortality (Cerezke 2009). Climate change and its interaction with ungulates and harvest dynamics is already a research priority in Midwestern United States, and may be an important upcoming research priority across Canada (Weiskopf, Ledee, and Thompson 2019).

2.5.1 BOREAL AND FOOTHILLS SHIFTING

In Alberta, a drier climate in the central, northern, and southern Boreal will cause changes in tree species composition (Cerezke 2009). Widespread aspen forest distribution and productivity is expected to be particularly affected, with aspen shifting northward in response to environmental change (Cerezke 2009). Periodic dieback is predicted primarily from drought stress and insect defoliator outbreaks (Cerezke 2009). White spruce in central and northern Alberta are also predicted to decline, and productivity and mortality is expected to increase. Lodgepole pine productivity has been increasing in the Foothills in recent years, it is unclear whether this is an effect of climate change or changes in management practices (Cerezke 2009).

Eventually, with climate change non-native fauna and flora from warmer climates will also arrive in the Boreal and Foothills (Schneider 2013). Insects and tree pathogens are expected to benefit from these changes include mountain pine beetle, spruce beetle, spruce budworm, wood borers, root disease, and stem cankers (Cerezke 2009). As climate

change and resulting effects increase, developing tools and advancing knowledge to better manage habitat will become increasingly important (Timmermann and Rodgers 2017).

Water scarcity leading to drought is the biggest climate risk in Alberta (Toews 2016), and increasing temperatures and evapotranspiration rates will impact wetlands and peatlands; water levels will subsequently drop and decomposition rate of dead plants will increase (Cerezke 2009). **As moose depend on aquatic habitats seasonally for nutrients, water scarcity and changes to wetlands are likely to impact moose, but the vulnerability of moose to these habitat changes has not been assessed in Alberta (e.g. Rempel 2012).**

2.5.2   RANGE EXPANSION AND SHIFTING

Recently, moose range has expanded north into Nunavut and the Northwest Territories (Timmermann and Rodgers 2017), south into the coastal rainforests in British Columbia (Darimont et al. 2005), and east into the prairies of Alberta (Bjorge et al. 2018), and Saskatchewan (Laforge, Michel, and Brook 2017). Although at a continental scale 10 of the 15 moose populations at the southern limit of their distribution are stable or increasing, recent information has described declines in local moose populations in Alberta and British Columbia (R. Corrigan pers. comm. In Timmermann and Rodgers 2017; Kuzyk, Hatter, et al. 2018; Timmermann and Rodgers 2017) (see Section 2.2.).

In Alberta, moose were first observed in the Parklands in the early 1970s (Bjorge 1996) and began to colonize them in the 1980s (Bjorge et al. 2018). More recently moose started to colonize the Grasslands in the early 2000s (Bjorge et al. 2018). In both the Parklands and Grasslands, the reduction of several population limiting factors contributed to this southern range expansion (Rippin 2001; Bjorge et al. 2018). Human activity declined as private farms were replaced by corporate farms (Rippin 2001; Bjorge et al. 2018). In addition, in the Parklands and Grasslands hunting pressure from illegal harvest is in decline, and predation risk (i.e., wolves, black bears, grizzly bears) is lower when compared to the Boreal (Rippin 2001; Bjorge et al. 2018).

In addition to a reduction of moose population limiting factors, Parklands and Grasslands areas also benefit moose because they contain important resources. In agricultural landscapes moose select crops (high protein forage), wetlands, and forests (Laforge, Michel, and Brook 2017). The current level of crop browsing and damage in Alberta is unknown (Bjorge et al. 2018), but oilseed and pulse crops in particular are preferred by moose in Saskatchewan (Laforge, Michel, and Brook 2017). Outside of farmlands, the Parklands and Grasslands have suitable moose habitat like river valleys and small wetlands, and the available browse from shrub communities in riparian habitats and remnant forest patches is expected to continue to support population growth (Bjorge et al. 2018). **Further research is required to understand how and why moose are expanding their ranges (Timmermann and Rodgers 2017).**

2.5.3   HEAT STRESS

Under climate change scenario models, mean annual temperatures in Alberta are predicted to increase between 2.0°C and 4.2°C by 2100 (Schneider 2013). Moose are well-adapted to cold (-5°C to -30°C), with a dense wool undercoat, long winter guard hairs, and a high volume-to-surface area ratio (Renecker and Hudson 1986; Rippin 2001; McCann, Moen, and Harris 2013). However, moose have a limited ability to reduce their internal heat load (Renecker and

Hudson 1986; Rippin 2001; McCann, Moen, and Harris 2013), which can limit moose distribution and activity (Dussault, Ouellet, and Courtois 2005), especially at the southern limits of their distribution (e.g. Ditmer et al. 2017).

Above 14°C in summer and -5°C in winter (Renecker and Hudson 1986; Schwartz and Franzmann 1991), moose become heat stressed and begin to pant to increase evaporative cooling (Renecker and Hudson 1986). Areas experiencing hot periods above 27°C without shade are unsuitable for moose (Kelsall and Telfer 1974). The limitations imposed by heat stress can affect the ability of moose to meet energetic requirements and affect their productivity and survival (Dussault et al. 2004; McCann, Moen, and Harris 2013). Combined with other population limiting factors, heat stress can contribute to population decline (Lowe, Patterson, and Schaefer 2010; Murray et al. 2006; Galatowitsch, Frelich, and Phillips-Mao 2009).

Moose primarily select habitat based on foraging requirements, but may alter their selection for stand types that provide thermal cover (Street, Rodgers, and Fryxell 2015). In response to hot periods during summer and fall, moose modify their behaviour by reducing their activity during the day, seeking shade and water, and increasing nocturnal activity (Renecker and Hudson 1986; Dussault et al. 2004). However, moose may have some variability in their response to heat stress, and heat tolerance thresholds may be higher than previously thought (Lowe, Patterson, and Schaefer 2010; McCann, Moen, and Harris 2013). At the southern limit of their distribution, moose in Ontario did not exhibit any signs of heat stress within the expected range of temperatures (Lowe, Patterson, and Schaefer 2010), and in Nova Scotia, moose sought thermal cover above the expected range at around 24°C (Broders, Coombs, and McCarron 2012). Solar radiation (Bourke 2003; Eigenberg et al. 2005) and wind (Berman et al. 1985; Mader, Johnson, and Gaughan 2010; McCann, Moen, and Harris 2013) can affect the onset of heat stress. In windy areas heat stress can occur at temperatures 4°C to 10°C higher than in other areas (McCann, Moen, and Harris 2013).

Within their current distribution, moose are predicted to respond to a warming climate by shifting their habitat use more into cooler low-lying (e.g., ravines, wetlands; Dussault et al., 2005). Existing thermal cover can be retained in the future through forestry management practices in cutblocks, so that moose can reduce their heat stress during critically hot periods (Broders, Coombs, and McCarron 2012). Retaining thermal cover may also benefit other ungulates (e.g. caribou; COSEWIC 2014). Young cutblocks are an attractive food source for moose, and retention patch design criteria could include placement and cover to support habitat resilience in these exposed areas (Dussault, Ouellet, and Courtois 2005). In the future, **research could quantify the ability of different cover types in Alberta (e.g. Street, Rodgers, and Fryxell (2015) in Quebec) to buffer high temperatures to support the development of best management practices for moose (Broders, Coombs, and McCarron 2012).**

2.6   MORTALITY RISK

In Alberta, the main causes of moose mortality are predation, disease, hunter harvest, and vehicular collisions (Rippin 2001). Other causes of mortality include starvation, heat stress, and natural accidents (Kuzyk, Marshall, et al. 2018). These mortality factors can be compensatory or additive in populations, and without proper documentation or knowledge of their changes they can have significant effects on management outcomes (Rippin 2001).

2.6.1 DISEASE

Moose populations in Alberta are historically most affected by winter tick (*Dermacentor albipictus* – primary host: moose; incidental host: deer), and to a lesser extent by spillover of giant liver fluke from infected elk and deer (*Fascioloides magna* – primary host: white-tailed deer; e.g.Pybus, Butterworth, and Woods 2015). In eastern Canada, brain worm (*Parelophostrongylus tenuis* – primary host: white-tailed deer) is prevalent and causes significant moose population declines. However brain worm has not been recorded in Alberta, since its range ends in Saskatchewan (Leighton 2011). Chronic wasting disease (CWD) primarily affects deer in Alberta, and although increasing in prevalence (1996-2017; GoC 2019), spill over into moose populations is not maintained and only occurs when CWD is well-established in deer (GoA 2013). In 2012, the first known moose CWD case in Canada occurred in Hilda, Alberta (GoA 2013).

The distribution of diseases are expected to expand north with a warming climate. For winter tick, a warmer climate will provide a more favourable environment for tick survival (Pybus 1999), and for giant liver fluke, brain worm, and CWD, a warmer climate will provide a more favourable environment for their host, deer (Dawe, Bayne, and Boutin 2014).

Winter tick has known to be present in moose populations Alberta since 1930 (Glines and Samuel 1989), and they are present on moose every year of their lives (Samuel 2004). However, widespread outbreaks that contribute significantly to moose population mortality occur less frequently. These events are known to have occurred between 1977 and 1979 (Samuel and Barker 1979) and in 1999 (Pybus 1999). In 1999, the tick outbreak coincided with a strong El Niño year, which produced a warmer more favourable climate for winter tick survival (Pybus 1999). After 1999, there is a gap in the literature (1999-2019) describing the timeline of significant tick outbreak.

Warming temperatures are expected to expand deer distribution by reducing snow cover and increasing warm weather (Dawe, Bayne, and Boutin 2014). Increased overlap between moose and deer distribution is expected to increase disease transmission and exposure to winter tick, giant liver fluke, and brain worm (Beazley, Ball, Isaacman, Mcburney, et al. 2006; Weiskopf, Ledee, and Thompson 2019). In Nova Scotia, the mainland moose population, at the southern limit of its distribution, began to decline from winter tick infection when the white-tailed deer population experienced significant growth (Beazley, Ball, Isaacman, McBurney, et al. 2006).

In Alberta, there is limited available information on the prevalence of diseases in moose. There is baseline disease surveillance of CWD and winter tick, but it is unclear if there is continuous surveillance for giant liver fluke. The methodology, spatial extent, and frequency of monitoring for the winter tick program is also unknown and there is a notable gap between 2000 and 2019 in winter tick publications. From 2015-2016, there was a strong El Niño year (GoC 2016), but we could find no information indicating that a significant winter tick outbreak occurred, or that significant moose mortality was recorded in Alberta. Given the cyclical nature of tick outbreaks and their significant contribution to moose mortality, it is important that this information is made available and monitored through partnerships with industry professionals, First Nation, stakeholders, biologists, and other interested parties. **The expansion of deer northwards into moose range, coupled with a more favourable predicted climate for winter tick survival, only highlights this need.**

2.6.2 PREDATION

Predators are often widespread across the landscape and when spatial refuge from predators is not an option, moose avoid predation risk (Dussault, Ouellet, and Courtois 2005). The main predators of the moose, wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), and black bears (*Ursus americanus*), are responsible for the majority of calf mortalities (3-55% of calves (Hauge and Keith 2007; Ballard and Van Ballenberghe 1998). Wolves are a significant predator of moose (Rippin 2001), predating on moose year-round (Rausch, Gasaway, and Schwartz 2008), and selecting their habitat based on prey availability (Kittle et al. 2017). Grizzly bears can also be a significant predator of moose calves, depending on prey availability (Boertje et al. 1988; Brockman et al. 2017). In northern Alberta, grizzly bears primarily predate on young of year or younger during the non-denning period (Larsen et al. 2019). Black bears, on the other hand, predate on moose calves primarily between May and June (Rausch, Gasaway, and Schwartz 2008). Cougars mainly kill young of year (<1 year, 74% of predations), but kill more adult moose (>200kg) in summer than winter; although adult cougars are physically capable of killing large adult moose (>400kg) they rarely do so (<2% of predations; Knopff et al. 2010).

Moose distribution is driven primarily by habitat availability, but they will trade-off foraging opportunities to reduce predation risk, minimizing their home-range overlap with wolves (Dussault, Ouellet, and Courtois 2005). During winter, wolves concentrate their hunting efforts in areas with low snow depth (Kunkel and Pletscher 2001), since they prefer to travel on shallow, compact snow (Droghini and Boutin 2018). Moose, on the other hand, can travel in snow depths of up to 65cm (Telfer 1970), but by avoiding areas of low snowfall and higher food availability to reduce predation risk they can increase their energy expenditure (Dussault, Ouellet, and Courtois 2005). In April when the snow starts to thaw and the ice has crusted, moose become more vulnerable to predation since they penetrate the snow, while wolves can run on top (Schramm and Krogman 2001).

Females with calves, in particular, will trade-off foraging for habitats with lower predation risk compared to solitary moose (e.g. Dussault, Ouellet, and Courtois 2005). Females with calves select habitats with forest cover over any other habitat type, trading off more open and higher quality foraging areas for less productive coniferous forests when compared to moose without calves (e.g. Bjørneraas et al. 2012). Moose also avoid disturbed areas like harvest blocks with better sightlines to reduce predation risk. For example, in British Columbia, females avoided recent cuts year-round, and high intensity harvest blocks during summer, preferring areas in or near mature conifer cover (Kuzyk et al. 2017). Bull moose, on the other hand, are less risk averse than females and will select areas with higher seismic line densities than females (Mumma and Gillingham 2017).

2.6.3 HUNTER HARVEST

Hunters in Alberta harvested 8,227 moose in 2018 and have harvested similar numbers over the past 7 years, representing approximately 6-10% of the population depending on the year (range: 7,618-9,006 moose; GoA 2014, 2015, 2016, 2017, 2018, 2019a). In 2018, 91% of the 133,543 hunters in Alberta were resident hunters (GoA 2019a), followed by First Nations and alien hunters. Depending on the WMU, there are special license antlered, antlerless, and/or calf moose draws (GoA 2019a).

Recreational hunter harvest is documented by the province, but First Nation hunter harvest and subsistence hunter harvest is not well documented. Moose meat for subsistence hunters (First Nation or non-First Nation) is an important food source, especially for those who are living marginally (Rippin 2001). In 2001, undocumented kills were estimated as 30% of the legal harvest (Rippin 2001). Information on subsistence and First Nation hunter harvest is needed for more effective management of moose populations, especially in areas where undocumented harvest is prevalent and a potential population limiting factor (Rippin 2001). Double allocation of moose due to unknown undocumented harvest can lead to exceeding annual population recruitment (Rippin 2001). In addition, industrial land use increases ease and accessibility of hunting, by facilitating travel and enabling the use of mechanized transport (e.g., ATVs, snowmobiles, 4X4 trucks) into previously remote areas through the development of trails, roads, and deforested areas (e.g. MacNearney et al. 2017). Increased hunter access puts additional pressure on moose (See **Section 4.4** Forestry Access and Other Anthropogenic Linear Features).
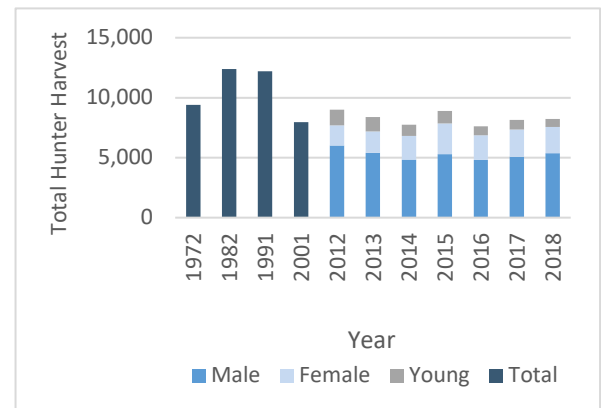

Figure 2.1. Hunter harvest in Alberta from 1972-2018.

In Norway, where there are fewer predators, there is high hunting pressure. Moose avoid open areas making trade-offs to avoid human activity (Bjørneraas et al. 2012; Lykkja et al. 2009). Females with young do so to the greatest extent compared to single females and males. In managed forests, visibility increases after clearcutting, so that within the 1-2 years after logging hunters can cause local moose population declines (e.g. Rehaume Courtois and Beaumont 1999). Eason (1985) recommend reducing harvest block size and leaving more forest to provide security cover, although new EBM approaches to forest harvesting warrants further investigation.

2.6.4 VEHICULAR COLLISIONS

Across Canada from 2000 to 2014, 236 people died in moose-vehicle collisions (WRRC 2017). Moose collisions (7%; 495) are the second most commonly reported wildlife collisions in Alberta (AWW 2019). Taking into consideration that the actual number of collisions are at least double those that are reported, the number of moose mortalities from vehicular collision is likely much larger (Bangs, Bailey, and Portner 1989). Moose, due to their large size, cause more vehicle damage and result in more injury and fatalities compared to other species (Mountrakis and Gunson 2009). Similar to other ungulates, during summer, moose are most active at dawn and dusk and during the rut in the fall (GoA 2009). They generally avoid roads, but can trade-off road mortality risk with roadside foraging opportunities by moving closer to roads at night compared to the day, and by moving closer to secondary roads with lower traffic volume rather than major roads with higher traffic volume (Eldegard, Lyngved, and Hjeljord 2012). **Whether moose respond differently to paved versus unpaved resource roads could provide valuable information for access planning.**

Between 2007 and 2009 the cost of moose-vehicle collisions on rural highways in Alberta was approximately $21.5million/year (Imran unpub. in Boyce, Baxter, and Possingham 2012). Between 1982 and 1991 there were 2,928

moose road mortalities in Alberta; the highest occurrence of these mortalities was in the Eastern Slopes and Peace River regions (41% and 31%), which are also in the areas with the highest provincial moose densities, followed by the Northeast Region (17%), and Central (10%), and Southern (1%) Regions (Rippin 2001).

Moose population density has a strong effect on vehicle collision rates, with collision risk increasing in areas with higher moose density (Rolandsen et al. 2011; Boyce, Baxter, and Possingham 2012). Moose road-crossing rates also increase proportionally with road density and differ across seasons, with higher crossing rates in summer than winter (Beyer et al. 2013). During winter, collisions increase with increasing traffic volume, decreasing temperatures, and increasing snow depth; moose are more active at colder temperatures, and during periods of deep snow (>50-70cm) they move into lower elevation areas with less snow that tend to be closer to roads and rail lines (Rolandsen et al. 2011)

Moose are generally negatively associated with roads (e.g. Beazley et al. 2004), but are attracted to salt pools and roadside forage. During winter, removing these salt pools decreases the attractiveness of roads (Laurian et al. 2008; Leblond et al. 2007). During summer, vehicular collisions can be effectively managed by reducing speeds, managing roadside forests and forage to make them less attractive to moose, and where required the highway itself can be altered (e.g., fencing, underpasses; Olsson and Widen 2008; Danks and Porter 2010).

3. MONITORING METHODS

Moose habitats can be monitored non-invasively using a range of approaches, including snow-tracking, camera trapping, forage availability, fecal pellets, and hunter observations. More invasive monitoring methods include aerial inventories, capture-mark-recapture, and collaring. Identifying the most appropriate survey method depends on factors like study area size, study objectives, season, habitat, access, and resources (i.e., money, staff, and expertise). Moose in Alberta, as in many other provinces, are primarily monitored by the provincial government's Fish and Wildlife Division. This monitoring is conducted within five Fisheries and Wildlife Management Areas (FWMAs) to regulate and monitor species by WMU; WMA in the northern Boreal and Foothills are the Peace, Lower Athabasca, and Upper Athabasca FWMAs.

3.1 NON-INVASIVE MONITORING: GROUND-BASED SURVEYS

Tracks and sign and opportunistic sightings are amongst the most widely employed methods to monitor ungulates. Ground-based techniques include fecal pellet-group counts, snow-tracking, and browse and forage surveys. Hunter observations have also been used to survey moose and monitor winter ticks, and more recently this approach has been revitalized through facilitated reporting with modern technology and apps (i.e., Moose Hunter Survey (Boyce and Corrigan 2017), Moose Tracker (GoBC 2019a)). More recent monitoring approaches include camera trapping, and the use of hair and scat to investigate population genetics, diet, and health. Scat can be used to extract DNA, determine diet, and identify parasites, and hair can be used to determine long-term stress and population genetics (e.g. Carroll et al. 2018; Joly and Messier 2004; Shave et al. 2019; Kretser et al. 2016).

3.1.1 PELLET-GROUP COUNTS

Pellet-group counts have been used to monitor ungulate population trends and habitat use for over half a decade (Bennett, English, and McCain 1940), and are considered the most suitable method for monitoring relative abundance of ungulates (RISC 1998). However, although widely applied, pellet-group counts may not be practical for large study areas or for assessing non-winter habitat use in densely vegetated habitats (RISC 1998).

To monitor ungulate winter range, surveys are typically conducted when pellets are most visible in the spring after snowmelt and before vegetation green-up (RISC 1998). By carrying out surveys when visibility is maximised, visibility bias from different habitat types and vegetation growth can be largely removed (Persson 2003). However, a future adaptation could be adopting a sightability correction factor in order to avoid underestimating populations (Persson 2003).

The experience and ability of the surveyor to accurately identify species is critical to the success of pellet-group surveys (RISC 1998). Moose pellets tend to be larger, more distinct, and more visible in ground cover than those of smaller ungulates (e.g. deer), excepting when there is overlap in size between large elk and smaller moose (Adamczewski et al. 1993; RISC 1998).

Two common sampling methods are used for pellet-groups counts: the plot (Neff 1968) and distance methods (Batcheler 1975). Both approaches estimate a moose index throughout the study area (e.g. Stewart and Kromers

2012). Sampling designs for the plot method include selecting circular plot centres within grids or on transects, and surveying pellet-groups from plot centre within a pre-defined radius (e.g. 5.64m; Neff 1968; Pfeffer et al. 2018). Larger plots have lower precision, since some pellet-groups may be missed (Neff 1968; Noor, Habib, and Kumar 2010). Preparing the plot for monitoring can include clearing, marking, or leaving pellet-groups in the fall prior to sampling in the spring (RISC 1998). Pellet-based distance sampling involves observing pellet-groups at pre-determined sampling points along transects. When a pellet-group is observed, it is recorded if it falls within a pre-defined distance; (1m or 2m; Härkönen and Heikkilä 1999; Torres et al. 2015). The distance of the pellet-group to the point or transect is recorded, as well as the distance to the centre of the nearest pellet-group within a pre-defined search distance (Kie 1988). Distance sampling is faster in areas with higher pellet-group densities, since at lower densities pellet-groups take longer and are more difficult to detect; therefore, the plot survey method, which is unaffected by pellet-group densities, is better in areas where moose are at low densities (Kie 1988; Eckervall 2007). Standardized protocols in British Columbia recommend conducting the plot method with a radius of ~1.71 m (~ 1.22 m in very dense cover) and a maximum search distance of 3.7m, and counting and clearing pellets each year (RISC 1998).

3.1.1.1 SNOW-TRACKING

Ground-based snow-tracking is often the only option for obtaining ungulate winter range data in heavily forested and mountainous terrain where aerial surveys are not practical (D'Eon, Wilson, and Hamilton 2006). For snow-tracking, the most suitable study areas are the size of drainages (e.g. ~10,000 Ha), where a single population is monitored. Larger study areas will likely need aerial inventories in order to have a sufficient number of survey transects covering the area (D'Eon, Wilson, and Hamilton 2006). While in smaller study areas (e.g. 100 Ha; cut-block), snow-tracking surveys are subject to sampling error (D'Eon, Wilson, and Hamilton 2006). Snow-tracking detects more species than camera traps, hair snares, and aerial surveys, but because of labour it is also more expensive than camera trapping and hair snares (Bayne, Moses, and Boutin 2005).

Standards for snow-tracking include pre-stratifying the study area into ecologically similar units so that snow-tracking transects sample the study area and its ecological variability. Ecological relationships that strongly influence ungulate distribution and that may be used to stratify the area include elevation, aspect, hydrology, forest cover, natural regions, and/or snow depth (D'Eon, Wilson, and Hamilton 2006).

Moose distribution is strongly influenced by snow conditions and track surveys should be conducted for a minimum of two winters, but ideally should span multiple years to sample a variation in inter-annual snow depth. Surveys can be conducted for the season of interest (e.g. early-, mid-, or late-winter) or for the entire winter, and require optimal snow conditions. Shorter sampling periods increase the precision of data due to the variation snow conditions can have from the start to the end of a sampling period (D'Eon, Wilson, and Hamilton 2006).

If sampling an entire season, the winter can be divided into early (late-November to early-January) and late winter (early January to early March), and sampled 3 days or a minimum of 12 hours after a snowfall (Bayne, Moses, and Boutin 2005; Stent and Hamilton 2007). Tracks and sign (e.g., scat, tracks, bed) of moose that cross transects within visibility are counted and classified. Moose tracks are easily identified, but they can still be misclassified as caribou or elk; if uncertain, tracks can be followed to find a scat to confirm species identification (Bayne, Moses, and Boutin

2005). Snow depths are also measured either at regular intervals of 100m or at each track occurrence. Variations in this sampling protocol include recording habitat measures like canopy cover (e.g. MacDonald and Mcnay 2010). However, if there is not enough time (e.g., high track frequency, long transects), habitat can also be sampled during the summer (D'Eon, Wilson, and Hamilton 2006).

3.1.2 BROWSE AND FORAGE SURVEYS

Moose browse and forage surveys are used to assess moose habitat and moose habitat use. Browse intensity (or pressure) surveys provide information on the degree of damage or browsing intensity of moose foraging in different habitats and can also be used to measure forage selectivity (e.g. Milligan and Koricheva 2013). Browse intensity surveys can be targeted to determine if and how browse intensity is affecting particular areas or habitats, such as regenerating forests and reclamation of disturbed areas (e.g. Bergeron et al. 2011; Andreozzi, Pekins, and Langlais 2014). In contrast, forage availability surveys provide an understanding of available moose forage in different habitats, which in turn can be linked to the spatial distribution and densities of moose (e.g. Månsson, Andrén, et al. 2007; Wam and Hjeljord 2010). In some cases, these different approaches might produce contradictory results, highlighting the importance of surveying by more than one method (Eastman 1974).

Browse intensity and forage survey areas are frequently focused in specific areas of interest (e.g. foraging paths; (Routledge and Roese 2004; Poole and Stuart-Smith 2005)) or on moose winter or summer ranges (e.g. Seaton et al. 2011). Survey windows for winter browse are during spring, before leaf emergence (e.g. Seaton et al. 2011), and for summer browse are during the summer between June and September, prior to leaf abscission (e.g. Wam and Hjeljord 2010; Månsson et al. 2015). Similar to pellet count surveys, habitat measurements are usually recorded at sampling sites (e.g. canopy cover, tree diameter, snow depth Poole and Stuart-Smith 2005).

Sampling designs for browse, forage, and pellet-group surveys can be combined to understand spatial patterns of browsing pressure in relation to forage availability and moose occurrence on the landscape (e.g. Bergqvist et al. 2018). Sampling designs that combine or conduct these surveys often survey from the same plot centres within a grid or along transects, but using different search radii (e.g. Månsson, Andrén, et al. 2007; Bergqvist et al. 2018).

Most browse and vegetation surveys apply a standard limitation to surveying only vegetation within the physical reach of a moose – 0.5m to 3.0m in North America (Telfer 1981). At less than 0.5m, browse is considered inaccessible, because of a moose's height and because during winter it is under snow (Telfer 1981). The lower limit may be set differently for different subspecies (e.g. Hörnberg 2001) and in regions with lower snow accumulation (e.g. Routledge and Roese 2004). During summer, studies may also exclude recording species that are negligibly browsed (e.g. Routledge and Roese 2004; Wam and Hjeljord 2010; Seaton et al. 2011). If present in the area, deer, cattle, and sheep, may bias results, but if present at low densities or if they intake very little biomass of the surveyed vegetation, this bias can be considered insignificant (Månsson, Kalén, et al. 2007; Wam and Hjeljord 2010). Grazing exclosures can also be created to provide reference estimates of ungrazed sites (Månsson et al. 2015).

Browse intensity estimates the amount of vegetation browsed per plot by comparing the browse eaten by moose (i.e., bites or stripped leaves bark, shoots, or buds (Wam and Hjeljord 2010) to the number of unbrowsed shoots (e.g.

2.52m; (Månsson, Kalén, et al. 2007)). During winter, the number of shoots browsed from the previous year's growth are counted (Wallgren et al. 2013; Bergqvist et al. 2018), whereas during summer, the number of unbrowsed shoots of the current year's growth are counted (Wam and Hjeljord 2010). These methods can be time consuming (Månsson, Kalén, et al. 2007), since bites in the spring are aged from that of previous years by the colour, resins, and dead bark tissue at the bite surface (Hörnberg 2001; Månsson et al. 2010).

Estimating total forage availability at sample plots is comparatively faster than twig counts and can be estimated as the percent cover for each browse species (Månsson, Kalén, et al. 2007; Bergqvist, Bergström, and Wallgren 2014; Poole and Stuart-Smith 2004). More destructive methods estimate total forage biomass by collecting and weighing fresh (in the field) and dry biomass (e.g. Månsson et al. 2015). Biomass can be estimated by clipping the current year's growth within a quadrat or circular plot (e.g. 2m radius; $0.25m^2$, $0.5m^2$ areas; Fraser 2004; Månsson et al. 2015). Other methods to measure biomass include measuring diameters or lengths of browsed and unbrowsed twigswhile also collecting representative samples of unbrowsed twigs for weighing (e.g. Telfer 1969; Potvin 1981). Although used infrequently for moose, disc pasture metres can measure biomass in pastures and grassland areas (e.g. Bergman et al. 2001).

3.1.3   HUNTER OBSERVATION SURVEYS

Population trends and abundance can be monitored indirectly through hunter harvest, and is very cost effective ($0.60 per hunter surveyed; Corrigan pers. Comm. In Boyce, Baxter, and Possingham 2012). However, hunter observations alone are insufficient for monitoring populations, and they need to be combined with more direct population monitoring approaches like aerial surveys (Boyce, Baxter, and Possingham 2012). Aerial inventories are considered the gold standard for moose population inventory, but are very cost prohibitive and take time – it takes 10 years to survey Alberta (Boyce, Baxter, and Possingham 2012).

Hunter observations are currently being collected by Alberta and British Columbia through survey apps (i.e., Moose Hunter Survey App (Boyce and Corrigan 2017), BC Moose Tracker App (GoBC 2019a)) and other platforms. Hunter observation data assists in moose management by monitoring moose population trends more frequently, but with lower precision than aerial inventories (Boyce and Corrigan 2017; GoBC 2019a). They are typically used to adjust hunting quotas and to prevent overharvest (Boyce, Baxter, and Possingham 2012). Hunter observations records include the number, sex, and location of moose that hunters encounter (GoBC 2019a), and this data has had success in reflecting moose population trends in size and reproductive rates (Boyce and Corrigan 2017). However, Boyce and Corrigan (Boyce and Corrigan 2017) caution that calibration of this data is required prior to assessment, and that the resulting moose density estimates have limited uses.

Hunter survey apps have great potential to support moose management and could also simultaneously gather information from hunters to meet other surveillance needs (e.g. winter tick surveillance). Hunter observation data should be synthesized and made publicly available online to maintain participant interest (Boyce and Corrigan 2017), and to provide industry professionals with the information to understand and verify concerns related to population trends in their area of interest. The ease of geolocating hunter observations with apps can also facilitate a spatially explicit understanding of access management issues, which can inform spatial restrictions for quotas in WMUs and

land use planning. If combined with tabletop consultations, these data could be used to develop access management strategies.

3.1.4 WINTER TICK SURVEYS

Winter tick outbreaks can cause significant declines in moose population numbers. The government of Alberta currently conducts a baseline winter tick surveillance program, but information from the program is not publicly available and the frequency, spatial extent, methods, and timeline on which existing datasets may have information for is unclear. We found no publications since 1999 for the Boreal region, although we found publications from the 2000s on winter tick in the Foothills region (BRL 2005). In British Columbia, the province launched a winter tick surveillance program in 2015, collecting opportunistic observations from wildlife professionals, forestry and environmental consultants, members of First Nation communities, and the public (GoBC 2019b). This program provides baseline monitoring of winter tick infestations to determine distribution, prevalence, and severity within populations (Bridger 2015). The program in British Columbia was based off of a program that ran in the 2000s in Alberta (Samuel 2004), and allows hunters to quickly document moose observations for any sign of hair loss using five descriptive categories.

This information can help biologists understand the impact winter tick outbreaks have over time on local moose populations, and the susceptibility of particular areas to increased outbreaks (e.g. favourable tick habitat). For example, in the Blue Ridge Lumber FMA, WMU 347 in the Alberta Foothills, between 1998 and 2005 the moose population decreased by 45.6%, with ~7.2% of the moose observed having light hair loss and 1.1% with moderate hair loss. The decrease is suspected to be caused by tick infestation through higher exposure to white-tail deer from surrounding agricultural areas (BRL 2005). A low cost winter tick surveillance program could help inform industry professionals of the prevalence and distribution of winter tick. Other more labour intensive survey methods include counting winter ticks on harvested moose hides, roadside hair-loss surveys, and larval sampling (Bergeron et al. 2011; Bergeron and Pekins 2014). Larval sampling (e.g. drag and flag) has previously been used to inform management practices to reduce tick survival and habitat suitability through prescribed burning of highly suitable tick habitat (Drew and Samuel 1985; Gleim et al. 2014). In managed forests, larval sampling could be used to co-manage for moose persistence, by targeting cutblocks with high winter tick suitability in areas experiencing continued decline of local moose populations with high winter tick infestation severity. Camera trapping is a new approach that holds potential to monitor disease non-invasively, in particular those with recognizable symptoms, such as hair loss (e.g. mange; Borchard, Eldridge, and Wright 2012). Differentiating between winter tick and mange hair loss patterns from photos may be difficult or unfeasible, but fortunately, ungulates in North America are largely unaffected or unexposed to mange (Astorga et al. 2018). At a minimum, camera traps surveys can be conducted to provide presence/not-detected data to understand disease occurrence and distribution in areas of interest. Camera traps also provide the opportunity to simultaneously record data to estimate host availability (e.g., moose, elk, caribou, deer) and host contact rates (e.g. Hofmeester, Rowcliffe, and Jansen 2017).

3.1.5 CAMERA TRAPPING

Camera trapping is a more recent monitoring method and is widely used to monitor occurrence, abundance, and behaviour of single and multispecies (Burton et al. 2015). However, although widely applied there are no standard

sampling protocols for camera trapping (Burton et al. 2015), although standards for BC and Alberta are in development. Camera trapping is still evolving with technology, methodology, and application, and has not yet reached its full potential (e.g. Caravaggi et al. 2017)).

Camera traps have been used in species population biology and ecology to understand population distribution, habitat use, relative abundance, community structure, and behaviour (Trolliet et al. 2014; Burton et al. 2015). Most studies do not require recognition of individuals to estimate spatial habitat use and derive population estimates and densities, e.g. Random Encounter Model, Bayesian, Occupancy Modelling (Burgar et al. 2018; Burgar, Burton, and Fisher 2019). Although density estimates can also be calculated by identifying individuals through distinctive markings (e.g., tags, stripe patterns) and employing mark-recapture protocols (Bayne, Moses, and Boutin 2005). Another advantage of camera traps over more traditional approaches, such as fecal pellet-group counts and snow tracking surveys, is that camera traps can provide clear species' identification and records, reducing observer misidentifications (e.g., age class, species, sex; Bayne, Moses, and Boutin 2005; Pfeffer et al. 2018), and be combined with other approaches (e.g. Pfeffer et al. 2018; Franklin, Macdonald, and Nielsen 2019).

Before using camera traps to monitor moose, sampling design, and camera settings must be carefully considered, as these will vary depending on the study area and goal of the study (Burton et al. 2015). In camera trap surveys, sampling designs can affect detectability through the selection of the number, location, spacing, and survey duration of cameras. The average home range of the focal species is often correlated to camera spacing, sampling unit area, and study area; regardless, when using the home range of the focal species to space cameras, sampling independence is often assumed, but seldom tested (Burton et al. 2015). Moreover, when cameras are first set up, not all species are equally detectable. Some species like moose have latency periods, which affect optimal survey durations, while more elusive or rare species have even longer latency periods and lower detection rates (Burton et al. 2015). In Alberta, the probability of false absences of moose was 50-80% within the first 4 weeks of sampling, but gradually declined to 10% after 10 weeks of sampling (Fisher and Burton 2012). Overall moose detectability by the end of the study was 77%, and Fisher et al. (2012) recommended that summer wildlife surveys sample for a minimum of 6-8 weeks and pilot programs for more than 18 weeks, to characterize and account for these latency periods in their respective study area.

Settings and setup of cameras can also alter detectability – including altering size of the detection zone, trigger speed, sensitivity, and camera height (Burton et al. 2015). When deploying cameras, camera sensitivity and camera height should be tailored to body size and speed of the focal species (Burton et al. 2015). Considering camera models, many are available (e.g. Rovero et al. 2013) and it is important to consider the key settings required to collect data from focal species and weigh the pros and cons of different models. For example, acquiring fewer expensive complex cameras versus many less expensive more simple cameras, especially considering the latter can be just as effective in answering the majority of research questions; however, mid-range cameras are recommended over low-end ones, since low-end cameras they may not survive harsh field conditions (van Berkel 2014). Multiple cameras at a site can also increase detectability. In Illinois, two cameras facing opposite directions nearly doubled detection rates of white-tailed deer (Pease, Nielsen, and Holzmueller 2016), but more than two cameras does not necessarily continue to increase detection rates (e.g. Evans, Mosby, and Mortelliti 2019).

Camera setup typically includes baiting (i.e. lure or attractants) to lure animals into the field of view to increase detection rates (Meek et al. 2014), but depending on the species some bait can act as repellants (Wearn and Glover-Kapfer 2019). Non-baited camera sites are thought to not directly influence animal behaviour and to provide a representative sample of what crosses at any random point (Bayne, Moses, and Boutin 2005). Cameras that are not baited can be placed in areas of high animal activity with natural attractants, such as game trails, roads, water sources – a non-random approach, which can produce strong bias in detection rates (Bayne, Moses, and Boutin 2005; Burton et al. 2015). The impacts of ungulate baiting on detection rates (Bayne, Moses, and Boutin 2005), and the biases associated with natural attractants and deterrents at camera sites is poorly understood. In addition, ungulate baiting is unlikely to remain a monitoring approach in areas with CWD. Game trails and logs are features that are known to inflate detection rates, game trails can do so by as much as 9.7 fold (Kolowski and Forrester 2017). Many studies assume equal detectability across sites (Burton et al. 2015), and if these biases, are neither documented nor controlled for in study design and analyses, they could lead to misleading conclusions on animal habitat use, activity patterns, distribution, and more (Kolowski and Forrester 2017).

Standard provincial camera trapping protocols targeted for Alberta's species and habitats would increase the scientific robustness, rigor, and replicability of the approach across studies (Meek et al. 2014).

3.1.5.1 STRESS, POPULATION GENETICS, AND DIET

Biological samples (e.g., muscle tissue, hair, scat, stomach contents) can be collected from carcasses and hunter sample submissions to assess short-term stress (e.g. Gentsch, Kjellander, and Röken 2018), long-term stress (e.g. Millspaugh et al. 2001; Shave et al. 2019), diet (e.g. Bao et al. 2017), and population genetic structure (e.g. Niedziałkowska et al. 2014) and gene flow (e.g. Sattler, Willoughby, and Swanson 2017).

Short-term stress can be sampled from blood and can assess trauma during captures (e.g. Huber et al. 2017). Long-term stress can be sampled from hair and scat (Ewacha 2016; Sheriff et al. 2011). With proper location data different spatial variables can be explored for links to long-term stress (e.g., fragmentation, distance to roads, predator densities).

Population genetics can be surveyed from samples of DNA extracted from hair, blood, muscle tissue, and scat. DNA extracted from moose pellets may be in lower quantities and quality than blood and tissue (Gschwantner et al. 2016). DNA degradation from rain and solar radiation can be reduced by collecting samples during a time of year with cooler temperatures (e.g. March and April; Rea et al. 2016).Genetics can determine if population genetic structure is altered by barriers, such as major highways and fencing, preventing dispersal and gene flow between populations (e.g. Wilson et al. 2015), or by isolation by distance due to insufficient moose dispersal rates (e.g. Schmidt et al. 2008). Isolated or small populations without enough genetic diversity can suffer from inbreeding, reduced disease resistance, and/or increased extinction risk (O'Brien and Evermann 1988; Loew 2000; Frankham 2003).

Feces can also be used to assess diet, but may be less accurate than browse surveys since fecal analyses of moose pellets overestimate the less digestible portions of their diet (Wam and Hjeljord 2010). Until correction factors are available, browse surveys (e.g. Routledge and Roese 2004) may be the more accurate technique to survey moose diet (Wam and Hjeljord 2010).

3.2   INVASIVE MONITORING

3.2.1   AERIAL-BASED SURVEYS

Aerial surveys are considered the gold-standard for moose population surveys (Boyce, Baxter, and Possingham 2012) and are the most practical monitoring approach for large study areas, preferably enclosing the entire survey population (RISC 1998). Aerial surveys are also the primary approach used to estimate population size, trends, distribution, and herd composition of ungulates (Boyce and Corrigan 2017; Timmermann and Rodgers 2017). Aerial surveys are typically conducted during winter as snow cover improves ungulate sightability (Gasaway et al. 1986; Timmermann and Rodgers 2017). However, aerial surveys are very expensive. On average, each WMU in Alberta (avg. 3,058 km^2; ArcGIS 10.3) costs $60,000 to survey (R. Anderson pers. comm. In Boyce and Corrigan 2017)). In one year only 9-11 WMUs are surveyed, and after 10 years all 99 provincial WMUs are completed (Boyce, Baxter, and Possingham 2012). This provides a somewhat static view of moose populations, which is best complemented with other methods that can monitor population fluctuations at more regular intervals (Boyce and Corrigan 2017).

During flights, observations include the number of moose and their age class and sex (e.g., juvenile, male, female). A sightability correction factor that accounts for the amount of snow cover and forest canopy density, both of which can affect the detectability of moose during the survey period (e.g. late- or early-winter surveys), can also be applied to reduce population estimate biases (RISC 2002). Optimal aerial survey windows depend on the type of survey being conducted and the study area. In the Boreal, late-November to mid-December is better for surveying population composition (e.g., calf, cow, yearling bull), since adult moose drop their antlers in December and snow cover improves their visibility. After December, classifying moose requires more effort and expense, and relies on identifying the presence of antlers (young bulls), pedicel scars, or the presence of a vulva patch (RISC 2002). If surveying for a population count, late winter from January to February is the best window (RISC 2002).

Moose tend to be scattered (i.e., singly, cow/calf family), but widely distributed over the landscape. However, surveying an entire region is not practical for costs and logistics, so for aerial surveys, sample-based surveys (e.g. stratified random block) are used where sample units (e.g., quadrats, blocks) are surveyed and the results extrapolated to estimate absolute abundance of the entire area (RISC 2002). Survey areas must be at least 200km^2 to encompass discrete populations. In survey areas less than 200km^2, total counts should be considered rather than sample-based counts (RISC 2002).

In Alberta, commonly employed methods for monitoring moose population sizes and trends include stratified random block (Gasaway et al. 1986) and distance sampling (Buckland et al. 2001), which provide population estimates, densities, and composition. Block surveys observe moose for the entire block along evenly spaced transects, and are more appropriate for dense moose populations in small survey areas and open habitats (Peters et al. 2014), while distance sampling observes sightable moose along the transect and estimates the distance to the moose (Buckland et al. 2001). Distance sampling surveys are more efficient than block surveys as they reduce flight costs and time. Although for both approaches, even though sight correction increases flight time correcting for sightability likely provides more accurate results (Peters et al. 2014).

Presently, at the forefront of innovating aerial-based methodologies is unmanned aerial vehicle (UAV) technology (e.g. Bushaw, Ringelman, and Rohwer 2019). UAVs have the potential to be more accurate than human observers (e.g. Hodgson et al. 2018) and to be combined with satellite imagery to survey populations over large areas (Wang, Shao, and Yue 2019). The opportunity to identify animals by observation and infrared technology simultaneously while operating UAVs remotely is a cost effective and attractive opportunity for monitoring in the future (Witczuk et al. 2018).

3.2.2   CAPTURE, MARKING, AND COLLARING

The best capture approach for moose is helicopter darting during the winter, but moose may also be darted from a vehicle (e.g., ATV, truck) or on foot (Arnemo, Kreeger, and Soveri 2003). Heli-darting moose can also include net-gunning, which requires experienced pilots and gunners (e.g. Peters 2010). Handling, capture, and/or immobilization of animals can result in adverse outcomes (e.g., capture myopathy, calf abandonment, internal hemorrhaging, hyoxemia) due to animal stress, improper dart placement, long chase times, poor animal health, drug-related complications, and more, so all captures should be carried out by experienced personnel, in collaboration with wildlife veterinarians, and in accordance with protocols outlined by the Canadian Council on Animal Care (CCAC 2003).

Captures frequently involve collaring and marking animals (i.e. GPS and/or VHF radio transmitters and tags) to study movement, population biology, predation, mortality, and habitat use (e.g. Leblond, Dussault, and Ouellet 2010). However, biological samples (e.g., hair, blood, ticks, teeth) and biometrics (e.g., weight, body condition, sex, age) are also commonly collected to study animal health, genetics, and ecology (e.g. Kuzyk, Marshall, et al. 2018; Murray et al. 2012). Studies that collar animals and collect biological samples and biometrics are likely to be the most informative moving forward as the interacting impacts of habitat disturbance and climate change shift the distribution of moose, and their pathogens.

Table 1. A Summary of Moose Monitoring Methods: Ground- and Aerial-Based Surveys.

Survey Type	Examples of Estimates & Data	Sampling Methods	
Non-Invasive Ground-Based Surveys			
Pellet-Group Counts	• **Estimates:** distribution, relative or absolute abundance, density. • **Data:** presence/absence	Pros: • Standardized protocols • Low cost ($$) • Can survey secondary species.	Cons: • Subject to misidentification and degradation. • Less appropriate for large areas (e.g. regions)
Snow-Tracking	• **Estimates:** density • **Data:** presence/absence	Pros: • Standardized protocols • Low cost ($$) • Can survey large areas • Can survey secondary species.	Cons: • Labour intensive. • Subject to misidentification and degradation. • Not appropriate for small areas
Camera Traps	• **Estimates:** size, distribution, density, relative abundance. • **Data:** presence/absence	Pros: • Easy to conduct • Low cost ($) • Can survey large areas • Less time/labour intensive • Can survey multiple species • Reduces misidentification • Similar density estimates to PGC	Cons: • Protocols are not standardized • Subject to malfunction and theft • Large volumes of photos to interpret • Vegetation may require regular cutting
Hunter Observation Surveys	• **Estimates:** disease distribution, density. • **Data:** presence only	Pros: • Easy to conduct • Very low cost (0.60$ per hunter surveyed) • Can survey large areas	Cons: • Protocols are not standardized, and may not be similar. • Subject to lack of participation • Subject to misclassification
Browse and Forage Surveys	• **Estimates (Forage):** forage diversity, site productivity, forage consumption • **Estimates (Browse):** browse intensity or damage to forage • **Estimates (Both):** forage selectivity. • **Data:** presence/absence	Pros: • Low cost ($) • Can survey large areas • Can be combined with pellet-group count surveys.	Cons: • Can be labour intensive. • May require personnel trained to ID difficult species (e.g. grasses) • Misidentification can occur for bite protocols. • Not appropriate in areas where cattle and deer may forage significantly. • Protocols are not standardized.
Scat and Hair Collection	• **Estimates:** long-term stress, genetic structure and flow. • **Data (Scat):** presence/absence, DNA. • **Data (Hair):** presence only, hormones, DNA.	Pros: • Scat collection is the only non-invasive approach to sample DNA from moose. • Hair collected during capture is the only successful approach to survey long-term stress (i.e. hormones) in moose.	Cons: • Subject to degradation in the field and in storage • Personnel can be exposed to disease • Costly ($$$ -e.g. DNA, hormones) • Hair collection is invasive or opportunistic (i.e. carcasses).
Invasive Surveys			
Aerial Surveys	• **Estimates:** Population density, calf:cow ratios, bull:cow ratios, composition. • **Data:** presence/absence	Pros: • Standardized protocols • Practical for very large survey areas (e.g., regions, provinces) • Gold standard for population inventory • Can survey wildlife in difficult terrain (e.g. mountain goats).	Cons: • Very costly ($60,000 per WMU) • May require lots of personnel • Requires trained wildlife pilots • Can take years to survey regions • Disruptive to wildlife and domestic animals (e.g., mountain goats, horses).

23

| Capture, Marking, and Collaring by Helicopter Darting | • **Estimates:** population size, distribution, density; movement corridors; biometrics; disease presence; and genetics.
• **Data:** GPS-collar movement data, biometrics (e.g., weight, condition), and biological samples (e.g., ticks, blood). | Pros:
• Protocols reviewed by CCAC.
• Provides biometrics and biological samples.
• Collars provide movement data.
• Markers allow future animal ID
• Heli-darting during winter is the best approach. | Cons:
• Costly ($$$)
• May require a veterinarian
• Requires an experienced dart-gunner.
• Negative animal welfare outcomes (e.g., drugs, chase times).
• Collars can have physical impacts.
• Can be dangerous for personnel (e.g., animal, drugs, flying, and disease exposure). |

4. RESPONSE TO DISTURBANCE

Moose evolved with natural disturbances including flood, disease, drought, and wildfire. In Alberta, wildfire and disease (mountain pine beetle) are currently the dominant natural disturbances changing forest mosaics, while forestry is the dominant anthropogenic disturbance (NRC 2019). Both natural and anthropogenic disturbances shape the structure and composition of forests resulting in a heterogeneous mosaic of habitats on the landscape. In response to climate change, wildfire is expected to be a stronger driver of future landscape disturbances (Stocks 1993; Weber and Flannigan 1997).

Moose interact with various habitat types within a landscape mosaic (Snaith and Beazley 2004; Stewart, Komers, and Bender 2010). Moose populations are naturally maintained at low densities by forage availability and predation, and have evolved to opportunistically exploit landscape disturbances that generate early-seral stage habitat (Geist 1974 in Timmermann and McNicol 1988). This initially leads to a rapid increase in their population's post-disturbance followed by a slow decline as forests mature (Geist 1974 in Timmermann and McNicol 1988). Both natural and anthropogenic disturbances can create population insurgence by providing "transient" habitats for moose in addition to more "permanent" habitats (Geist 1971).

Moose, however, are also limited in their ability to optimally exploit changing landscapes. Although they are capable of dispersing large distances, they typically disperse distances less than 15km (Labonte et al. 1998). If moose do not shift their movement patterns and home ranges, they may not encounter and exploit new disturbances (e.g. Gasaway et al. 1989). The focus of this section is on moose interactions with both natural (i.e., wildfire, insect epidemics) and anthropogenic ecosystem disturbances, specifically managed forests.

4.1 NATURAL DISTURBANCES

Natural ecosystems exist within a natural disturbance regime that forms an equilibrium transitioning between multiple stable states; generating a spatial mosaic of habitats whose diversity creates ecosystem resiliency (Lewontin 1969; Holling 2017; Briske, Illius, and Anderies 2017; Falk, Watts, and Thode 2019). Forested ecosystems have a mosaic of stands with different stand ages and dominant tree species (Stockdale, Flannigan, and Macdonald 2016). In the early- to mid-1900s natural disturbances were once viewed as a deviation away from a stable ecosystem, and were historically suppressed or eradicated to sustain a "climax" forest (Stockdale, Flannigan, and Macdonald 2016). The history of this management approach is part of the pattern of forest mosaics seen today. However, more recently forestry has shifted to emulate natural disturbance (Stockdale, Flannigan, and Macdonald 2016).

4.1.1 INSECT EPIDEMICS

Wildlife and forests have evolved for centuries with periodic outbreaks of insect epidemics, which shape forest composition and structure (Ritchie 2008; Ivan et al. 2018). In Alberta, prominent defoliators of conifers are the mountain pine beetle (MPB; *Dendroctonus ponderosae;* 993,908 Ha in 2016; AFPA 2019), while defoliators of deciduous (1,645, 030 Ha in 2015) include the forest tent caterpillar (*Malacosoma disstria*), large aspen tortrix (*Choristoneura*), and Bruce spanworm (*Operophtera bruceata;* AAF 2017a). Since fire suppression began in the early 20th century, MPB has been an important driver of forest mosaics (Axelson, Alfaro, and Hawkes 2010). However,

favourable climatic conditions have more recently increased the extent and severity of MPB outbreaks compared to historical trends (Ivan et al. 2018). The spruce beetle (*Dendroctonus rufipennis*) is another notable bark beetle, which targets spruce and occurs infrequently in small, scattered infestations in Alberta (AAF 2017b). However, in adjacent regions near Prince George, British Columbia, infestations have been more significant (251,000 Ha in 2017; GoBC 2019c).

The current epidemic of MPB started in western Canada with an initial outbreak in British Columbia in the 1990s, which then spread east into Alberta's Boreal forests at a rate of 80km/year (Cooke and Carroll 2017). Since the initial outbreak in the 1990s, MPB has caused 20 million Ha of tree mortality in western Canada (Westfall and Ebata 2014). MPB targets all pines (Furniss and Carolin 1977), but its primary host is mature lodgepole pine (*Pinus contorta*) (Safranyik and Carroll 2006). Deciduous trees and vegetation, and small diameter pines are unaffected by MPB (Safranyik and Carroll 2006). Depending on the intensity of the outbreak, small gaps to large stand replacements are created by MPB infestation (Axelson, Alfaro, and Hawkes 2010). This reduction in tree canopy cover increases sunlight and soil moisture into the understory layer releasing existing understory trees and vegetation from competition, resulting in complex uneven-aged stand structures (Williston and Cichowski 2006; Axelson, Alfaro, and Hawkes 2010; NRC 2019). This forest then transitions into an early successional stage with increased productivity of shrubs and forbs, which may benefit moose through an increase in forage (Williston and Cichowski 2006; Ritchie 2008).

Both outbreak severity, resulting in a differing degree of defoliation and tree mortality, and time since outbreak, resulting in differing forest successional stages, influences moose habitat use over time (Ivan et al. 2018). Moose are likely to benefit from MPB infestations over the short-term (3-5 years; Williston and Cichowski 2006), as beetle-caused tree mortality results in more open canopy cover and creates edge habitat (Stone, Spolc, and Urquhart 1995; Chan-McLeod 2006; Ivan et al. 2018). In the southern Rocky Mountains of Colorado, moose use of forested stands adjacent to preferred willow habitat peaked at 3-7 years post-outbreak, but only at high outbreak severity (Ivan et al. 2018). In a simulation of MPB-attack, sites with increasing severity had greater understory vegetation richness and diversity (Steinke 2019b). Moose can benefit from beetle-caused tree mortality (Stone, Spolc, and Urquhart 1995; Ivan et al. 2018), but in some cases the benefits are inconclusive (Munro, McLellan, and Apps 2008).

Over the mid- to long-term moose may decline in response to MPB infestations (Ritchie 2008), as MPB infestations occur at very large scales and may magnify habitat changes associated with natural recovery and reforestation (Chan-McLeod 2006; Ritchie 2008). Also salvage logging occurs at larger scales than traditional harvest practices (Ritchie 2008), associated linear infrastructure and resulting landscape homogeneity may negatively impact moose (Klenner 2006; Ritchie 2008). 30-40 years post-outbreak, once forests have regenerated with large diameter trees, the cycle of MPB disturbance and salvage logging may re-occur (Alfaro, Campbell, and Hawkes 2010; Alfaro, van Akker, and Hawkes 2015).

Large-scale salvage logging associated with MPB can result in even-aged stands (Wall, Belisle, and Luke 2011), which could impact moose. Tree species that were present in the understory prior to an outbreak are likely to dominate the canopy in the future (Steinke 2019a). In west-central Alberta, sites left to regenerate naturally after MPB-outbreaks had 70% broadleaf and 90% spruce regeneration, with slower lodgepole pine regeneration (Steinke 2019a). Practices

associated with salvage logging (e.g., mechanical site preparation, partial harvesting) accelerate the transition of the stand into lodgepole pine dominance (Steinke 2019a). Forestry practices that increase landscape heterogeneity and wildlife biodiversity, and that provide an interspersion of open and closed forest cover could benefit moose over the long-term (Chan-McLeod 2006) . These management practices could include limiting salvage of i) uneven-aged stands, that can regenerate quickly into mature stands that intercept snow and provide cover; ii) stands with mature residual live trees, that provide thermal and security cover in defoliated areas; and iii) stands with a well-established shrub layer, that provide forage. Moreover, moose movement and access in these areas may be more difficult (e.g. elk; (Lamont et al. 2019) as dead pines blow over (Cichowski 2007), thermal and security cover is reduced (Chan-McLeod 2006), and potential for severe fires increases due to high fuel loads (Ritchie 2008).

Future work is required to investigate the response of moose to MPB infestation, as only three studies have directly assessed this relationship (i.e., (Ivan et al. 2018; Stone, Spolc, and Urquhart 1995; Munro, McLellan, and Apps 2008)). It would be beneficial to assess moose associations with MPB outbreak severity, time since outbreak, and/or degree of tree mortality. It is likely that moose response to MPB disturbance will be similar to other disturbances that change stand age, structure, and composition. Moreover, in order to aid future work, an effort should be made to ensure pre-outbreak information is available to help interpret post-outbreak studies (Bunnell, Kremsater, and Houde 2011).

4.1.2 WILDFIRE

Nationwide fire regimes are changing and can greatly alter landscapes – creating a mosaic of burned and unburned patches (Hanes et al. 2018). Over the last 57 years, large fires (≥200 Ha) have doubled in size and are more frequent. Fire seasons have also been getting longer – starting one week earlier and ending one week later (Hanes et al. 2018). The Albertan and Saskatchewan Boreal Plain forests are predicted to experience the greatest annual increase (35-400%) in fire spread days by 2050 compared to any other ecozone, but also have great fire suppression capacity (Wang et al. 2014).

In western Canada, lightning-caused fires are increasing, and their more recent increase (1984-2015) has been directly linked to anthropogenic climate change (Abatzoglou and Williams 2016). In Alberta, most wildfires are human-caused (65%), but lightning-caused fires (35%) typically burn more area (AW 2017). Historically (1902-2008) long-term fire trends have followed multidecadal climate oscillations (Higuera et al. 2015).

Alberta's Boreal is projected to experience a 75-120% increase in area burned by 2100 (Flannigan et al. 2005). Drier conditions are also expected to decrease forest stand health and increase fuel availability, fire intensity, and fire severity (Flannigan et al. 2005).

Burns are generally positively associated with moose forage availability by shifting coniferous dominant forests into deciduous dominant and early successional stage forests (Lord and Kielland 2015). Moose may sometimes not even be displaced by fire (e.g. Gasaway and Dubois 1985).

The composition of the pre-fire plant community strongly influences browse regrowth, which can be abundant within two months after a fire. Moose generally browse more where there is more biomass production (MacCracken and Viereck 1990). Aspen sites produce the most browse followed by white spruce, birch, and black spruce, and browse

species like aspen, paper birch, and willow can all regrow from root and stump sprouting (MacCracken and Viereck 1990). However, moose may not always use burned areas, for example if burned areas lack forage (e.g. burned peatlands; DeMars et al. 2019), or if burned areas are associated with increased predation risk (Courtois et al. 2002).

Mixed-severity fires can influence the longevity of habitat and forage availability for moose (Brown et al. 2018). The productive life of a burn can be 35 years or longer (Eastman 1974), but varies with burn location (Courtois et al. 2002), regenerated species (DeMars et al. 2019), and severity (Lord and Kielland 2015). In Alaska, moose were positively associated with 11-30 year old burns, but negatively associated with burns of ≤ 10 years or > 30 years (Maier et al. 2005). Fire severity impacts vegetation and soils, influencing tree species composition, age structure, and patch size decades post-disturbance (e.g. Shenoy et al. 2011; Brown et al. 2017). High-severity fires can even shift coniferous stands into deciduous dominant stands (Shenoy et al. 2011; Johnstone et al. 2010; Lord and Kielland 2015). During winter, moose in Alaska selected low-severity burns with higher availability of willow biomass more than high-severity burns with more woody browse biomass and higher plant mortality (Brown et al. 2017). During summer, moose can select high-severity burns due to a higher availability of forage biomass, and deciduous tree and shrub cover in those burns (Lord and Kielland 2015; Brown et al. 2017). Forage biomass production, however, can last longer in low-severity burns compared to high-severity burns, with high-severity burns in some cases reaching peak production seven years prior to 20 year old low-severity burns (Brown et al. 2017).

4.2 FORESTRY PRACTICES

Landscape disturbance associated with forestry include polygonal features (e.g. harvest blocks), and associated linear infrastructure (e.g. roads) that fragment the landscape. The presence and configuration of these features on the landscape can alter or influence habitat use, movement, and species' ecological relationships at different scales. Generally, practices that shift mixed forests into single-species coniferous stands and increase access into the landscape do not favour moose (Snaith and Beazley 2004; NCASI 2006). While linear infrastructure with high density and/or activity can be associated with increased moose mortality risk (Beazley et al. 2004)

4.2.1 FOREST PLANNING

Management practices that affect forage distribution and availability impact moose spatial distribution and abundance (NCASI 2009). At the landscape scale, the spatial harvest sequence is often designed to emulate the pattern – size, frequency, and severity – of fire regimes to maintain ecosystem processes and conditions (Stockdale, Flannigan, and Macdonald 2016). At the patch scale, stand structure, age, and composition is also designed to emulate natural patterns of disturbance. In order to simultaneously maintain forest ecosystem resiliency and optimize yield, forest planning aims to retain the full range of cover types and seral stages including areas of old, mature, and young forest by cover class. The targets for each-seral stage are set over a 200 year planning period (ASRD 2006).

Alberta, like many other governments and state agencies in North America, primarily manages moose populations by regulating hunter harvest and predators across the province, and to a lesser extent manage moose via their habitat (Timmermann and Rodgers 2017). Although forestry does not alter landscapes with the intention of changing moose

population dynamics, it is the dominant anthropogenic landscape driver changing habitats and forest stand age structure in Alberta's boreal forests.

Prior to harvest, forest planners select and design the harvest system (e.g. clear-cut, clear-cut with patch retention, clear-cut with dispersed retention, shelterwood, etc.)) based on stand characteristics (e.g., stand structure and age, tree species composition, wetness). Post-harvest strategic reforestation may include several steps: site preparation, seeding and planting, tending (including chemical tending using herbicide), and subsequent or repeated tending to achieve government regulated reforestation standards.

4.3 HARVESTING

At the landscape scale, forest planners can design age class distributions, harvest intervals, and spatial configurations of stands. At the stand scale, planners can modify the number of residual trees, the frequency distribution of patch sizes, and within-stand spatial arrangements, which are designed to mimic wildfire (Serrouya et al. 2004) and optimize yield (ASRD 2006). With the historical and ongoing suppression of fire in the boreal, forestry is an alternative to maintaining early seral diversity for moose (e.g. Telfer 1974). Harvest block sizes and harvest frequency can approximate fire size and frequency (Lee et al. 2002).

4.3.1 SILVICULTURAL SYSTEMS

In Alberta, clearcutting with retention is the primary method for timber harvesting (97%) followed by partial-cuts/shelterwood/seed tree (2%), and commercial thinning (<1% in 2016; AAF 2017a). Large-scale harvesting that leaves few interspersed mature stands and cultivates even-aged, single-species stands, reduces and fragments moose habitat, and results in higher stand homogeneity (Snaith and Beazley 2004). On the other hand, retention practices, selective harvesting or partial cut systems may create browse areas while retaining adequate supply of shelter for moose (Snaith and Beazley 2004).

Generally, moose prefer partially harvested stands of 11-20 years, over clearcuts (Eastman 1974), **although research assessing moose response to more recent harvest approaches is needed.** Partial-harvesting creates a more heterogeneous stand with a mosaic of habitats providing cover and forage that resembles highly productive natural range (Eastman 1974). Although there are numerous known benefits for wildlife including moose, selective harvest is not often applied in forestry in Alberta, in some areas this is because of the increased risk of windthrow, or because it is difficult to bring these stands to a free-to-grow state (Ritchie pers. comm. In Triton 2005), but in other areas where the expected disturbance regime is high severity fire, selective harvest may be inappropriate as it does not emulate natural disturbance (Trout pers. comm). However, moose also use clearcuts, and depending on stand age, harvest blocks can be used to the same extent as natural forests (Eastman 1974). Clearcutting increases the availability of ungulate forage and use in regenerating stands compared to mature forests (Newbury, Simon, and Chubbs 2007), and partial harvesting or thinning (Lykke and Cowan 1968). Clearcutting also allows more sunlight to reach shade-intolerant browse species, increasing forage production (Murphy and Ehrenreich 1965; Lautenschlager et al. 1997). Although moose generally use clearcuts with a higher amount of browse, moose may not use clearcuts that lack cover (Telfer 1978). In addition, during winter, snow depth is a major limiting factor to moose movement and browsing, and reduces

winter forage availability (Telfer 1978). When there is less snow, browse in clearcuts can be used more than uncut vegetation, but when snow accumulates this browse can become inaccessible (Eastman 1974). In areas with more deep snow, protecting moose winter range from disturbance and leaving some cover is likely beneficial for ungulates (Telfer 1978).

In addition, cut spacing can also influence snow interception ability (Todesco, Cumming, and McNicol 1985) and thermal cover for moose (Renecker and Hudson 1986; Schwab and Pitt 1991). When moose habitat is a priority, spacing and sizing of clearcuts can be optimized to enhance moose habitat – for example a study in Ontario found that moose select clear cuts over strip cuts, but female moose preferred strip cuts over clear cuts, and strip cuts were less used by predators (Todesco, Cumming, and McNicol 1985).

4.3.2   STAND STRUCTURE AND AGE

Changes in habitat generated by forestry, can have variable impacts on moose depending on the resulting stand age and stand structure. Recent clearcuts are used least (Eastman 1974) or not selected at all by moose, since young stands of < 10 years may not have enough shrub production (Poole and Stuart-Smith 2004). Favourable browse regenerates at higher densities in young stands between 5 and 40 years post-disturbance (e.g. Bjørneraas et al. 2011; Lynch 1979), and moose prefer clearcuts with early-seral (Serrouya et al. 2011) and intermediate-aged vegetation (Toews 2016). However, as some moose may not select clearcuts until forest cover has also returned (e.g. 10-15 years; Dodds 1960; Monthey 1984; Potvin, Courtois, and Bélanger 1999), peak suitability of clearcuts for moose can fall within the age range of 7-20 years post-disturbance (Dodds 1960; Lynch 1979). As young forests age over 20 years, much of the available browse grows out of reach for moose (Lynch 1979), leaving a lower density of accessible browse (Bjørneraas et al. 2011), and resulting in moose avoiding older clearcuts. Seasonally, young stands are selected more between spring and autumn, while transitioning into winter, older stands are selected more due to higher forage availability, higher snow interception, and potentially as moose select for cover as the hunting season starts (Bjørneraas et al. 2011).

Moose stand structure and age preferences are also reflected in browse intensity patterns. In northern New Hampshire, the most damage by moose to commercial species occurred in 11-15 year old stands, but even in an area with the highest moose density (range: 0.26-0.83km^2) the damage was not considered to impact regeneration of commercial species and stocking rates (Bergeron et al. 2011). In cases where forest regeneration is impaired as a result of hyper-abundant moose, moose delay vertical growth of preferred browse species, preventing browse species from growing beyond browsing height (Gray 2012).

4.3.3   TREE SPECIES COMPOSITION

The stocking standard defines the tree species heterogeneity of cutblocks by natural subregion (e.g., Upper Foothills, Upper Boreal; ASRD 2006), with a goal of having sufficient trees to maintain timber productivity.

During summer, moose prefer cutblocks with more deciduous trees, more deciduous shrubs, and fewer pine or spruce trees within browsing height (Pigeon, McKay, and Finnegan 2019). Possibly because cutblocks with low densities of trees are likely to have more browse year-round (Réhaume Courtois, Ouellet, and Gagné 1998; Garrett Street et al.

2015; Pigeon, McKay, and Finnegan 2019). Since moose density is correlated to browse damage (e.g. Bergeron et al. 2011), cutblocks in areas with more moose may have fewer trees in the canopy layer and a well-developed shrub and herb understory (e.g. (McInnes et al. 1992). However, when moose are abundant they can severely browse preferred deciduous forage, causing shifts in tree species composition from deciduous to coniferous dominance in cut stands (Andreozzi, Pekins, and Langlais 2014). By browsing deciduous shrubs, moose can release conifers from competition and increase conifer density (e.g. Snyder and Janke 1976; Heikkilä et al. 2003; McInnes et al. 1992; Abaturov and Smirnov 2002; Bergeron et al. 2011), resulting in commercially valuable stands for conifer operators (Andreozzi, Pekins, and Langlais 2014). Therefore, providing sufficient forage for moose need not be exclusive from producing commercially valuable timber (Milner, van Beest, and Storaas 2013). Understanding tree species composition shifts or stability under differing intensities of moose browse pressure in different silvicultural systems could provide a better understanding to aid in wildlife-forest co-management planning. Moreover additional challenges associated with climate change will require preparation and planning for the future of these forests (e.g. drought tolerance, aspen die-back) as tree species shift (Cerezke 2009).

4.3.4   RETENTION PATCHES

Live tree legacies are important for ecosystem disturbance resilience (Seidl, Rammer, and Spies 2014); these residual trees are what is naturally left behind after a fire (Serrouya et al. 2004). In an effort to mimic the patterns and structures resulting from natural disturbances, forestry practices and planning often emulate the fire disturbance pattern using retention harvesting to promote continued species persistence on the landscape (Bergeron et al. 2002). Retention harvesting retains mature trees in harvest blocks, increasing mature habitat connectivity, enhancing structural complexity, and facilitating recovery of species within harvested areas (Franklin, Macdonald, and Nielsen 2019). These residual patches are more beneficial to biodiversity than traditional harvesting, particularly clearcutting (Fedrowitz et al. 2014; Franklin, Macdonald, and Nielsen 2019).

The amount of residual trees increases with fire size (e.g. Perera et al. 2009), and therefore the size of the retention patch should also increase with harvest block size (Lee et al. 2002). A lack of residual trees can isolate animals and greatly reduce their potential range (MWLAP 2005). Clearcuts improve sightlines for predators (Welsh et al. 1980) and reduce moose thermal and escape cover (Snaith and Beazley 2004). Harvest blocks can alter moose foraging behaviour, since they will only venture a maximum of < 60m to 200m from the forest into a harvest block (OMNR 1990 in Chikoski 2003). During spring and summer, moose forage in young stands at night, and in older stands during the day to mitigate heat stress and predation risk (Bjørneraas et al. 2011). Suitable thermal cover throughout a clearcuts may not return until 30 years after disturbance (Telfer 1970). Therefore, selective or partial cutting can enhance moose habitat in the short-term by providing an interspersion of forage with available cover (Telfer 1984; Cederlund and Sand 1992; Snaith and Beazley 2004). In Alberta's Boreal, although moose use of harvest blocks was not linked to retention patch size in 15-18 year old harvests; retention patches of late successional forests may be more important for moose immediately after a clearcut, when they provide thermal and escape cover, and during the winter, when canopy cover can intercept snow and improve movement (Franklin, Macdonald, and Nielsen 2019). Generally for moose, 55-70% of the forest should provide mature cover distributed in patches of ≥ 8 Ha, and should have some retention patches of up to 100 Ha so that there is never > 200m to cover from any point (Snaith and Beazley 2004). If harvest blocks do not

provide adequate cover, like in clearcuts, moose will browse at the edges of the harvest blocks to reduce predation risk, resulting in uneven regeneration (e.g. mixedwood at the edges and aspen at the centre; (Schmitz 2005)). In Saskatchewan, when there were 10-20 residual patches (1 Ha in size) in harvest blocks (50-100 Ha in size), moose browsed uniformly at a similar activity level to unharvested areas (Schmitz 2005). In west-central Alberta, moose preferred clearcuts (41-80 Ha in size) with a minimum distance of 101m between neighbouring harvest blocks (Tomm, Beck Jr., and Hudson 1981).

Although numerous studies provided recommendations for retention patch design criteria, based on moose use of clearcuts, few studies directly studied moose use of retention patches. **In order to better understand how moose use retention patches of differing designs, future work could study this directly.**

4.3.5 ECOLOGICALLY SENSITIVE SITES

Aquatic moose feeding areas (preferred water bodies with abundant aquatic macrophytic plants and minerals – usually cool, shallow lakes or rivers with slow-moving (but not stagnant) water (Ranta 1998)) are critical sources of nutrients during spring and summer (Chikoski 2003). The quality of habitat surrounding these feeding areas influences their use (Chikoski 2003). A 'no harvest' reserve around aquatic feeding areas and mineral licks is typically recommended, but the size and shape of this reserve depends on the best approach to ensure habitat connectivity to the resource for moose (OMNR 1988). It is recommended that aquatic feeding areas have a 120m reserve, that adjacent clearcuts are limited to 80-130 Ha (OMNR 1988), and that aquatic feeding areas are not within 200m of access roads (KWR 2006). Lemke (2001) also recommends habitat connectivity among aquatic feeding areas via mature forest corridors be at least 100m wide and include 5m tall cover. Moose use of aquatic feeding areas can be influenced by reserve width, time since last cut, and the silvicultural system employed (Chikoski 2003). For example, in Ontario in areas harvested by selective cutting, moose use was greatest adjacent to old cuts (> 20 years) and large reserve widths (> 120m reserves), in areas harvested by shelterwood cutting, moose use was greatest adjacent to recent cuts (120m reserves); and in areas harvested by clearcutting, moose use was greatest adjacent to harvest blocks >10 years (>120m reserves; Chikoski 2003).

There is a wealth of information on management of moose aquatic feeding areas (e.g. KWR 2006) and criteria to identify moose aquatic feeding areas (e.g. Ranta 1998). The goal or these criteria are to i) provide adequate forest cover for moose, ii) reduce or avoid impacts to the aquatic feeding area, iii) ensure habitat connectivity, and iv) prevent moose-vehicular collisions.

4.4 FORESTRY ACCESS AND OTHER ANTHROPOGENIC LINEAR DISTURBANCES

Harvesting removes cover and creates accessibility (Crete 1988). Linear features associated with industrial development like seismic lines, pipelines, roads, power lines, and trails, fragment continuous forests – facilitating movement, visibility, and access for hunters and predators into remote areas (Dickie et al. 2017; Mumma et al. 2018; Finnegan, Pigeon, and MacNearney 2019). These linear features are prevalent in Boreal Alberta , and can result in overharvesting (e.g. Ontario; Timmermann and Gollat 1983) and increased predation rates of some ungulates (e.g. caribou; McNay et al. 2016). For moose, access roads should avoid areas of special concern (e.g., aquatic feeding areas,

mineral licks, calving sites, winter concentration areas), since they can destroy habitat or potentially cause vehicular collision hotspots (OMNR 1988).

Since the late 1960s recreational hunting and public access have increased alongside technology, facilitating hunting and transport through rugged terrain (e.g., ATVs, snowmobiles; Lynch 1979; Rippin 2001). Exacerbating the issue are predators, like wolves, that use man-made linear features as travel corridors, facilitating their introduction into new habitats and increasing their encounter rates with ungulates like moose (Mumma et al. 2018). Moose experience increased predation rates and risk in highly accessible landscapes (Rippin 2001). If access and moose recreational harvest are left unmanaged, increased access can dampen or nullify the benefits of favourable moose habitat and forage resulting from disturbances that typically support high moose densities (Serrouya et al. 2011). In Ontario and British Columbia, when hunter access increased with road density favourable clearcut and forestry practices had no beneficial effect on moose ((Rempel et al. 1997; Serrouya et al. 2011)). In order to reduce mortality risk from hunters and predators, moose change their behaviours and do not fully exploit young forests with open habitat (Bjørneraas et al. 2011). Moreover, as young forests age, moose populations naturally decline (Lynch 1979), which can be problematic for populations that are already experiencing low recruitment rates (Bjørneraas et al. 2011). Declining moose populations may also create cascading effects on other species, since there is a time lag when predators may seek alternative prey prior to declining in response to declining moose populations; wolves, however, experience a strong effect from moose declines (e.g. Serrouya et al. 2017).

Seismic lines in particular, have increased predation risk for moose, since wolves and other predators use these features as travel corridors and increase their encounter rates with prey species by doing so (Latham et al. 2011). In addition, linear features, like seismic lines, provide access to early-seral stage browse (e.g. Finnegan, Pigeon, and MacNearney 2019), which exposes moose to increased predation risk while feeding in these areas, since they are willing to compromise availability of cover to do so (Wasser et al. 2011). Further research is warranted to determine if seismic lines may be acting as ecological traps for moose and how this may be affecting moose populations, especially in areas of high seismic line density (e.g. Dickie et al. 2019). Similar to seismic lines, moose do not avoid crossing power lines, and may also be using them for browse (Bartzke et al. 2015). In Alberta, moose avoided increased human-caused disturbance and predation risk at the landscape scale, but selected human caused disturbance at the home range scale in order to meet forage requirements (Peters 2010b). However, impacts may be different between seasons and by region. During winter, when forage is limited, moose do not avoid roads and select harvest blocks for forage, exposing themselves to higher risk compared to during summer when they avoid these disturbances (Peters 2010b). Geographically, moose in the Foothills have also used more disturbed landscapes with double the linear feature density (summer: 1.67km/km^2 winter: 1.86km/km^2) compared to moose in the mountains (summer: 0.49km^2 winter: 0.64km/km^2; Peters 2010b). Peters (2010b) suggests that since available habitat composition was similar in these landscapes that these differences are more due to different habitat configurations between the Foothills and the mountains. It is likely that increasing risk exposure to disturbances as a strategy to best exploit available habitat composition and configuration in the landscape has its limits; therefore, it would be beneficial to determine total linear disturbance density thresholds for moose to aid in co-management. Given the high density of total linear disturbance

in Alberta, compared to the rest of Canada , the impacts of linear features on moose may be cumulative from local to regional scales.

4.5 MOVEMENT AND CONNECTIVITY

Moose are negatively associated with roads and increasing road density, and avoid areas near linear features (Laurian et al. 2010; Wasser et al. 2011; Wattles, Zeller, and DeStefano 2018; Dickie et al. 2019). In Alberta, moose have been seen to avoid roads and linear features more than caribou (Peters 2010b). Although moose are not known to use anthropogenic linear features as travel corridors, moose can travel along linear features when looking for crossing opportunities (Dussault et al. 2007; Bartzke et al. 2015) or to exploit forage (Laurian et al. 2008, 2010). Roads can act as complete or partial barriers to moose movement depending on their size, traffic volume, and design (e.g. Shanley and Pyare 2011; Laurian et al. 2012). At the landscape scale, roads not only increase access-related mortalities, but also negatively affect moose by increasing human activity and increasing vehicular collisions (Laurian et al. 2010; Toews 2016). At a more local scale, roads can be beneficial over the short-term as roadsides provide deciduous browse (Rempel et al. 1997) and salt deposits (Laurian et al. 2010; Toews 2016), but over the long-term roads can be detrimental as they increase moose vehicular collision risk. Other movement barriers for moose include mountain ranges dividing drainages (White et al. 2012), fencing (Olsson and Widen 2008), and rivers (Bartzke et al. 2015). Roads and power lines, and roads and rivers occurring together can also cause increased barrier effects for moose (Bartzke et al. 2015).

Roads with high traffic volumes can act as a movement barrier for moose, and high road densities can inhibit moose movement (Seiler 2005) and overall roads have a negative effect on moose (Wattles, Zeller, and DeStefano 2018). In Québec, moose that stay longer within habitat patches surrounded by a high amount of harvest blocks and roads in comparison to habitat patches with higher connectivity (Courbin et al. 2014). In Sweden, increased road density has been linked to an increase in non-migratory movements of moose (Singh et al. 2012), and roads can also have disproportionate impacts on movements of female versus male moose (Finnegan et al. 2012). The impacts of roads can also vary by season. For example, during periods of deep snow (>50-70 cm) during winter, moose can move into areas of lower elevation with less snow that are also closer to rail lines and roads, and if the roads have tall snowbanks moose may run down and not across the road to escape collision, resulting in increased vehicular collisions (Rolandsen et al. 2011). In BC, forestry truck drivers did not report collisions due to a lack of damage to their trucks (i.e. 1969-1997; BCFSC 2005). It is important to encourage reporting of these collisions, and to appropriately sign and speed control mortality hotspots to mitigate wildlife and human mortality.

In moose populations that are already experiencing declines, mitigating vehicular mortality may be especially important. On roads where salt is applied, removal of salt pools or use of a de-icing salt that is not sodium chloride can reduce roadside attractiveness (Laurian et al. 2010). Management of roadside vegetation and adjacent habitats (e.g. regenerating cutblocks) can also reduce foraging opportunities and vehicular collision risk for moose (Danks and Porter 2010).

Considering other linear features, although moose use natural linear features like rivers as travel corridors, moose are not known to use anthropogenic linear features to redistribute themselves into new habitats (Dickie et al. 2019),

instead they track suitable habitat types through the landscape. Moose do, however, use riparian corridors as travel corridors to facilitate their movements (Dickie et al. 2019). Moose may potentially use seismic lines for travel or forage (Pigeon, McKay, and Finnegan 2019; Finnegan, Pigeon, and MacNearney 2019); in north east Alberta moose do not seem to use seismic lines for travel (Dickie et al. 2019), but it is unclear whether this pattern is consistent across Alberta and during winter. Further research is warranted to clearly determine whether moose use seismic lines as travel corridors during different seasons, and how and if individuals are avoiding predation risk (e.g., sex, family status, travel speed) while traveling or foraging in these areas to better understand the use and impact of these features for moose.

4.6 POST-HARVEST MANAGEMENT

Post-harvest silvicultural techniques can enhance or reduce moose habitat quality depending on the timing, harvest method use, and post-harvest site preparation (Collins and Schwartz 1998), and should take into consideration the potential impact on the quantity and quality of moose habitat surrounding the harvest block (OMNR 1988).

Post-harvest activities typically occur within two years after harvest (AAF 2017c), but may be completed within 14 years of harvest to meet reforestation requirements and achieve a 'free to grow' status. In Alberta, when sites have good soil conditions for seedling establishment (warm, well drained) with little competing vegetation, or when vegetative reproduction can be successful for deciduous tree regeneration, "Leave-for-Natural" (LFN) reforestation can be employed where natural regeneration establishes seedlings (AAF 2017c).

Figure 4.1. Total area of different post-harvest silvicultural techniques used in Albertan forestry from 2010-2016 (AAF 2017).

Typically site preparation accompanies "artificial reforestation" (AR), where direct planting, and sowing seedlings or seeds regenerate the forest (AAF 2017a). Direct planting (61,273 Ha per year) is more prevalent in Alberta than LFN (18,687 Ha per year; ESRD 2012, 2013, 2014, 2016; AAF 2017b, 2017c).

Moose browse can be more abundant in post-harvest naturally regenerating stands (e.g. LFN) when compared to fire origin or AR stands 10 to 30 years post-disturbance (Boan, McLaren, and Malcolm 2011). In Ontario, post-harvest naturally regenerating stands were not directly associated with higher moose use, however at the landscape scale areas with more naturally regenerating stands were more likely to be used by moose (Boan, McLaren, and Malcolm 2011). The intensity of post-harvest silviculture activity influences moose habitat suitability (Boan, McLaren, and Malcolm 2011).
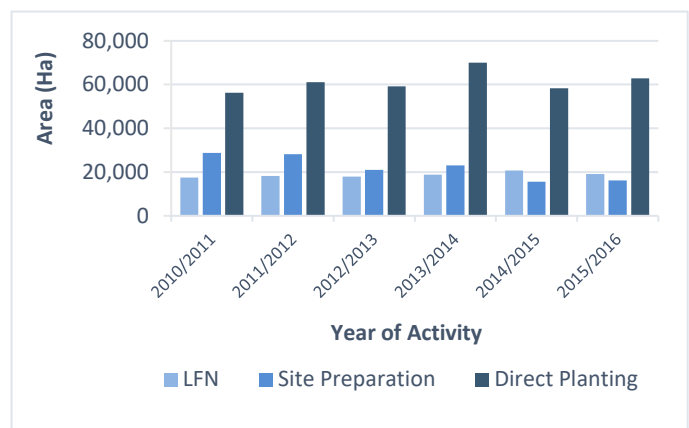
4.6.1 SITE PREPARATION

Site preparation in Boreal Alberta is the primary approach used to regenerate trees (Ehrentraut and Branter 1990). Site preparation occurs in more than half of all harvested sites prior to planting seedlings, and includes mechanical (19,507 Ha per year) preparation methods, but also infrequently includes prescribed fire (AAF 2017c).

By removing competing vegetation, improving soil conditions, and facilitating tree growth, site preparation prepares the site and soil for successful seed germination and seedling growth (AAF 2017c). Site preparation also variably results in improved or reduced wildlife forage and/or cover (e.g. Enns et al. 1994).

Figure 4.2. Total of area of different site preparation techniques used in Albertan forestry from 2009-2016 (AAF 2017).

4.6.1.1 MECHANICAL SITE PREPARATION

Mechanical site preparation can produce a range of soil conditions that affect seedling establishment (Löf et al. 2012). Moose response to mechanical site preparation varies based on the resulting tree and browse species available for forage, which can vary by technique, but also by location and season (Pigeon, McKay, and Finnegan 2019). Mechanical site preparation includes techniques like mounding and ploughing, dragging (chain scarification), disc trenching, scalping, and mixing (e.g. Fraser, Landhäusser, and Lieffers 2003).

Mechanical site preparation techniques penetrate into the soil and can have varying effects on moose browse. For example, scalping, can severely damage root systems and shrub growth, mounding maintains the vegetation community, while mixing stimulates suckering (Triton 2005). Mechanical site preparation techniques initially reduce shrub production, but can suppress forest succession at mid-seral stages (Triton 2005). If penetration into the soil is too shallow, does not expose mineral soil, or is too deep exposing subsoil, seedlings may not establish well or at all (Densmore 1988 in Collins 1996). For some mechanical site preparation techniques, birch and willow seedlings can be almost absent, while others like scarification using a clearing blade (root rake) produces high birch seedling density and growth rates (Densmore 1988 in Collins 1996).

Mounding and ploughing raises the planting spot, creating a site of warm, drained soil that promotes good root growth and increases seedling survival at wetter sites (AAF 2017c). Dragging, on the other hand, only exposes or mixes mineral soil enhancing root and seedling growth (AAF 2017c). Heavy soil scarification, such as mounding and ploughing, increases mineral nutrients in the shoots of regenerating species (similar to fertilization), and results in a mixture of deciduous and pine species preferred for browsing by moose (Nikula et al. 2008). However during winter, grasses and herbs can mat under the snow smothering hardwood seedlings or reducing their competitive ability for the next growing season (Collins and Schwartz 1998). In Alberta, preliminary analysis found that during summer, moose in the lower and upper Foothills preferred sites that were mechanically prepared during summer (Pigeon, McKay, and
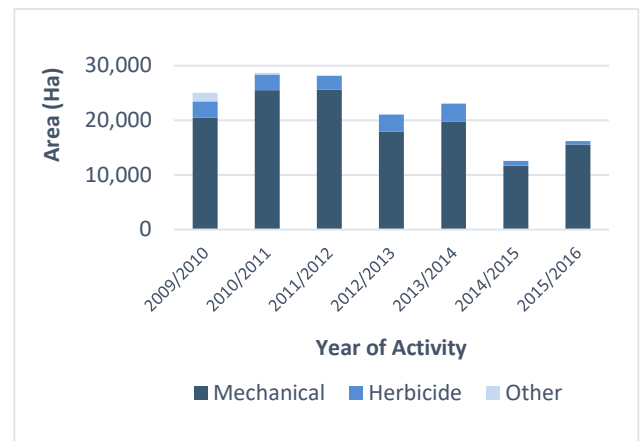
Finnegan 2019). Therefore, further research is warranted to determine if, and which, current mechanical site preparation techniques may be most beneficial to winter browse in moose winter ranges and to what extent.

Properly regenerated clearcuts can produce moose browse for approximately 20 years post-harvest (Collins and Schwartz 1998). Conversely, poor harvest practices with no scarification rarely exceed carrying capacities of mature forest (0.2 moose/km^2 Alaska). With soil scarification and good seedling establishment, forage supply can increase moose carrying capacity by 20-45 times (4-9 moose/km^2) over mature forest (Collins and Schwartz 1998). A detailed assessment of moose response to site preparation in west-central Alberta is underway, but studies in other areas and subregions would provide additional insights into moose response to site preparation (pers. comm. L. Finnegan 2019).

4.6.2 HERBICIDES

Herbicides release conifers from competition (McCormack 1994). They are applied either after seedling establishment; most commonly by aerial application due to its cost effectiveness in relation to the size of the area and the difficulty of access (Thompson and Pitt 2011). Herbicides improve tree survival and seedling establishment by reducing competition from grass and shrubs for one to two years post-treatment (AAF 2017c).

There are five herbicides registered for use in Canadian forestry (i.e., hexazinone; simazine; triclopyr; glyphosate; 2,4-D), with glyphosate being the most commonly and widely used in Canada (Thompson and Pitt 2011; NFD 2019). In Alberta, over the last 20 years (2000-2017), glyphosate has been applied to 29,052 Ha of forest on average per year (NFD 2019).

In British Columbia, glyphosate is being reduced to promote growth of moose winter browse to bolster declining populations (Fletcher 2018). However in Alberta, glyphosate use has increased over time due to "free-to-grow" standards and sustainability objectives (Thompson and Pitt 2011).

4.6.2.1 FORAGE AND HABITAT USE

Herbicides affect overall moose forage biomass production, habitat use and selection, and cumulatively affect regional habitat suitability and capability. Glyphosate suppresses the initial growth of deciduous species, reducing shrub biomass and shifting young forests to coniferous dominance reducing moose forage availability (Raymond et al. 1996). In combination with other limiting factors (e.g., hunter harvest, predation rates), herbicides can limit the carrying capacity of the landscape for moose (Milner, van Beest, and Storaas 2013).

After treatment with herbicides, overall biomass and consequently moose forage and habitat use in harvest blocks is lowered compared to untreated sites, but can still be higher than in uncut older forests (Olav Hjeljord and Grønvold 1988; Raymond et al. 1996; Sullivan and Sullivan 2003; Strong and Gates 2006; Milner, van Beest, and Storaas 2013). This reduction in moose forage generally persists for 1-5 years after treatment (Kennedy and Jordan 1985; Sullivan and Sullivan 2003; Strong and Gates 2006; Milner, van Beest, and Storaas 2013), but this time period differs depending on the herbicide used, its concentration, and the affected browse species at the site. In Maine, within 1-2 years post-treatment, moose were more than 50% less abundant, but by 7-11 years post-treatment conifers were twice as abundant, and moose forage and use was higher compared to untreated harvest blocks (Eschholz et al. 1996). Similarly

in Norway, in an area where moose had been in decline, 4 years after herbicide application ceased, both the area of regenerating forest and the moose population increased (Milner, van Beest, and Storaas 2013).

Although, herbicides generally affect moose over the short-term, they can have effects over the long-term as well. Hexazinone, for example, affected Boreal vegetation for at least 17 years after application (Strong and Gates 2006; Sullivan and Sullivan 2003). Long-term presence of these chemicals in soils may reduce the quality and palatability of vegetation (Corbould pers. comm. In Triton 2005). Benefits from forest re-initiation to increase browse production can be shorter-lived than in untreated harvest blocks. In Alberta, treated harvest blocks stopped producing increased browse at 26 years, several years before untreated cutblocks (Strong and Gates 2006).

The duration of herbicide effect varies and depends on site characteristics, herbicide type, and application rate, as well as plant species (Raymond et al. 1996). For example, rowan is more sensitive to herbicides than birch (Olav Hjeljord and Grønvold 1988). Consequently, over the long- term (7–30 years) browse biomass on treated sites may be lower (Hjeljord 1994; Boan, McLaren, and Malcolm 2011), similar (Raymond et al. 1996), or higher (Newton et al. 1989) than on untreated sites, and can also vary by season (Strong and Gates 2006).

Herbicides have a stronger effect on reducing browse species important for moose during winter (Strong and Gates 2006; Milner, van Beest, and Storaas 2013). During winter when moose movement and forage is limited, moose prefer areas of high browse production (Telfer 1978). Low availability of winter browse can affect reproduction and survival through declines in calving rates (Milner, van Beest, and Storaas 2013), fat reserves, fetal development, birth weights, and calf growth rates (Mech et al. 1987).

Herbicides are applied in forests at small spatial-scales, and by using alternative habitats moose can reduce their use of treated sites (Olav Hjeljord and Grønvold 1988; Eschholz et al. 1996; Milner, van Beest, and Storaas 2013) or avoid these treated sites (Pigeon, McKay, and Finnegan 2019). However, cumulatively at the regional scale reduced forage production over the long-term can cause regional habitat degradation. Moreover, the sites where herbicides are applied are those that are highly competitive sites, which may be targeting sites with the highest potential for moose forage production (Wagner et al. 2004; Strong and Gates 2006).

Biologists advise against broad-scale application of herbicides (Poole and Stuart-Smith 2004) on high value moose forage species, including willow (*Salix* spp.), red-osier dogwood (*Cornus stolifera*), high-bush cranberry (*Vibernum edule*; (Wall, Belisle, and Luke 2011). If herbicides are used, especially in areas where local moose populations are declining (e.g., poor body condition, starvation, low pregnancy rates), sufficient regeneration of moose shrubs should be allowed (Poole and Stuart-Smith 2005). **Decision-support tools and beneficial management practices may assist foresters in determining the best use of herbicides in areas where important moose forage is found.**

4.6.2.2 WILDLIFE HEALTH AND HERBICIDES

Glyphosate use is controversial, since it is considered a probable carcinogen by the International Agency for Research on Cancer (IARC 2016; Tarazona et al. 2017), but not by Health Canada, and therefore meets Canadian health and safety standards (Canada 2019). In Québec, glyphosate has been banned since 2001 (Thompson and Pitt 2011), in Austria glyphosate will be banned by 2020 (FSA 2019) and in Germany by 2023 (BMU 2019) due to public health

concerns. A lack of research and ongoing use of glyphosate in forestry has generated concern amongst First Nations, stakeholders, and members of the public in Alberta (pers. comm. L. Trout 2019).

Glyphosate is currently not recognized as affecting wildlife or human health (Canada 2017). Its wide application across Canada operates under the understanding that it is excreted rapidly in urine and feces over the short-term, and over the long-term does not accumulate in organs or muscle tissues (Thompson and Pitt 2011). Some studies administering glyphosate at low chronic doses to animals have seen effects including reduction in male fertility (Cai et al. 2017), difficulty with embryo implantation (Ingaramo et al. 2017), neurological disorders (Coullery, Ferrari, and Rosso 2015; Ait Bali et al. 2019), modifying the gut microbiome (Mao et al. 2018), liver and kidney damage, and development of tumors (van Bruggen et al. 2018).

There is also concern that glyphosate and its derivatives (e.g. AMPA) may be accumulating in the environment (e.g., soil, water; Battaglin et al. 2014; van Bruggen et al. 2018). AMPA is mildly toxic to plants and its potential accumulation in soil may not only cause issues for plants, but also invertebrates and soil bacteria (van Bruggen et al. 2018). **The long-term effects of glyphosate and its derivative compounds consumed by animals at low chronic doses** (similar to managed forests), **and its accumulation in the environment should be made a research priority; there is currently not enough information to clearly state that glyphosate does not persist in Canadian forest ecosystems**. Moreover, in the Boreal, potential accumulation of glyphosate may be particularly detrimental, since the region experiences long biologically inactive winters and short growing seasons (Helander, Saloniemi, and Saikkonen 2012). The study of species with increased vulnerability, can be especially valuable, since they may also act as biosentinels for not only wildlife, but also human health (Kissane and Shephard 2017).

4.6.3   PLANTING , SEEDING, AND STAND TENDING

Stand tending activities increase timber production and can be both mechanical (e.g., spacing, thinning, brushing, pruning) and chemical (e.g., fertilization, herbicides). In order to benefit moose, stand tending practices should allow some shrubs to persist (Poole and Stuart-Smith 2004).

Native seed mixes can increase ungulate forage availability for moose. Mixedwood and broadleaf species provide a good mix for areas in important moose winter and summer habitats (Wall, Belisle, and Luke 2011). In Alberta, commercially available standard seed mixes have been developed for different physiographic regions to manage elk (Triton 2005). Moose could also be managed in a similar way to regenerate stands for declining populations.

Moose benefit from planting seedlings, since it increases available forage in the cut. Moose prefer deciduous seedlings, but will also browse on conifer seedlings (Andreozzi, Pekins, and Langlais 2014; Mathisen, Milner, and Skarpe 2017; also see **Section 4.3.3** Tree Species Composition). Stocking densities and spacing of adjacent cutblocks can also improve moose winter habitat, forage production, and habitats of special concern (e.g., mineral licks, rutting sites, wetlands, riparian areas; Wall, Belisle, and Luke 2011).

4.6.3.1   THINNING

Thinning includes pre-commercial thinning, which designs the spacing of juvenile trees, and commercial thinning, which removes older trees to increase timber yield in younger trees (Greenough and Kurz 1996). These methods

reduce competition between trees, resulting in reduced tree mortality and increased growth rates. Thinning is beneficial for shrub production, since shrub cover decreases with increasing canopy cover; this includes both shade-tolerant and intolerant shrubs (Greenough and Kurz 1996). Thinning can provide increased moose forage (Härkönen and Heikkilä 2000), although depending on the intensity of the thinning, benefits may be limited. In British Columbia, 12-15 years after heavy thinning (<=1,000 stems/Ha), moose benefited from increased herbs and shrubs, and greater species and structural diversity of conifers, compared to unthinned, old-growth stands or stands thinned to > 1,000 stems/Ha (Sullivan et al. 2006). Thinning has the potential to improve moose forage (Sullivan et al. 2006). However, if both shade-intolerant and shade-tolerant shrubs are not present for more than 10 years, shrub cover will not regenerate by thinning because the bud bank dies. Debris loading during stand tending can also impede understory recovery (Greenough and Kurz 1996).

4.6.3.2 FERTILIZATION

Nitrogen-based fertilizers are usually applied immediately after thinning to increase plant growth rates and seed production by reducing competition for nutrients without reducing stand density (Greenough and Kurz 1996; Triton 2005). Fertilizers increase biomass production of commercial species, but also increases moose forage biomass, nutritional value (Triton 2005), and potentially productivity (Sullivan 2018). The effects of fertilizers are typically limited to the first year after treatment (Triton 2005). Although in south-central British Columbia, biomass production of grasses increased within 5 years after the first application of fertilizer, whereas shrubs (e.g., Saskatoon berry, willow) herbs and forbs (e.g. Fireweed (*Epilobium angustifolium*) only increased after a second application of fertilizer 5-10 years after the initial treatment (Sullivan 2018). However, repeated applications reduced the biomass of some dwarf shrubs, mosses, and lichens (Sullivan 2018).

5. FUTURE DIRECTIONS

Alberta's Boreal forests are dynamic, with insect infestations, wildfires, climate, and human disturbance constantly changing the landscape. The climate and habitat disturbances impacting the Boreal forest today are different from historical records and are expected to change even further in the future, especially with the increasing effects of climate change (e.g. Schneider et al. 2009; Hanes et al. 2018). As the impacts of these changes are better understood, it is important to incorporate this new knowledge into proactive and adaptive management strategies to improve best management practices and long-term planning for forestry and moose across the Boreal forest. The **Key Gaps** and recommended **Future Directions** are discussed in the following section.

5.1 NINE KEY KNOWLEDGE GAPS AND RECOMMENDATIONS

Forestry is the dominant anthropogenic landscape driver changing habitats by design in Alberta's Boreal forests, these recommendations aim to improve forest planning and management practices to better support moose-forestry co-management. These ten key recommendations with forestry professionals in mind have been identified through their relationship to key issues for moose regionally across the Boreal. Specific forestry tenures may have their own suite of ecologically, culturally, and economically distinctive considerations (e.g., highly suitable winter tick habitat, high risk of wildfire).

Table 2. Nine Key Knowledge Gaps and Recommendations.

FUTURE DIRECTIONS
1. Research Moose Population Sizes and Trends. 2. Participate in Winter Tick Surveillance. 3. Develop Industrial Access Management Plans. 4. Plan for Climate Resilient and Connected Habitats. 5. Herbicides and Moose Health and Forage Availability. 6. Advances in Moose Monitoring Methods 7. Improve Forest Planning Design and BMPs for Moose. 8. Mountain Pine Beetle Effects on Available Moose Habitat and Forage. 9. Landscape Scale Criteria for Moose Cumulative Effects Assessments.

Future Direction	Key Gaps and Recommendations
1	**Research Moose Population Sizes and Trends.** **Gap:** *There is a lack of published information on moose population sizes and trends from 2015-2019.* Parkland and grasslands populations have been increasing significantly over time (i.e. Bjorge et al. 2018), but the overall provincial population is declining (i.e. Timmermann and Rodgers 2017). For this review we gathered data from available aerial inventory reports between 1980 and 2020. A preliminary mapping comparison of these data and data collected between 2010 and 2020, suggests that in the Boreal the greatest amount of change in moose population estimates have occurred over the last decade. A statistical comparison may confirm these trends.

	• **Synthesize Moose Population Size and Trends by Region for the Boreal and Foothills** Synthesize and evaluate publicly available population data for moose from WMU ungulate aerial survey reports from 1980-2020 to statistically evaluate whether moose populations in the Foothills and Boreal regions have declined from 2000-2020. As a deliverable from this work to aid in future research, ensure that a shared geodatabase is provided that includes WMU shapefiles (i.e. WMU polygon shapes change over time) and spatially referenced population data by WMU from 1980-2020. • **Determine Causal Factors of Local Moose Population Declines** Identify forestry tenures, if any, where local moose populations have experienced continued or significant decline over the long- and/or short-term. Prioritize these areas for future research to determine the causal factors of declines in the area of interest (e.g. Kuzyk, Marshall, et al. 2018; Kuzyk, Dehn, and Farnell 1999).
2	**Liaise with the Government to Participate in Winter Tick Surveillance in Managed Forests.** **Gap:** *There is a lack of published information on moose winter tick outbreaks from 2000-2019.* Significant winter tick outbreaks are a cyclical population limiting factor for moose. In tenures that have more suitable winter tick habitat, monitoring of winter tick is especially important. Moreover, as climate change makes new areas more favourable for winter tick survival, baseline monitoring in forest tenures will be important to support managing forests in moose habitat sustainably to ensure moose persistence. As a management intervention, forestry could target cutblocks in areas that are more abundant for ticks to decrease their abundance. • **Develop a Forestry *Surveillance of Ticks on Wildlife* program.** Develop a partner program with the provincial government of a similar structure to British Columbia's Provincial Moose Winter Tick Surveillance Program to collect information from hunters, trappers, and personnel reporting opportunistic hair loss observations for moose in forest tenures. Identify specific tenures, such as Blue Ridge, that have reported significant winter tick infestations and moose population declines in the past to begin pilot programs. This information can also be valuable for other ungulates (e.g., caribou, elk). • **Synthesize Winter Tick Prevalence and Trends by Region for the Boreal and Foothills.** Partner with the government to acquire any existing reports or datasets that can aid in creating a timeline of winter tick outbreaks from 2000 to 2019. Identify gaps in this information and spatial hotspots over time of outbreaks in forest tenures. Prioritize these areas of historically high infestation and areas of interest for pilot programs. • **Develop Research Partnerships in Tenures with High Winter Tick Infestation History** Conduct winter tick surveys investigating disease occurrence and host availability and host contact rates. Camera trapping is a novel approach that can non-invasively record presence/absence records of moose hair loss sightings and host contact rates of other ungulates (e.g., elk, caribou, deer). Target highly infested areas for cutblocks in areas where moose populations have been experiencing continued decline.
3	**Liaise with the Government to Develop Industrial Access Management Plans.** **Gap:** *There is a lack of provincial Regional Access Management Plans and guidelines to support industrial access management planning for moose.* • **Determine if Seismic Lines are Acting as Ecological Traps for Moose**

	Assess relationships of total linear disturbance, but focus specifically on roads, seismic lines, and power lines. Determine how seismic and power lines are influencing moose behaviour and if they are acting as ecological traps.
	• **Encourage Reporting of Moose-Vehicle Collisions in Forest Management Areas.**
	Assess whether there is a lack of wildlife collision reporting. If so, incorporate mandatory reporting of species such as moose and caribou into protocols. Map road mortality hotspots to mitigate human and moose mortalities and support access management planning.
	• **Reduce Hunter and Predator Landscape Accessibility.**
	Consider using movement connectivity maps of wolves and hunters to manage accessibility and inform decisions for road optimization and linear feature reclamation. Linear features that contribute most to network connectivity overall can strategically be chosen and reclaimed or managed to reduce access for predators and hunters. Engage in consultations with First Nations, stakeholders, and other organizations to assure removed access does not generate public conflict.
4	**Climate Resilient and Connected Habitats.** **Gap:** *There are a lack of guidelines and plans providing direction on how to prepare habitats in managed forests for climate change and forecasted habitat shifts.*
	• **Identify Potentially Climate Resilient Moose Habitats.**
	Project the shift of suitable moose habitats northwards into the Boreal and determine the importance of the present Boreal and Foothills habitats in this range. Identify climate resilient habitats that are currently important for moose and that will continue to be important under most or all climate change scenarios. Minimize the risk of impairing the functionality of these areas and prioritize BMP efforts there.
	Moose are also susceptible to heat stress. Design (e.g., cover, density) the retention of natural features (e.g. low-lying areas) to provide thermal shelter. Prioritize and develop guidelines for provision of thermal shelter within or adjacent to highly suitable natural habitat and/or within cutblocks that are in areas with the highest probability of warming trends.
	• **Climate Sensitive Wetlands.**
	Moose specialize on aquatic vegetation from mid-June to July. These areas are considered areas of special concern for moose in many management guidelines and are buffered from roads and cutblocks. Identify wetlands, specifically potential or known aquatic feeding areas, which are the most vulnerable to climate change and prioritize the protection of the habitat and hydrological connectivity of these wetlands to support their climate resiliency.
	• **Identify Core Areas and Connectivity for Northwestern Alberta Boreal and Foothills Regions.**
	Identify core areas and connectivity for moose in western Alberta, where the highest total linear disturbance and moose densities exist for the entire province (e.g. Apps et al. 2007).
5	**Herbicides Cumulative and Long-Term Effects on Moose Health and Forage Availability.** **Gap:** *There is a lack of clarity on the long-term and cumulative effects of herbicides on moose health and forage availability.*
	Given the extent and timeframe over which herbicides are applied in Alberta and that the their application has only been increasing over time in response to "free-to-grow" standards, if herbicides do

persist in the environment or wildlife, any effects will occur at large spatial scales on both habitats and wildlife populations.

- **Clarify the Relationship Between Glyphosate and Wildlife Health.**

Determine if long-term application of herbicides at low chronic doses impacts to moose health. This could be achieved via a literature review on the effect of herbicides on mammalian health applied at low chronic doses combined with new research if necessary.

- **Determine Persistence and Accumulation of Glyphosate in the Environment.**

Determine if glyphosate and/or its derivatives (e.g. AMPA) persist and accumulate in the environment. Determine whether there are any relationships between these compounds persisting in the environment and water quality, soil quality, vegetation growth, and overall ecosystem functioning and disturbance resiliency.

- **Determine the Additive Effects of Herbicides on Forage Availability.**

Herbicides are known to reduce overall forage biomass for moose through shrub reduction over the short- and long-term. They have been applied annually in the Boreal for over 30 years. It is possible that local stand scale reductions in forage biomass may be clustered at the landscape scale and cumulatively exerting pressure on local moose populations over time. Moreover, reduction in forage biomass and consequently habitat suitability for moose may be causing short- or long-term redistribution of individuals. Assess how moose forage biomass has potentially been reduced at the stand and landscape scale over time. Use this information to improve forest planning and best management practices, if required.

6	**Support Advances in Monitoring Methods to Improve Moose Surveillance.** **Gap:** *A lack of standardized approaches and technology for modern surveillance methods.*

- **Determine baselines for monitoring programs**

Determine the most appropriate approach to determine baseline population vital rates – e.g., abundance, occupancy, habitat use, or distribution.

- **Trans boundary Standardization of Aerial Surveys**

In Alberta, aerial surveys apply distance sampling more so than stratified random block, which is the approach commonly taken in British Columbia. Aerial surveys in the past in Alberta did not apply sightability correction factors, but its application would likely improve the accuracy of estimates (Peters et al. 2014), and comparability to estimates in adjacent jurisdictions.

- **Pilot Project - Unmanned Aerial Vehicles for Monitoring Moose.**

This technology to survey wildlife has only recently been employed. It may be more accurate as an application for moose, compared to other ungulates present in herds, since it will be easier to eliminate the possibility of double counting. Moreover, infrared technology might make moose more easily detectable to cameras compared to observers. However, testing will be required to see how difficult it may be to sex moose outside of seasons where they retain their antlers, especially in dense vegetation, deep snow, and/or steep terrain, where drones may have difficulty photographing moose vulva patches.

- **Develop Standardized Camera Trapping Protocols.**

Camera trapping is currently widely applied and its use and applications are only increasing. Given the lack of standardized protocol, as is available for other well-established inventory methods (e.g., aerial inventory, snow-tracking), it would greatly advance the quality and reliability of camera trapping methods, if best practices were consolidated into a standard protocol. This need has been recognized

	elsewhere and is currently being conducted by the Government of Alberta (Laura Finnegan pers. comm. 2019).
7	**Improve Forest Planning Design and BMPs for Moose.** **Gap:** *Moose response to some commonly employed best management practices is not clear.* Consider using this review and other publications and documents as a starting point to update forest planning design and best management practices for moose. • **Evaluate Effectiveness of Retention Patches for Moose.** Assess whether existing retention patches function for moose by providing habitat connectivity, forage, or thermal cover. • **Compartment-scale planning for thermal cover** Determine links between forest stand characteristics, patch size and connectivity to maintain thermal cover for moose. • **Shifting Tree species Composition into Commercially Viable Stands.** Investigate co-management strategies and scenarios wherein moose browsing and suppression of deciduous species can be employed to produce commercially viable stands. • **Impact of Mechanical Site Preparation on Browse Species.** Determine the scale at which mechanical site preparation techniques are most detrimental to the establishment of moose browse species within home ranges, especially on winter ranges. This information can potentially be assembled via a literature review.
8	**Mountain Pine Beetle Effects on Available Moose Habitat and Forage.** **Gap:** *There is a lack of literature on moose response to mountain pine beetle.* • **Moose Response to MPB.** Determine the effect of MPB infestation on moose forage availability and use of habitats, e.g. increased predation risk. Assess the relationships between moose and MPB disturbance over time at the landscape scale in both naturally regenerated (control) and managed forests (i.e. salvage logging).
9	**Landscape Scale Criteria for Moose Cumulative Effects Assessments.** When conducting cumulative effects assessments for moose, consider the following criteria in addition to guidelines for special areas of concern (e.g. calving sites, aquatic feeding areas, winter range) that characterize the following landscape scale effects on moose habitat: • Reduction of forage biomass on herbicide treated cutblocks. • Linear infrastructure associated with logging, especially salvage logging, increasing access to habitats for predators and hunters. • Reduced cover due to disturbances reducing winter movement ability and escape and thermal cover. • Disturbances increasing forage availability (i.e., fire, cutblocks, potentially MPB). • Climate change in areas that are at the maximum tolerance of moose to heat (>27°C) during the summer. • Landscape level forest age class distribution relative to expected (i.e., NRV), with special consideration to the negative relationship homogeneous landscapes (mature forests lacking species diversity) have on moose population growth. • Landscape scale barriers to movement (e.g., major highways, mountain ranges). • Migratory routes.

LITERATURE CITED

AAF, Alberta Agriculture and Forestry. 2017a. "Sustainable Forest Management. 2016 Facts & Statistics. Area Harvested."

———. 2017b. "Sustainable Forest Management 2015 Facts & Statistics. Aspen Defoliators."

———. 2017c. "Sustainable Forest Managment 2016 Facts & Statistics. Site Preparation."

Abaturov, Boris D, and Konstantin A Smirnov. 2002. "Effects of Moose Population Density on Development of Forest Stands in Central European Russia." *Alces*. Alces.

Abatzoglou, John T, and A Park Williams. 2016. "Impact of Anthropogenic Climate Change on Wildfire across Western US Forests." *Proceedings of the National Academy of Sciences* 113 (42): 11770–75. https://doi.org/10.1073/pnas.1607171113.

ABMI, Alberta Biodiversity Monitoring Institute. 2018. "Explore the Status and Trend of Human Footprint Status by Alberta's Natural Regions." Alberta Biodiversity Monitoring Institute. 2018. https://abmi.ca/home/reports/2018/human-footprint/Natural-Regions.

Adamczewski, Jan, Wiktor L. Adamowicz, Peter C. Boxall, Ludwig. N. Carbyn, Denis Chabot, John R. Gunson, Robert J. Hudson, et al. 1993. *Hoofed Mammals of Alberta*. Edited by Brad J. Stelfox. Edmonton, Alberta: Lone Pine Publishing.

AEDT, Alberta Economic Development and Trade. 2019. "Highlights of the Alberta Economy." https://investalberta.ca/media/1080313/highlights-of-the-alberta-economy-2019-march-2019.pdf.

AEP, Alberta Environment and Parks. 2017. "Alberta Wild Species General Status Listing - 2015." https://open.alberta.ca/dataset/ad0cb45c-a885-4b5e-9479-52969f220663/resource/763740c0-122e-467b-a0f5-a04724a9ecb9/download/sar-2015wildspeciesgeneralstatuslist-mar2017.pdf.

AFPA, Alberta Forest Products Association. 2019. "Working Forests. The Role of Forest Management in Alberta's Environment Econonmy & Culture." http://albertaforestproducts.ca/wp-content/uploads/2019/06/Working-Forests-MLA-Kit-final.pdf.

Ait Bali, Yassine, Nour-eddine Kaikai, Saadia Ba-M'hamed, and Mohamed Bennis. 2019. "Learning and Memory Impairments Associated to Acetylcholinesterase Inhibition and Oxidative Stress Following Glyphosate Based-Herbicide Exposure in Mice." *Toxicology* 415 (March). https://doi.org/10.1016/j.tox.2019.01.010.

Alexis, Deana. 2010. "Woodland Caribou (Rangifer Tarandus Caribou) Aboriginal Traditional Knowledge Report: Alberta." https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/publications/woodland-caribou-aboriginal-knowledge-summary-report.html.

Alfaro, Rene I, Lara van Akker, and Brad Hawkes. 2015. "Characteristics of Forest Legacies Following Two Mountain Pine Beetle Outbreaks in British Columbia, Canada." *Canadian Journal of Forest Research* 45 (November): 1387+. https://doi.org/10.1139/cjfr-2015-0042.

Alfaro, Rene I, Elizabeth Campbell, and B. C. Hawkes. 2010. *Historical Frequency, Intensity and Extent of Mountain Pine Beetle Disturbance in British Columbia. Mountain Pine Beetle Working Paper CN - SB945.M78 A44 2010*. Victoria, B.C: Pacific Forestry Centre.

Allen, Andrew M, Johan Månsson, Håkan Sand, Jonas Malmsten, Göran Ericsson, and Navinder J Singh. 2016. "Scaling up Movements: From Individual Space Use to Population Patterns." *Ecosphere* 7 (10): e01524. https://doi.org/10.1002/ecs2.1524.

Altmann, Margaret. 1958. "Social Integration of the Moose Calf." *Animal Behaviour* 6 (3): 155–59. https://doi.org/https://doi.org/10.1016/0003-3472(58)90045-9.

Andreozzi, Haley A, Peter J Pekins, and Matt L B T - Alces Langlais. 2014. "Impact of Moose Browsing on Forest Regeneration in Northeast Vermont" 50 (November): 67+.

Arnemo, Jon M., Terry J. Kreeger, and Timo Soveri. 2003. "Chemical Immobilization of Free-Ranging Moose." *Alces* 39: 243–53.

ASRD, Alberta Sustainable Resource Development. 2006. "Alberta Forest Management Planning Standard."

Astorga, Francisca, Scott Carver, Emily S Almberg, Giovane R Sousa, Kimberly Wingfield, Kevin D Niedringhaus, Peach Van Wick, et al. 2018. "International Meeting on Sarcoptic Mange in Wildlife, June 2018, Blacksburg, Virginia, USA." *Parasites & Vectors* 11 (1): 449. https://doi.org/10.1186/s13071-018-3015-1.

AW, Alberta Wildfire. 2017. "10-Year Wildfire Statistics." Government of Alberta. 2017. https://wildfire.alberta.ca/resources/historical-data/10-year-statistical-summary.aspx.

AWW, Alberta Wildlife Watch. 2019. "Alebrta Wildlife Watch Animal Carcass Records." Government of Alberta.

Axelson, Jodi N, René I Alfaro, and Brad C Hawkes. 2010. "Changes in Stand Structure in Uneven-Aged Lodgepole Pine Stands Impacted by Mountain Pine Beetle Epidemics and Fires in Central British Columbia." *The Forestry Chronicle* 86 (1): 87–99.

Ball, John P, Caroline Nordengren, and Kjell Wallin. 2001. "Partial Migration by Large Ungulates: Characteristics of Seasonal Moose *Alces Alces* Ranges in Northern Sweden." *Wildlife Biology* 7 (3): 39–47. https://doi.org/10.2981/wlb.2001.007.

Ballard, W B, and V Van Ballenberghe. 1998. "Moose-Predator Relationships: Research and Management Needs." *Alces* 34: 91–106.

Bangs, Edward E, Theodore N Bailey, and Mary F Portner. 1989. "Survival Rates of Adult Female Moose on the Kenai Peninsula, Alaska." *The Journal of Wildlife Management* 53 (3): 557–63. https://doi.org/10.2307/3809176.

Bao, Heng, Hongliang Dou, Yingjie Ma, Hui Liu, and Guangshun Jiang. 2017. "Moose Winter Diet Components from Feces and Field Feeding Signs: Consistency and Variability Related to Forage Availability and Nutritional Requirements." *Ecological Research* 32 (5): 685–92. https://doi.org/10.1007/s11284-017-1483-y.

Bartzke, G, Roel May, Erling Johan Solberg, Christer Rolandsen, and Eivin P D - 2015/04/ Røskaft. 2015. "Differential Barrier and Corridor Effects of Power Lines, Roads and Rivers on Moose (Alces Alces) Movements." *Ecosphere* 6: art67. https://doi.org/10.1890/ES14-00278.1.

Batcheler, C L. 1975. "Development of a Distance Method for Deer Census from Pellet Groups." *The Journal of Wildlife Management* 39 (4): 641–52. https://doi.org/10.2307/3800222.

Battaglin, William, Michael Meyer, K M Kuivila, and J E Dietze. 2014. "Glyphosate and Its Degradation Product AMPA Occur Frequently and Widely in U.S. Soils, Surface Water, Groundwater, and Precipitation." *JAWRA Journal of the American Water Resources Association* 50 (April). https://doi.org/10.1111/jawr.12159.

Bayne, Erin, Richard Moses, and Stan Boutin. 2005. "Evaluation of Winter Tracking Protocols as a Method for Monitoring Mammals in the Alberta Biodiversity Monitoring Program." Edmonton, Alberta, Canada. https://abmi.ca/home/publications/51-100/66.

BCFSC, BC Forest Safety Council. 2005. "Overview of Forestry Truck Crashes in BC."

Beazley, Karen, Mark Ball, Lisa Isaacman, Scott Mcburney, and Paul Wilson. 2006. "Complexity and Information Gaps in Recovery Planning for Moose (Alces." *Alces* 42.

Beazley, Karen, Mark Ball, Lisa Isaacman, Scott McBurney, Paul Wilson, and Tony B T - Alces Nette. 2006. "Complexity and Information Gaps in Recovery Planning for Moose (Alces Alces Americana) in Nova Scotia, Canada" 42 (November): 89+.

Beazley, Karen, Tamaini Snaith, F. MacKinnon, and D. Colville. 2004. "Road Density and Potential Impacts on Wildlife Species Such as American Moose in Mainland Nova Scotia." In *Proceedings of the Nova Scotian Institute of Science*, 339–57.

Bennett, Logan J, P F English, and Randal McCain. 1940. "A Study of Deer Populations by Use of Pellet-Group Counts." *The Journal of Wildlife Management* 4 (4): 398–403. https://doi.org/10.2307/3796010.

Bergeron, Daniel H, and Peter J B T - Alces Pekins. 2014. "Evaluating the Usefulness of Three Indices for Assessing Winter Tick Abundance in Northern New Hampshire" 50 (November): 1–15.

Bergeron, Daniel H, Peter J Pekins, Henry F Jones, and William B B T - Alces Leak. 2011. "Moose Browsing and Forest Regeneration: A Case Study in Northern New Hampshire" 47 (November): 39–51.

Bergeron, Yves, Alain Leduc, Brian Harvey, and Sylvie Gauthier. 2002. "Natural Fire Regime: A Guide for Sustainable Management of the Canadian Boreal Forest." *Aspen Bibliography* 36 (January). https://doi.org/10.14214/sf.553.

Bergman, Carita M, John M Fryxell, C Cormack Gates, and Daniel Fortin. 2001. "Ungulate Foraging Strategies: Energy Maximizing or Time Minimizing?" *Journal of Animal Ecology* 70 (2): 289–300. https://doi.org/10.1111/j.1365-2656.2001.00496.x.

Bergqvist, Göran, Roger Bergström, and Märtha Wallgren. 2014. "Recent Browsing Damage by Moose on Scots Pine, Birch and Aspen in Young Commercial Forests-Effects of Forage Availability, Moose Population Density and Site Productivity." *Silva Fennica* 48 (1): 1–13. https://doi.org/10.14214/sf.1077.

Bergqvist, Göran, Märtha Wallgren, Hans Jernelid, and Roger Bergström. 2018. "Forage Availability and Moose Winter Browsing in Forest Landscapes." *Forest Ecology and Management* 419–420: 170–78. https://doi.org/https://doi.org/10.1016/j.foreco.2018.03.049.

Berkel, Tim van. 2014. *Camera Trapping for Wildlife Conservation: Expedition Field Techniques*. London, United Kingdom: Geography Outdoors.

Berman, A, Y Folman, M Kaim, M Mamen, Z Herz, D Wolfenson, A Arieli, and Y Graber. 1985. "Upper Critical Temperatures and Forced Ventilation Effects for High-Yielding Dairy Cows in a Subtropical Climate." *Journal of Dairy Science* 68 (6): 1488–95.

Beyer, Hawthorne, Ricardo Ung, Dennis Murray, and Marie-Josee Fortin. 2013. "Functional Responses, Seasonal Variation and Thresholds in Behavioural Responses of Moose to Road Density." *Journal of Applied Ecology* 50 (April): 286–94. https://doi.org/10.1111/1365-2664.12042.

Bjorge, Ronald R. 1996. "Recent Occupation of the Aspen Parkland Ecoregion by Moose." *Alces* 32: 141–47.

Bjorge, Ronald R, Delaney Anderson, Emily Herdman, and Scott B T - Alces Stevens. 2018. "Status and Management of Moose in the Parkland and Grassland Natural Regions of Alberta" 54 (September): 71+.

Bjørneraas, Kari, Ivar Herfindal, Erling Johan Solberg, Bernt-Erik Sæther, Bram van Moorter, and Christer Moe Rolandsen. 2012. "Habitat Quality Influences Population Distribution, Individual Space Use and Functional Responses in Habitat Selection by a Large Herbivore." *Oecologia* 168 (1): 231–43. https://doi.org/10.1007/s00442-011-2072-3.

Bjørneraas, Kari, Erling Johan Solberg, Ivar Herfindal, Bram Van Moorter, Christer Moe Rolandsen, Jean-Pierre Tremblay, Christina Skarpe, Bernt-Erik Saether, Rune Eriksen, and Rasmus Astrup. 2011. "Moose Alces Alces Habitat Use at Multiple Temporal Scales in a Human-Altered Landscape." *Wildlife Biology* 17 (1): 44–54. https://doi.org/10.2981/10-073.

BMU, Environment Nature Conservation and Nuclear Safety. 2019. *Aktionsprogramm Insektenschutz*. Germany. https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/aktionsprogramm_insektenschutz_kabinettversion_bf.pdf.

Boan, Julee J., Brian E. McLaren, and Jay R. Malcolm. 2011. "Influence of Post-Harvest Silviculture on Understory Vegetation: Implications for Forage in a Multi-Ungulate System." *Forest Ecology and Management* 262 (9): 1704–12. https://doi.org/10.1016/j.foreco.2011.07.022.

Boan, Julee, Brian McLaren, and Jay Malcolm. 2011. "Influence of Post-Harvest Silviculture on Understory Vegetation: Implications for Forage in a Multi-Ungulate System." *Forest Ecology and Management* 262 (August): 1704–12.

Boertje, R. D., W. C. Gasaway, D. V. Grangaard, and D. G. Kelleyhouse. 1988. "Predation on Moose and Caribou by Radio-Collared Grizzly Bears in East Central Alaska." *Canadian Journal of Zoology* 66 (11): 2492–99. https://doi.org/10.1139/z88-369.

Borchard, Philip, David J Eldridge, and Ian A Wright. 2012. "Sarcoptes Mange (Sarcoptes Scabiei) Increases Diurnal Activity of Bare-Nosed Wombats (Vombatus Ursinus) in an Agricultural Riparian Environment." *Mammalian Biology* 77 (4): 244–48. https://doi.org/https://doi.org/10.1016/j.mambio.2012.04.004.

Bourke, C A. 2003. "Evidence That Enforced Sunlight Exposure Can Cause Hyperthermia in Cattle Ingesting Low Levels of Ergot of Rye (Claviceps Purpurea), When Air Temperature and Humidity Conditions Are Only Moderate." *Australian Veterinary Journal* 81 (9): 553–58.

Boyce, Mark S., Peter W J Baxter, and Hugh P. Possingham. 2012. "Managing Moose Harvests by the Seat of Your Pants." *Theoretical Population Biology*. https://doi.org/10.1016/j.tpb.2012.03.002.

Boyce, Mark S., and Rob Corrigan. 2017. "Moose Survey App for Population Monitoring." *Wildlife Society Bulletin*. https://doi.org/10.1002/wsb.732.

Bridger, Michael C. 2015. "Provincial Moose Winter Tick Surveillance Program." Prince George, British Columbia, Canada.

Briske, David D, Andrew W Illius, and J Marty Anderies. 2017. "Nonequilibrium Ecology and Resilience Theory BT - Rangeland Systems: Processes, Management and Challenges." In , edited by David D Briske, 197–227. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-46709-2_6.

BRL, Blue Ridge Lumber Inc. 2005. "Detailed Forest Managmenet Plan Text Report." In . Blue Ridge Lumber Inc.

Brockman, Christopher J., William B. Collins, Jeffery M. Welker, Donald E. Spalinger, and Bruce W. Dale. 2017. "Determining Kill Rates of Ungulate Calves by Brown Bears Using Neck-Mounted Cameras." *Wildlife Society Bulletin* 41 (1): 88–97. https://doi.org/10.1002/wsb.733.

Broders, Hugh G, Andrea B Coombs, and J R McCarron. 2012. "Ecothermic Responses of Moose to Thermoregulatory Stress on Mainland Nova Scotia." *Alces*. Alces.

Brown, Casey, Knut Kielland, Eugénie Euskirchen, Todd Brinkman, Roger Ruess, and Kalin Kellie. 2017. "Fire-Mediated Patterns of Habitat Use by Male Moose in Alaska." *Canadian Journal of Zoology* 96 (October). https://doi.org/10.1139/cjz-2017-0069.

Brown, Casey, Knut Kielland, Eugénie Euskirchen, Sophie Gilbert, and Todd Brinkman. 2018. "Resource Selection and Movement of Male Moose in Response to Varying Levels of off Road Vehicle Access." *Ecosphere* 9 (September). https://doi.org/10.1002/ecs2.2405.

Bruggen, Ariena van, He MM, Keumchul Shin, Mai V, K C Jeong, Maria Finckh, and Morris Jr. 2018. "Environmental and Health Effects of the Herbicide Glyphosate." *Science of The Total Environment* 616–617 (March): 255–68. https://doi.org/10.1016/j.scitotenv.2017.10.309.

Buckland, Stephen T, D.R. Anderson, KP Burnham, David L Borchers, and L. Thomas. 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*. Oxford, England, UK: Oxford University Press.

Bunnell, Fred L, L L Kremsater, and Isabelle Houde. 2011. *Mountain Pine Beetle: A Synthesis of the Ecological Consequences of Large-Scale Disturbances on Sustainable Forest Management, with Emphasis on Biodiversity*. *Information Report*. Victoria, B.C: Pacific Forestry Centre.

Burgar, Joanna M., A. Cole Burton, and Jason T. Fisher. 2019. "The Importance of Considering Multiple Interacting Species for Conservation of Species at Risk." *Conservation Biology* 33 (3): 709–15. https://doi.org/10.1111/cobi.13233.

Burgar, Joanna M, Frances E C Stewart, John P Volpe, Jason T Fisher, and A Cole Burton. 2018. "Estimating Density for Species Conservation: Comparing Camera Trap Spatial Count Models to Genetic Spatial Capture-Recapture Models." *Global Ecology and Conservation* 15: e00411. https://doi.org/https://doi.org/10.1016/j.gecco.2018.e00411.

Burton, A. Cole, Eric Neilson, Dario Moreira, Andrew Ladle, Robin Steenweg, Jason T. Fisher, Erin Bayne, and Stan Boutin. 2015. "Wildlife Camera Trapping: A Review and Recommendations for Linking Surveys to Ecological Processes." *Journal of Applied Ecology* 52 (3): 675–85. https://doi.org/10.1111/1365-2664.12432.

Bushaw, D Jacob, M Kevin Ringelman, and C Frank Rohwer. 2019. "Applications of Unmanned Aerial Vehicles to Survey Mesocarnivores." *Drones* . https://doi.org/10.3390/drones3010028.

Cai, Wenyan, Ying Ji, Xianping Song, Haoran Guo, Lei Han, Feng Zhang, Xin Liu, Hengdong Zhang, Baoli Zhu, and Ming Xu. 2017. "Effects of Glyphosate Exposure on Sperm Concentration in Rodents: A Systematic Review and Meta-Analysis." *Environmental Toxicology and Pharmacology* 55 (July). https://doi.org/10.1016/j.etap.2017.07.015.

Canada, Health. 2019. "Statement from Health Canada on Glyphosate." Government of Canada. 2019. https://www.canada.ca/en/health-canada/news/2019/01/statement-from-health-canada-on-glyphosate.html.

Caravaggi, Anthony, Peter B. Banks, A. Cole Burton, Caroline M.V. Finlay, Peter M. Haswell, Matt W. Hayward, Marcus J. Rowcliffe, and Mike D. Wood. 2017. "A Review of Camera Trapping for Conservation Behaviour Research." *Remote Sensing in Ecology and Conservation* 3 (3): 109–22. https://doi.org/10.1002/rse2.48.

Carroll, Emma L, Mike W Bruford, J Andrew DeWoody, Gregoire Leroy, Alan Strand, Lisette Waits, and Jinliang Wang. 2018. "Genetic and Genomic Monitoring with Minimally Invasive Sampling Methods." *Evolutionary Applications* 11 (7): 1094–1119. https://doi.org/10.1111/eva.12600.

CCAC, Canadian Council on Animal Care. 2003. "CCAC Guidelines on the Care and Use of Wildlife." Ottawa, Ontario, Canada.

Cederlund, G, and H Sand. 1992. "Population Dynamics and Yield of a Dense Moose Population Without Predators." In *The Biology of Deer*, edited by Robert D Brown, 83. New York, NY: Springer New York. http://link.springer.com/10.1007/978-1-4612-2782-3_18.

Cederlund, Göran, Finn Sandegren, and Kjell Larsson. 1987. "Summer Movements of Female Moose and Dispersal of Their Offspring." *The Journal of Wildlife Management* 51 (2): 342–52. https://doi.org/10.2307/3801014.

Cerezke, H F. 2009. "Climate Change and Alberta's Forests: An Information and Discussion Paper of Predicted Implications." *Alberta Sustainable Resource Development*.

Chan-McLeod, Ann C Allaye. 2006. "A Review and Synthesis of the Effects of Unsalvaged Mountain-Pine-Beetle- Attacked Stands on Wildlife and Implications for Forest Management." *BC Journal of Ecosystems and Management* 7 (2): 119–32.

Chikoski, Jennifer Marie. 2003. "Effects of Timber Management Practices on the Use of Aquatic Feeding Areas by Moose (Alces Alces) in the Great Lakes-St. Lawrence and Boreal Transition Forests of Central Ontario." http://knowledgecommons.lakeheadu.ca:7070/handle/2453/4011.

Cichowski, D. 2007. "Literature Review: Effects of Mountain Pine Beetles on Caribou." *Prepared for Alberta Sustainable Resources Development, Public Lands and Forests Division, Forest Health Section, 49pp*.

Collins, William B. 1996. "Wildlife Habitat Enhancement in the Spruce-Hardwood Forest of the Matanuska and Susitna River Valleys." Juneau, Alaska, United States.

Collins, William B, and C C Schwartz. 1998. "Logging in Alaska's Boreal Forest: Creation of Grasslands or Enhancement of Moose Habitat." *Alces* 34 (2): 355–74. https://digitalcommons.usu.edu/aspen_bib/6937.

Cooke, Barry J., and Allan L. Carroll. 2017. "Predicting the Risk of Mountain Pine Beetle Spread to Eastern Pine Forests: Considering Uncertainty in Uncertain Times." *Forest Ecology and Management* 396 (July): 11–25. https://doi.org/10.1016/j.foreco.2017.04.008.

Coullery, Romina, María Ferrari, and Silvana Rosso. 2015. "Neuronal Development and Axon Growth Are Altered by Glyphosate through a WNT Non-Canonical Signaling Pathway." *NeuroToxicology* 52 (December).

https://doi.org/10.1016/j.neuro.2015.12.004.

Courbin, N, D Fortin, Christian Dussault, and R Courtois. 2014. "Logging-Induced Changes in Habitat Network Connectivity Shape Behavioural Interactions in the Wolf-Caribou-Moose System." *Ecological Monographs* 84: 265–85.

Courtois, Rehaume, and Aldee B T - Alces Beaumont. 1999. "The Influence of Accessibility on Moose Hunting in Northwestern Quebec," November, 41+.

Courtois, Rehaume, Christian Dussault, Francois Potvin, and Gaétan Daigle. 2002. "Habitat Selection by Moose (Alces Alces) in Clear-Cut Landscapes." *ALCES* 38 (January): 117–92.

Courtois, Réhaume, Jean-Pierre Ouellet, and Benoît Gagné. 1998. "Characteristics of Cutovers Used by Moose (Alces Alces) in Early Winter." *Alces* 34 (1): 201–11.

D'Eon, Robert G., Steven F. Wilson, and Dennis Hamilton. 2006. *Ground-Based Inventory Methods for Ungulate Snow-Track Surveys*. Version 1. The Province of British Columbia. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/ungulate_snow_track.pdf.

Danks, Zachary D, and William F Porter. 2010. "Temporal, Spatial, and Landscape Habitat Characteristics of Moose–Vehicle Collisions in Western Maine." *Journal of Wildlife Management* 74 (6): 1229–41. https://doi.org/10.2193/2008-358.

Darimont, Chris, Paul Paquet, Thomas Reimchen, and V Crichton. 2005. "Range Expansion by Moose into Coastal Temperate Rainforests of British Columbia, Canada." *Diversity and Distributions* 11 (May): 235–39. https://doi.org/10.1111/j.1366-9516.2005.00135.x.

Dawe, K., E.M. Bayne, and S. Boutin. 2014. "Influence of Climate and Human Land Use on the Distribution of White-Tailed Deer (Odocoileus Virginianus) in the Western Boreal Forest." *Canadian Journal of Zoology* 92 (4): 353–363.

Demarchi, Mike W. 2000. "Moose in the Nass Wildlife Area." Nisga'a Tribal Council. https://www.for.gov.bc.ca/hfd/library/documents/bib101798_finalreport.pdf.

———. 2003. "Migratory Patterns and Home Range Size of Moose in the Central Nass Valley, British Columbia." *Northwestern Naturalist* 84 (3): 135–41. https://doi.org/10.2307/3536539.

DeMars, C A, R Serrouya, Matthew A Mumma, M P Gillingham, R S McNay, and S Boutin. 2019. "Moose, Caribou, and Fire: Have We Got It Right Yet?" *Canadian Journal of Zoology* 97 (10): 866–79. https://doi.org/10.1139/cjz-2018-0319.

Dickie, Melanie, R S McNay, G D Sutherland, M Cody, and T Avgar. 2019. "Corridors or Risk? Movement along, and Use of, Linear Features Vary Predictably among Large Mammal Predator and Prey Species." *Journal of Animal Ecology*, October. https://doi.org/10.1111/1365-2656.13130.

Dickie, Melanie, Robert Serrouya, R. Scott McNay, and Stan Boutin. 2017. "Faster and Farther: Wolf Movements on Linear Features and Implications for Hunting Behaviour." *Journal of Applied Ecology* 54: 253–63.

Ditmer, Mark A, Ron A Moen, Steve K Windels, James D Forester, Thomas E Ness, and Tara R Harris. 2017. "Moose at Their Bioclimatic Edge Alter Their Behavior Based on Weather, Landscape, and Predators." *Current Zoology* 64 (4): 419–32. https://doi.org/10.1093/cz/zox047.

Dodds, Donald G. 1960. "Food Competition and Range Relationships of Moose and Snowshoe Hare in Newfoundland." *The Journal of Wildlife Management* 24 (1): 52–60. https://doi.org/10.2307/3797356.

Drew, Mark L, and W M Samuel. 1985. "An Evaluation of Burning for Control of Winter Ticks, Dermacentor Albipictus, in Central Alberta." *Journal of Wildlife Diseases* 21 (3): 313–15. https://doi.org/10.7589/0090-3558-21.3.313.

Droghini, Amanda, and Stan Boutin. 2018. "The Calm during the Storm: Snowfall Events Decrease the Movement Rates of Grey

Wolves (Canis Lupus)." *PLOS ONE* 13 (10): e0205742. https://doi.org/10.1371/journal.pone.0205742.

Dussault, Christian, Jean-Pierre Ouellet, Réhaume Courtois, Jean Pettorelli, Laurier Breton, and Jacques Larochelle. 2004. "Behavioural Responses of Moose to Thermal Conditions in the Boreal Forest." *Ecoscience* 11 (January): 321–28. https://doi.org/10.1080/11956860.2004.11682839.

Dussault, Christian, Jean-Pierre Ouellet, Catherin Laurian, Réhaume Courtois, Marius Poulin, and Laurier Breton. 2007. "Moose Movement Rates Along Highways and Crossing Probability Models." *Journal of Wildlife Management* 71 (7): 2338–45. https://doi.org/10.2193/2006-499.

Dussault, Christian, JP Ouellet, and R Courtois. 2005. "Linking Moose Habitat Selection to Limiting Factors." *Ecography* 5 (28): 619–28. http://onlinelibrary.wiley.com/doi/10.1111/j.2005.0906-7590.04263.x/full.

Eastman, D .S. 1974. "Habitat Use By Moose of Burns, Cutovers and Forests in North Central British Columbia." In *Tenth North American Moose Conference and Workshop*, 238–56. Duluth, Minnesota, United States. https://www.arlis.org/docs/vol2/hydropower/APA_DOC_no._1065.pdf.

Eckervall, Anneli. 2007. "Comparison of Plot Survey and Distance Sampling as Pellet Group Counts for Deer in Sweden." Institutionen för ekologi.

Ehrentraut, G, and K Branter. 1990. "Vegetation Management by Manual and Mechanical Means in Alberta Boreal Forests." *The Forestry Chronicle* 66 (4): 366–68. https://doi.org/10.5558/tfc66366-4.

Eigenberg, R A, T M Brown-Brandl, John A Nienaber, and G Leroy Hahn. 2005. "Dynamic Response Indicators of Heat Stress in Shaded and Non-Shaded Feedlot Cattle, Part 2: Predictive Relationships." *Biosystems Engineering* 91 (1): 111–18.

Elbroch, L. Mark. 2003. *Mammal Tracks & Sign: A Guide to North American Species*. First Edit. Mechanicsburg, Pennsylvania, United States: Stackpole.

Eldegard, Katrine, Jo Trygve Lyngved, and Olav Hjeljord. 2012. "Coping in a Human-Dominated Landscape: Trade-off between Foraging and Keeping Away from Roads by Moose (Alces Alces)." *European Journal of Wildlife Research* 58 (6): 969–79.

Enns, K A, Canadian Forest Service, Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II., and British Columbia. Ministry of Forests. Research Branch. 1994. *Effects of Mechanical Site Preparation on Wildlife in British Columbia : Problem Analysis*. FRDA Report Series. Canadian Forest Service.

Eschholz, William E, Frederick A Servello, Brad Griffith, and Kevin S Raymond. 1996. "Winter Use of Glyphosate-Treated Clearcuts by Moose in Maine." *Journal of Wildlife Management* 60 (4): 764–69.

ESRD, Environment and Sustinable Resource Development. 2012. "Sustainable Forest Management. Current Facts & Statistics 2011. Site Preparation."

———. 2013. "Sustainable Forest Management. Current Facts & Statistics 2012. Site Preparation."

———. 2014. "Sustainable Forest Management. Current Facts & Statistics 2013. Site Preparation."

———. 2016. "Sustainable Forest Management. Current Facts & Statistics 2014. Site Preparation."

Evans, Bryn E, Cory E Mosby, and Alessio Mortelliti. 2019. "Assessing Arrays of Multiple Trail Cameras to Detect North American Mammals." *PLOS ONE* 14 (6): e0217543. https://doi.org/10.1371/journal.pone.0217543.

Ewacha, M. 2016. "Stress Response of Boreal Woodland Caribou, Moose, and Wolves to Disturbance in Eastern Manitoba." University of Manitoba.

Falk, Donald A, Adam C Watts, and Andrea E Thode. 2019. "Scaling Ecological Resilience ." *Frontiers in Ecology and Evolution* . https://www.frontiersin.org/article/10.3389/fevo.2019.00275.

Fedrowitz, Katja, Julia Koricheva, Susan C Baker, David B Lindenmayer, Brian Palik, Raul Rosenvald, William Beese, et al. 2014. "Can Retention Forestry Help Conserve Biodiversity? A Meta-Analysis ." *The Journal of Applied Ecology* . England : Wiley Subscription Services, Inc . https://doi.org/10.1111/1365-2664.12289.

Finnegan, Laura A., Karine E. Pigeon, and Doug MacNearney. 2019. "Predicting Patterns of Vegetation Recovery on Seismic Lines: Informing Restoration Based on Understory Species Composition and Growth." *Forest Ecology and Management* 446 (May): 175–92. https://doi.org/10.1016/j.foreco.2019.05.026.

Finnegan, Laura A., P J Wilson, G N Price, and S J Lowe. 2012. "The Complimentary Role of Genetic and Ecological Data in Understanding Population Structure : A Case Study Using Moose (Alces Alces)." *European Journal of Wildlife Research* 58: 415–23. https://doi.org/10.1007/s10344-011-0590-2.

Fisher, Jason T., and Cole Burton. 2012. "Monitoring Mammals in Alberta: Recommendations for Remote Camera Trapping." Edmonton, Albterta, Canada.

Flannigan, Mike, K A Logan, B Amiro, W Skinner, and B Stocks. 2005. "Future Area Burned in Canada." *Climatic Change* 72 (January): 1–16. https://doi.org/10.1007/s10584-005-5935-y.

Fletcher, Tom. 2018. "B.C. Forestry Ministry Cutting Back on Use of Herbicide Glyphosate." *The Columbia Valley Pioneer*, November 10, 2018.

Frankham, Richard. 2003. "Genetics and Conservation Biology." *Comptes Rendus Biologies* 326: 22–29. https://doi.org/https://doi.org/10.1016/S1631-0691(03)00023-4.

Franklin, Caroline M A, S Ellen Macdonald, and Scott E Nielsen. 2019. "Can Retention Harvests Help Conserve Wildlife? Evidence for Vertebrates in the Boreal Forest." *Ecosphere* 10 (3). https://doi.org/10.1002/ecs2.2632.

Fraser, Doug. 2004. *Determining Available Forage*. Brochure 7. Victoria, BC, Canada: Forest Practices Branch, British Columbia Ministroy of FOrests. url: http://www.for.gov.bc.ca/hfp/range/range.htm%0A.

Fraser, Erin, Simon Landhäusser, and Victor Lieffers. 2003. "The Effects of Mechanical Site Preparation and Subsequent Wildfire on Trembling Aspen (Populus Tremuloides Michx.) Regeneration in Central Alberta, Canada." *New Forests* 25 (January): 49–66. https://doi.org/10.1023/A:1022382314822.

FSA, Federal State of Austria. 2019. *Parlamentskorrespondenz Nr. 767 Vom 02.07.2019*. Austria. https://www.parlament.gv.at/PAKT/PR/JAHR_2019/PK0767/index.shtml.

Furniss, Robert Livingston, and Valentine M Carolin. 1977. *Western Forest Insects*. Vol. 1339. US Department of Agriculture, Forest Service.

Galatowitsch, Susan, Lee Frelich, and Laura Phillips-Mao. 2009. "Regional Climate Change Adaptation Strategies for Biodiversity Conservation in a Midcontinental Region of North America." *Biological Conservation* 142 (10): 2012–22. https://doi.org/https://doi.org/10.1016/j.biocon.2009.03.030.

Gasaway, W. C., SD Dubois, DJ Reed, and S. J. Harbo. 1986. "Estimating Moose Population Parameters from Aerial Surveys." *Biological Papers of The University of ALaska, Fairbanks*.

Gasaway, W C, and S D Dubois. 1985. "Initial Response of Moose, Alces Alces, to Wildfire in Interior Alaska." 99 (January): 135–40.

Gasaway, W C, S D Dubois, R D Boertje, D J Reed, and D T Simpson. 1989. "Response of Radio-Collared Moose to a Large Burn in Central Alaska." *Canadian Journal of Zoology* 67 (2): 325–29. https://doi.org/10.1139/z89-047.

Geist, Valerius (viaf)64574555. 1971. *Mountain Sheep : A Study in Behavior and Evolution*. Chicago (Ill.) : University of Chicago press. http://lib.ugent.be/catalog/rug01:001253985.

Gentsch, Regina P, Petter Kjellander, and Bengt O Röken. 2018. "Cortisol Response of Wild Ungulates to Trauma Situations:

Hunting Is Not Necessarily the Worst Stressor." *European Journal of Wildlife Research* 64 (1): 11. https://doi.org/10.1007/s10344-018-1171-4.

Gleim, Elizabeth R, L Mike Conner, Roy D Berghaus, Michael L Levin, Galina E Zemtsova, and Michael J Yabsley. 2014. "The Phenology of Ticks and the Effects of Long-Term Prescribed Burning on Tick Population Dynamics in Southwestern Georgia and Northwestern Florida." *PLOS ONE* 9 (11): e112174. https://doi.org/10.1371/journal.pone.0112174.

Glines, M V, and W M Samuel. 1989. "Effect OfDermacentor Albipictus (Acari: Ixodidae) on Blood Composition, Weight Gain and Hair Coat of Moose,Alces Alces." *Experimental & Applied Acarology* 6 (3): 197–213. https://doi.org/10.1007/BF01193980.

GoA, Government of Alberta. 2009. "Watch out for Wildlife on Alberta's Roads."

———. 2013. "Spill over into Moose Populations Is Not Maintained and Only Occurs When CWD Is Well-Established in Deer (GoA 2013)."

———. 2014. "Big Game Harvest Estimates 2013 - Moose."

———. 2015. "Big Game Harvest Estimates 2014 – Moose."

———. 2016. "Big Game Harvest Estimates 2015 – Moose."

———. 2017. "Big Game Harvest Estimates 2016 -Moose."

———. 2018. "Big Game Harvest Estimates 2017 - Moose."

———. 2019a. *2019 Alberta Guide to Hunting Regulations*. Government of Alberta.

———. 2019b. "Hunter Harvest Report Moose. Wildlife Management Policy Big Game Harvest Estimates 2018."

———. 2019c. "Mountain Pine Beetle Population Forecast Survey Spring 2019." Government of Alberta. https://open.alberta.ca/dataset/e399754c-0f56-472f-84fb-eaecd1d687f7/resource/361318cb-aafb-4e7c-a8af-bfdfe16e33e5/download/af-mpb-2019-r-value.pdf.

GoBC, Government of British Columbia. 2019a. "BC Moose Tracker App." 2019. https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-health/wildlife-health-matters/moose-health/bc-moose-tracker.

———. 2019b. "BC Wildlife Health Program Moose Winter Tick Survey." 2019. https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-health/wildlife-health-matters/moose-health/moose-winter-tick-survey.

———. 2019c. "Omineca Spruce Beetle Outbreak." Government of British Columbia. 2019. https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/forest-pests/bark-beetles/spruce-beetle/omineca-spruce-beetle.

GoC, Government of Canada. 2016. "El Nino." 2016. https://www.canada.ca/en/environment-climate-change/services/el-nino.html#ENImpacts.

———. 2019. "Chronic Wasting Disease (CWD) Surveillance Update: October 8, 2019." Government of Alberta. 2019. https://www.alberta.ca/chronic-wasting-disease-updates.aspx.

Gray, Emily. 2012. "The Role of Site Conditions and Moose Browsing on the Regeneration Failure of Balsam Fir Forests in Gros Morne National Park, NL, Canada." North Bay, Ontario, Canada: Nipissing University.

Greenough, Julee A, and Werner Alexander C N - QH106.2.B8 G74 1996 Kurz. 1996. *Stand Tending Impacts on Environmental Indicators*. Victoria, B.C.: The Branch.

Gschwantner, Thomas, Adrian Lanz, Claude Vidal, Michal Bosela, Lucio Di Cosmo, Jonas Fridman, Patrizia Gasparini, Andrius Kuliešis, Stein Tomter, and Klemens Schadauer. 2016. "Comparison of Methods Used in European National Forest Inventories for the Estimation of Volume Increment: Towards Harmonisation." *Annals of Forest Science* 73 (4): 807–21. https://doi.org/10.1007/s13595-016-0554-5.

Hanes, Chelene C, Xianli Wang, Piyush Jain, Marc-André Parisien, John M Little, and Mike D Flannigan. 2018. "Fire-Regime Changes in Canada over the Last Half Century." *Canadian Journal of Forest Research* 49 (3): 256–69. https://doi.org/10.1139/cjfr-2018-0293.

Härkönen, Sauli, and Risto Heikkilä. 1999. "Use of Pellet Group Counts in Determining Density and Habitat Use of Moose *Alces Alces* in Finland." *Wildlife Biology* 5 (1): 233–39. https://doi.org/10.2981/wlb.1999.028.

———. 2000. "Thinning Residues as a Source of Browse for Moose in Managed Forests in Finland." *Alces* 36 (January): 85–92.

Hauge, Thomas M., and Lloyd B. Keith. 2007. "Dynamics of Moose Populations in Northeastern Alberta." *The Journal of Wildlife Management*. https://doi.org/10.2307/3808692.

Hebblewhite, Mark. 2017. "Billion Dollar Boreal Woodland Caribou and the Biodiversity Impacts of the Global Oil and Gas Industry." *Biological Conservation* 206: 102–11. https://doi.org/10.1016/j.biocon.2016.12.014.

Heikkilä, Risto, Pertti Hokkanen, Mira Kooiman, Nilay Ayguney, and Cyril Bassoulet. 2003. "The Impact of Moose Browsing on Tree Species Composition in Finland." *Alces* 39 (January).

Helander, Marjo, Irma Saloniemi, and Kari Saikkonen. 2012. "Glyphosate in Northern Ecosystems." *Trends in Plant Science* 17 (June): 569–74. https://doi.org/10.1016/j.tplants.2012.05.008.

Higuera, Philip E, John T Abatzoglou, Jeremy S Littell, and Penelope Morgan. 2015. "The Changing Strength and Nature of Fire-Climate Relationships in the Northern Rocky Mountains, U.S.A., 1902-2008." Edited by Christopher Carcaillet. *PLOS ONE* 10 (6): e0127563. https://doi.org/10.1371/journal.pone.0127563.

Hjeljord, O. 1994. "Moose (Alces Alces) and Mountain Hare (Lepus Timidus) Use of Conifer Plantations Following Glyphosate Application." *Norwegian Journal of Agricultural Sciences (Norway)*.

Hjeljord, Olav, and Svein Grønvold. 1988. "Glyphosate Application in Forest—Ecological Aspects. VI. Browsing by Moose (Alces Alces) in Relation to Chemical and Mechanical Brush Control." *Scandinavian Journal of Forest Research* 3: 115–21.

Hjeljord, Olav, Nils Hövik, and Helge B Pedersen. 1990. "Choice of Feeding Sites by Moose during Summer, the Influence of Forest Structure and Plant Phenology." *Holarctic Ecology* 13 (4): 281–92.

Hodgson, Jarrod C, Rowan Mott, Shane M Baylis, Trung T Pham, Simon Wotherspoon, Adam D Kilpatrick, Ramesh Raja Segaran, Ian Reid, Aleks Terauds, and Lian Pin Koh. 2018. "Drones Count Wildlife More Accurately and Precisely than Humans." *Methods in Ecology and Evolution* 9 (5): 1160–67. https://doi.org/10.1111/2041-210X.12974.

Hoffman, Justin D, Hugh H Genoways, and Jerry R Choate. 2006. "Long-Distance Dispersal and Population Trends of Moose in the Central United States." *Alces* 42: 000–011.

Hofmeester, Tim R, J Marcus Rowcliffe, and Patrick A Jansen. 2017. "Quantifying the Availability of Vertebrate Hosts to Ticks: A Camera-Trapping Approach ." *Frontiers in Veterinary Science* . https://www.frontiersin.org/article/10.3389/fvets.2017.00115.

Holling, C S. 2017. "Resilience and Stability of Ecological Systems (1973)." *The Future of Nature*. New Haven: Yale University Press. https://doi.org/10.12987/9780300188479-023.

Hörnberg, Staffan. 2001. "Changes in Population Density of Moose (Alces Alces) and Damage to Forests in Sweden." *Forest Ecology and Management* 149 (1): 141–51. https://doi.org/https://doi.org/10.1016/S0378-1127(00)00551-X.

Hornseth, Megan, Karine Pigeon, Doug Macnearney, Terry Larsen, Gordon Stenhouse, Jerome Cranston, and Laura Finnegan. 2018. "Motorized Activity on Legacy Seismic Lines: A Predictive Modeling Approach to Prioritize Restoration Efforts." *Environmental Management*, May. https://doi.org/10.1007/s00267-018-1063-0.

Huang, Jianping. 2017. "Cold & Warm Episodes by Season." National Weather Service Climate Prediction Center. 2017. https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php.

Huber, Nikolaus, Sebastian G Vetter, Alina L Evans, Petter Kjellander, Susanne Küker, Ulrika A Bergvall, and Jon M Arnemo. 2017. "Quantifying Capture Stress in Free Ranging European Roe Deer (Capreolus Capreolus)." *BMC Veterinary Research* 13 (1): 127. https://doi.org/10.1186/s12917-017-1045-0.

IARC, International Agency for Research on Cancer. 2016. "IARC Monograph on Glyphosate." World Health Organization. 2016. https://www.iarc.fr/featured-news/media-centre-iarc-news-glyphosate/.

Ingaramo, Paola, Jorgelina Varayoud, María Milesi, Marlise Schimpf, Ramiro Alarcón, Monica Muñoz-de-Toro, and Enrique Luque. 2017. "Neonatal Exposure to a Glyphosate-Based Herbicide Alters Uterine Decidualization in Rats." *Reproductive Toxicology* 73 (August). https://doi.org/10.1016/j.reprotox.2017.07.022.

Ivan, Jacob S, Amy E Seglund, Richard L Truex, and Eric S Newkirk. 2018. "Mammalian Responses to Changed Forest Conditions Resulting from Bark Beetle Outbreaks in the Southern Rocky Mountains." *Ecosphere* 9 (8): e02369.

Jesmer, Brett R, Jerod A Merkle, Jacob R Goheen, Ellen O Aikens, Jeffrey L Beck, Alyson B Courtemanch, Mark A Hurley, et al. 2018. "Is Ungulate Migration Culturally Transmitted? Evidence of Social Learning from Translocated Animals ." *Science (New York, N.Y.)* . United States : American Association for the Advancement of Science . https://doi.org/10.1126/science.aat0985.

Johnstone, Jill F, Teresa N Hollingsworth, F Stuart Chapin, and Michelle C Mack. 2010. "Changes in Fire Regime Break the Legacy Lock on Successional Trajectories in Alaskan Boreal Forest." *Global Change Biology* 16 (4): 1281–95. https://doi.org/10.1111/j.1365-2486.2009.02051.x.

Joly, Damien O, and François Messier. 2004. "The Distribution of Echinococcus Granulosus in Moose: Evidence for Parasite-Induced Vulnerability to Predation by Wolves?" *Oecologia* 140 (4): 586–90. https://doi.org/10.1007/s00442-004-1633-0.

Kelsall, John P, and E S Telfer. 1974. "Biogeography of Moose with Particular Reference to Western North America." *Naturaliste Canadien* 101: 117.

Kennedy, E R, and P A Jordan. 1985. "Glyphosate and 2,4-D: The Impact of Two Herbicides on Moose Browse in Forest Plantations." *Alces* 21: 149–60.

Kie, John G. 1988. "Performance in Wild Ungulates: Measuring Population Density and Condition of Individuals." Berkely,California, United States. https://doi.org/10.2737/PSW-GTR-106.

Kissane, Zoe, and Jill Shephard. 2017. "The Rise of Glyphosate and New Opportunities for Biosentinel Early-Warning Studies." *Conservation Biology : The Journal of the Society for Conservation Biology* 31 (May). https://doi.org/10.1111/cobi.12955.

Kittle, Andrew M., Morgan Anderson, Tal Avgar, James A. Baker, Glen S. Brown, Jevon Hagens, Ed Iwachewski, et al. 2017. "Landscape-Level Wolf Space Use Is Correlated with Prey Abundance, Ease of Mobility, and the Distribution of Prey Habitat." *Ecosphere* 8 (4): e01783. https://doi.org/10.1002/ecs2.1783.

Klassen, Nicole A, and Roy V B T - Alces Rea. 2008. "What Do We Know about Nocturnal Activity of Moose?" 44 (October): 101+.

Klenner, Walt. 2006. *Retention Strategies to Maintain Habitat Structure and Wildlife Diversity during the Salvage Harvesting of Mountain Pine Beetle Attack Areas in the Southern Interior Forest Region*. British Columbia Ministry of Forests and Range, Southern Interior Forest.

Knopff, Kyle H., Aliah A. Knopff, Andrea Kortello, and Mark S. Boyce. 2010. "Cougar Kill Rate and Prey Composition in a Multiprey System." *Journal of Wildlife Management* 74 (7): 1435–47. https://doi.org/10.2193/2009-314.

Kolowski, Joseph M, and Tavis D Forrester. 2017. "Camera Trap Placement and the Potential for Bias Due to Trails and Other Features." *PLOS ONE* 12 (10): e0186679. https://doi.org/10.1371/journal.pone.0186679.

Kretser, Heidi, Michale Glennon, Alice Whitelaw, Aimee Hurt, Kristine Pilgrim, and Michael B T - Alces Schwartz. 2016. "Scat-Detection Dogs Survey Low Density Moose in New York" 52 (November): 55+.

Kunkel, Kyran, and Daniel H Pletscher. 2001. "Winter Hunting Patterns of Wolves in and Near Glacier National Park, Montana." *The Journal of Wildlife Management* 65 (3): 520–30. https://doi.org/10.2307/3803105.

Kuzyk, Gerald W. 2016. "Provincial Population and Harvest Estimates of Moose in British Columbia." *Akces* 52: 1–11.

Kuzyk, Gerald W., Michael M. Dehn, and Richard S. Farnell. 1999. "Body-Size Comparisons of Alpine- and Forest-Wintering Woodland Caribou Herds in the Yukon." *Canadian Journal of Zoology* 77 (7): 1017–24. https://doi.org/10.1139/cjz-77-7-1017.

Kuzyk, Gerald W., Ian Hatter, Shelley Marshall, Chris Procter, Becky Cadsand, Daniel Lirette, Heidi Schindler, et al. 2018. "MOOSE POPULATION DYNAMICS DURING 20 YEARS OF DECLINING HARVEST IN BRITISH COLUMBIA." *ALCES*.

Kuzyk, Gerald W., S. Marshall, C. Procter, H. Schindler, H. Schwantje, M. Gillingham, S. White, and M. Mumma. 2018. "Determining Factors Affecting Moose Population Change in British Columbia: Testing The Landscape Change Hypothesis." Victoria, British Columbia, Canada.

Kuzyk, Gerald W., Shelley Marshall, Chris Procter, Becky Cadsand, Heidi Schindler, Michael Klaczek, Helen Schwantje, and M. Gillingham. 2017. "DETERMINING FACTORS AFFECTING MOOSE POPULATION CHANGE IN BRITISH COLUMBIA: TESTING THE LANDSCAPE CHANGE HYPOTHESIS." Victoria, British Columbia, Canada.

KWR, Keystone Wildlife Research Ltd. 2006. "Identification and Management of Moose Winter Habitat in the Cariboo Region: Literature Review and Mapping Pilot Study." White Rock, British Columbia, Canada.

Labonte, Johanne, Jean-Pierre Ouellet, Réhaume Courtois, and Francis Belisle. 1998. "Moose Dispersal and Its Role in the Maintenance of Harvested Populations." *The Journal of Wildlife Management* 62 (1): 10. http://www.jstor.org/stable/3802282.

Ladle, Andrew, Tal Avgar, Matthew Wheatley, Gordon Stenhouse, Scott Nielsen, and Mark P D - 2018/10/01 Boyce. 2018. "Grizzly Bear Response to Spatio-temporal Variability in Human Recreational Activity." *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13277.

Laforge, Michel P, Nicole L Michel, and Ryan K Brook. 2017. "Spatio-Temporal Trends in Crop Damage Inform Recent Climate-Mediated Expansion of a Large Boreal Herbivore into an Agro-Ecosystem ." *Scientific Reports* . England : Nature Publishing Group . https://doi.org/10.1038/s41598-017-15438-x.

Lamont, Bryan G., Kevin L. Monteith, Jerod A. Merkle, Tony W. Mong, Shannon E. Albeke, Matthew M. Hayes, and Matthew J Kauffman. 2019. "Multi-Scale Habitat Selection of Elk in Response to Beetle-Killed Forest." *Journal of Wildlife Management* 83 (3): 679–93. https://doi.org/10.1002/jwmg.21631.

Larsen, Terry, Karen Graham, Catherine Deny, and Gord Stenhouse. 2019. "Linkages between Forestry Practices, Ungulates, and the Habitat Use, Predation Behavior, and Biological Performance of Grizzly Bears in and Adjacent to Woodland Caribou Range." Hinton, Alberta, Canada.

Latham, Andrew David M, Maria Cecilia Latham, Mark S Boyce, and Stan Boutin. 2011. "Movement Responses by Wolves to Industrial Linear Features and Their Effect on Woodland Caribou in Northeastern Alberta." *Ecological Applications* 21 (8): 2854–65. https://doi.org/10.1890/11-0666.1.

Laurian, Catherine, Christian Dussault, Jean-Pierre Ouellet, Réhaume Courtois, and Marius Poulin. 2012. "Interactions between a Large Herbivore and a Road Network." *Ecoscience* 19 (March): 69–79. https://doi.org/10.2980/19-1-3461.

Laurian, Catherine, Christian Dussault, Jean-Pierre Ouellet, Réhaume Courtois, Marius Poulin, and Laurier Breton. 2008. "Behavior of Moose Relative to a Road Network." *Journal of Wildlife Management* 72 (7): 1550. https://doi.org/10.2193/2008-063.

———. 2010. "Behavioral Adaptations of Moose to Roadside Salt Pools." *The Journal of Wildlife Management* 72 (December): 1094–1100. https://doi.org/10.2193/2007-504.

Lautenschlager, R A, Hewlette S Crawford, Martin R Stokes, and Timothy L Stone. 1997. "Forest Disturbance Type Differentially Affects Seasonal Moose Forage." *Alces. 33: 49-73.* 33.

Leblond, Mathieu, Christian Dussault, and Jean-Pierre Ouellet. 2010. "What Drives Fine-Scale Movements of Large Herbivores? A Case Study Using Moose." *Ecography* 33 (6): 1102–12.

Leblond, Mathieu, Christian Dussault, Jean-Pierre Ouellet, Marius Poulin, Rehaume Courtois, and Jacques Fortin. 2007. "Management of Roadside Salt Pools to Reduce Moose–Vehicle Collisions." *Journal of Wildlife Management* 71 (7): 2304–10. https://doi.org/10.2193/2006-459.

Lee, B S, Martin Alexander, Brad Hawkes, T J Lynham, B Stocks, and P Englefield. 2002. "Information Systems in Support of Wildland Fire Management Decision Making in Canada." *Computers and Electronics in Agriculture* 37 (December): 185–98. https://doi.org/10.1016/S0168-1699(02)00120-5.

Leighton, F A. 2011. *Wildlife Pathogens and Diseases in Canada*. Ottawa, Ontario, Canada: Canadian Councils of Resource Ministers. http://www.biodivcanada.ca/EB97BF3F-C987-4E2A-9D7E-E4C8B84CC4C0/6151No.7_Wildlife Pathogens and Diseases May 2011_E.pdf.

Lemke, S L. 2001. "Lillooet Forest District Moose Habitat Handbook." Ministry of Environment, British Columbia. http://www.env.gov.bc.ca/thompson/documents/work_windows/Lillooetmoosebook.pdf.

Lewontin, Richard C. 1969. "The Meaning of Stability." In *Brookhaven Symposia in Biology*, 22:13–24.

Lieffers, Victor, Glen Armstrong, Kenneth Stadt, and Eckehart Marenholtz. 2008. "Forest Regeneration Standards: Are They Limiting Management Options for Alberta's Boreal Mixedwoods?" *The Forestry Chronicle* 84 (February): 76–82. https://doi.org/10.5558/tfc84076-1.

Loew, Sabine S. 2000. "Role of Genetics in Conservation Biology BT - Quantitative Methods for Conservation Biology." In , edited by Scott Ferson and Mark Burgman, 226–58. New York, NY: Springer New York. https://doi.org/10.1007/0-387-22648-6_14.

Löf, Magnus, Daniel C Dey, Rafael M Navarro, and Douglass F Jacobs. 2012. "Mechanical Site Preparation for Forest Restoration." *New Forests* 43 (5): 825–48. https://doi.org/10.1007/s11056-012-9332-x.

Lord, Rachel, and Knut Kielland. 2015. "Effects of Variable Fire Severity on Forage Production and Foraging Behavior of Moose in Winter." *Alces: A Journal Devoted to the Biology and Management of Moose* 51: 23–34.

Lowe, Stacey J., Brent R. Patterson, and James a. Schaefer. 2010. "Lack of Behavioral Responses of Moose (*Alces Alces*) to High Ambient Temperatures near the Southern Periphery of Their Range." *Canadian Journal of Zoology* 88 (10): 1032–41. https://doi.org/10.1139/Z10-071.

Lykke, Jon, and I M Cowan. 1968. "1968. Moose Management and Population Dynamics on the Scandinavian Peninsula, with Special Reference to Norway." In *Proceedings of the North American Moose Workshop*, 5:1–22.

Lykkja, Odd, Erling Johan Solberg, Ivar Herfindal, Jonathan Wright, Christer Rolandsen, and Martin Hanssen. 2009. "The Effects of Human Activity on Summer Habitat Use by Moose." *Alces* 45 (January): 849–59.

Lynch, Gerry M. 1979. "Moose Management Plan for Alberta."

———. 2006. "Does First Nation'S Hunting Impact Moose Productivity in Alberta?" *Alces*.

Lynch, Gerry M., B Lajeunesse, J Willman, and E S Telfer. 1995. "Moose Weights and Measurements from Elk Island National Park,

Canada." *Alces*, 199–208.

MacCracken, James G, and Leslie A Viereck. 1990. "Browse Regrowth and Use by Moose after Fire in Interior Alaska." *Northwest Science* 64 (1).

MacDonald, Fraser, and Scott Mcnay. 2010. "Using Snow-Track Surveys to Evaluate Wildlife Use of Forests Affected by Mountain Pine Beetle in North-Central British Columbia." Mackenzie, British Columbia, Canada.

MacNearney, D., K. Pigeon, Barry R Nobert, and L Finnegan. 2017. "Investigating the Response of Caribou and Wolves to Human Activity at Well Sites in the Chinchaga Caribou Range."

Mader, Terry, Leslie Johnson, and J Gaughan. 2010. "A Comprehensive Index for Assessing Environmental Stress in Animals." *Journal of Animal Science* 88 (June): 2153–65. https://doi.org/10.2527/jas.2009-2586.

Maier, Julie, Jay Ver Hoef, A McGuire, R Bowyer, Lisa Saperstein, and Hilmar Maier. 2005. "Distribution and Density of Moose in Relation to Landscape Characteristics: Effects of Scale." *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere - CAN J FOREST RES* 35 (September): 2233–43. https://doi.org/10.1139/x05-123.

Månsson, Johan, Henrik Andrén, Åke Pehrson, and Roger Bergström. 2007. "Moose Browsing and Forage Availability: A Scale-Dependent Relationship?" *Canadian Journal of Zoology* 85 (3): 372–80. https://doi.org/10.1139/Z07-015.

Månsson, Johan, Roger Bergström, Åke Pehrson, Mariana Skoglund, and Christina Skarpe. 2010. "Felled Scots Pine (Pinus Sylvestris) as Supplemental Forage for Moose (Alces Alces): Browse Availability and Utilization." *Scandinavian Journal of Forest Research* 25 (1): 21–31. https://doi.org/10.1080/02827581003620354.

Månsson, Johan, Christer Kalén, Petter Kjellander, Henrik Andrén, and Henrik Smith. 2007. "Quantitative Estimates of Tree Species Selectivity by Moose (Alces Alces) in a Forest Landscape." *Scandinavian Journal of Forest Research* 22 (5): 407–14. https://doi.org/10.1080/02827580701515023.

Månsson, Johan, Jean-Michel Roberge, Lars Edenius, Roger Bergström, Lovisa Nilsson, Maria Lidberg, Karl Komstedt, and Göran Ericsson. 2015. "Food Plots as a Habitat Management Tool: Forage Production and Ungulate Browsing in Adjacent Forest." *Wildlife Biology* 21 (5): 246–53. https://doi.org/10.2981/wlb.00019.

Mao, Qixing, Fabiana Manservisi, Simona Panzacchi, Daniele Mandrioli, Ilaria Menghetti, Andrea Vornoli, Luciano Bua, et al. 2018. "The Ramazzini Institute 13-Week Pilot Study on Glyphosate and Roundup Administered at Human-Equivalent Dose to Sprague Dawley Rats: Effects on the Microbiome." *Environmental Health* 17 (1): 50. https://doi.org/10.1186/s12940-018-0394-x.

Mathisen, Karen Marie, Jos M Milner, and Christina Skarpe. 2017. "Moose–Tree Interactions: Rebrowsing Is Common across Tree Species." *BMC Ecology* 17 (1): 12. https://doi.org/10.1186/s12898-017-0122-3.

McCann, Nicholas, Ron Moen, and T R Harris. 2013. "Warm-Season Heat Stress in Moose (Alces Alces)." *Canadian Journal of Zoology* 91 (December). https://doi.org/10.1139/cjz-2013-0175.

McCormack, Maxwell. 1994. "Reductions in Herbicide Use for Forest Vegetation Management." *Weed Technology* 8 (June): 344–49. https://doi.org/10.1017/S0890037X00038902.

McInnes, Pamela F, Robert J Naiman, John Pastor, and Yosef Cohen. 1992. "Effects of Moose Browsing on Vegetation and Litter of the Boreal Forest, Isle Royale, Michigan, USA." *Ecology* 73 (6): 2059–75. https://doi.org/10.2307/1941455.

McNay, Robert, Glenn D Sutherland, Meghan S Anderson, Viktor Brumovsky, Line Giguere, Melanie Dickie, and Michael Cody. 2016. "Understanding the Functional Components of Predator-Prey Response to Habitat Restoration: A Bayesian Approach." *PeerJPreprints*. https://doi.org/10.7287/PEERJ.PREPRINTS.1996V1.

Mech, L D, R E McRoberts, R O Peterson, and R E Page. 1987. "Relationship of Deer and Moose Populations to Previous Winters' Snow." *Journal of Animal Ecology* 56 (2): 615–27. https://doi.org/10.2307/5072.

Meek, P D, G Ballard, A Claridge, R Kays, K Moseby, T O'Brien, A O'Connell, et al. 2014. "Recommended Guiding Principles for Reporting on Camera Trapping Research." *Biodiversity and Conservation* 23 (9): 2321–43. https://doi.org/10.1007/s10531-014-0712-8.

Milligan, Harriet T, and Julia Koricheva. 2013. "Effects of Tree Species Richness and Composition on Moose Winter Browsing Damage and Foraging Selectivity: An Experimental Study." *Journal of Animal Ecology* 82 (4): 739–48. https://doi.org/10.1111/1365-2656.12049.

Millspaugh, Joshua J, Rami J Woods, Kathleen E Hunt, Kenneth J Raedeke, C Brundige, Brian E Washburn, Samuel K Wasser, E Hunt, J Millspaugh, and Gary C Brundige. 2001. "Fecal Glucocorticoid Assays and the Physiological Stress Response in Elk." *Wildlife Society Bulletin* 29: 899–907.

Milner, Jos M, Floris M van Beest, and Torstein Storaas. 2013. "Boom and Bust of a Moose Population: A Call for Integrated Forest Management." *European Journal of Forest Research* 132 (5–6): 959–67. https://doi.org/10.1007/s10342-013-0727-9.

Mistakis Institute. 2019. "Wildlife Vehicle Collision Prevention Along Highway 3 - Stay Alert." Mistakis Institute. 2019. https://www.rockies.ca/roadwatch/images/Poster_WVCHotspots_Highway3_RoadWatch_Final.jpg.

Monthey, R W. 1984. "Effects of Timber Harvesting on Ungulates in Northern Maine." *The Journal of Wildlife Management* 48 (1): 279–85. https://doi.org/10.2307/3808489.

Mountrakis, Giorgos, and Kari Gunson. 2009. "Multi-scale Spatiotemporal Analyses of Moose–Vehicle Collisions: A Case Study in Northern Vermont." *International Journal of Geographical Information Science* 23 (11): 1389–1412. https://doi.org/10.1080/13658810802406132.

Mumma, Matthew A., and Michael Gillingham. 2017. *Assessing Caribou Survival in Relation to the Distribution and Abundance of Moose and Wolves*. BC Oil and Gas Research and Innovation and Society.

Mumma, Matthew A., Michael P. Gillingham, Katherine L. Parker, Chris J. Johnson, and Megan Watters. 2018. "Predation Risk for Boreal Woodland Caribou in Human-Modified Landscapes: Evidence of Wolf Spatial Responses Independent of Apparent Competition." *Biological Conservation* 228 (May): 215–23. https://doi.org/10.1016/j.biocon.2018.09.015.

Munro, Robin, Bruce N McLellan, and CD Apps. 2008. "Implications of Forest Management in Response to the 1970's Mountain Pine Beetle Infestations on Grizzly Bears and Moose in the Flathead Drainage."

Murphy, A, and John Ehrenreich. 1965. "Effects of Timber Harvest and Stand Improvement on Forage Production." *The Journal of Wildlife Management* 29 (October): 734. https://doi.org/10.2307/3798550.

Murray, Dennis L, Karen F Hussey, Laura A Finnegan, Stacey J Lowe, Glynis N Price, John Benson, Karen M Loveless, et al. 2012. "Assessment of the Status and Viability of a Population of Moose (Alces Alces) at Its Southern Range Limit in Ontario." *Canadian Journal of Zoology* 434: 422–34. https://doi.org/10.1139/Z2012-002.

Murray, DL, EW Cox, WB Ballard, HA Whitlaw, MS Lenarz, TW Custer, T Barnett, and TK Fuller. 2006. "Pathogens, Nutritional Deficiency, and Climate Influences on a Declining Moose Population." *Wildlife Monographs* 166: 1–29.

MWLAP, Ministry of Water, Land and Air Protection. 2005. "Omineca Regional Wildlife Tree Patch (WTP) Retention Guideline."

NCASI, National Council for Air and Stream Improvement Inc. 2006. "Similarities and Differences Betwen Harvesting- and Wildfire-Induced Disturbances in Fire-Mediated Canadian Landscapes." Rouyn-Noranda, Québec, Canada.

———. 2009. "Wildlife Responses to Stand-Level Structural Retention Practices in the Boreal Forest." Nanaimo, British Columbia. https://www.ncasi.org/wp-content/uploads/2019/02/tb964.pdf.

Neff, Don J. 1968. "The Pellet-Group Count Technique for Big Game Trend, Census, and Distribution: A Review." *The Journal of Wildlife Management* 32 (3): 597–614. https://doi.org/10.2307/3798941.

Nelson, Mark. 2003. "Forestry and Cultural Sustainability in the Little Red Cree Nation." University of Alberta.

Newbury, Tina L., Neal P.P. Simon, and Tony E. Chubbs. 2007. "Moose, Alces Alces, Winter Browse Use in Central Labrador." *Canadian Field-Naturalist* 121 (4): 359–63.

Newton, Michael, Elizabeth C Cole, R A Lautenschlager, Diane E White, and M L McCormack. 1989. "Browse Availability after Conifer Release in Maine's Spruce-Fir Forests." *The Journal of Wildlife Management* 53 (3): 643–49. https://doi.org/10.2307/3809189.

NFD, National Forestry Database. 2019. "Pest Control Product Use - Forest Area Treated with Herbicides and Insecticides." Canadian Council of Forest Ministers. 2019.

Niedziałkowska, Magdalena, Kris J Hundertmark, Bogumiła Jędrzejewska, Krzysztof Niedziałkowski, Vadim E Sidorovich, Marcin Górny, Rauno Veeroja, et al. 2014. "Spatial Structure in European Moose (Alces Alces): Genetic Data Reveal a Complex Population History." *Journal of Biogeography* 41 (11): 2173–84. https://doi.org/10.1111/jbi.12362.

Nikula, Ari, Ville Hallikainen, Risto Jalkanen, Mikko Hyppönen, and Kari Mäkitalo. 2008. "Modelling the Factors Predisposing Scots Pine to Moose Damage in Artificially Regenerated Sapling Stands in Finnish Lapland." *Silva Fennica* 42 (4): 587–603.

Noor, Athar, Bilal Habib, and Satish Kumar. 2010. "Effects of Plot Size and Shape on the Encounter Rate of Ungulate Faecal Pellet Groups and Abundance Estimate Precision." *Current Science* 99 (6): 800–804. http://www.jstor.org/stable/24109609.

Natural Regions Committee. 2006. *Natural Regions and Subregions of Alberta.* Edited by D J Downing and W W Pettapiece. Government of Alberta. Pub. No. T/852.

NRC, Natural Resource Canada. 2019. "Statistical Data." Government of Canada. 2019. https://cfs.nrcan.gc.ca/statsprofile/overview/ab.

NRC, Natural Resources Canada. 2019. "Stand Development Following Mountain Pine Beetle Outbreaks in South-Central British Columbia." Government of Canada. 2019. https://cfs.nrcan.gc.ca/projects/63.

O'Brien, Stephen J, and James F Evermann. 1988. "Interactive Influence of Infectious Disease and Genetic Diversity in Natural Populations." *Trends in Ecology & Evolution* 3 (10): 254–59. https://doi.org/https://doi.org/10.1016/0169-5347(88)90058-4.

Olsson, Mattias, and Per Widen. 2008. "Effects of Highway Fencing and Wildlife Crossings on Moose Alces Alces Movements and Space Use in Southwestern Sweden." *Wildlife Biology* 14 (1): 111–17. https://doi.org/10.2981/0909-6396(2008)14[111:EOHFAW]2.0.CO.

Olsson, Ola, Joel S. Brown, and Henrik G. Smith. 2002. "Long- and Short-Term State-Dependent Foraging under Predation Risk: An Indication of Habitat Quality." *Animal Behaviour* 63 (5): 981–89. https://doi.org/10.1006/anbe.2001.1985.

OMNR, Ontario Ministry of Natural Resources. 1988. *Timber Management Guidelines for the Provision of Moose Habitat*. Ontario, Canada: Queen's Printer for Ontario.

Osko, Terrance J, Michelle N Hiltz, Robert J Hudson, Shawn M Wasel, and Allen Press. 2004. "Moose Habitat Preferences in Response to Changing Availability." *Journal of Wildlife Management* 68 (3): 576–84.

Pease, Brent S, Clayton K Nielsen, and Eric J Holzmueller. 2016. "Single-Camera Trap Survey Designs Miss Detections: Impacts on Estimates of Occupancy and Community Metrics." *PLOS ONE* 11 (11): e0166689. https://doi.org/10.1371/journal.pone.0166689.

Perera, Ajith H., Tarmo K. Remmel, Lisa J. Buse, and Marc R. Ouellette. 2009. "As Assessment of Residual Patches in Boreal Fires in Relation to Ontario's Policy Directions for Emulating Natural Forest Disturbances." Sault Ste. Marie, Ontario, Canada.

Persson, Inga-lill. 2003. "Seasonal and Habitat Differences in Visibility of Moose Pellets." *Alces* 39 (January): 233–41.

Peters, Wibke. 2010a. "Resource Selection and Abundance Estimation of Moose : Implications for Caribou Recovery in a Human

Altered Landscape."

———. 2010b. "RESOURCE SELECTION AND ABUNDANCE ESTIMATION OF MOOSE: IMPLICATIONS FOR CARIBOU RECOVERY IN A HUMAN ALTERED LANDSCAPE." University of Montana.

Peters, Wibke, Mark Hebblewhite, Kirby G. Smith, Shevenell M. Webb, Nathan Webb, Mike Russell, Curtis Stambaugh, and Robert B. Anderson. 2014. "Contrasting Aerial Moose Population Estimation Methods and Evaluating Sightability in West-Central Alberta, Canada." *Wildlife Society Bulletin*. https://doi.org/10.1002/wsb.433.

Peterson, Randolph L. 1955. *North America Moose*. Toronto, Ontario, Canada: University of Toronto Press.

Pfeffer, Sabine E, Robert Spitzer, Andrew M Allen, Tim R Hofmeester, Göran Ericsson, Fredrik Widemo, Navinder J Singh, and Joris P G M Cromsigt. 2018. "Pictures or Pellets? Comparing Camera Trapping and Dung Counts as Methods for Estimating Population Densities of Ungulates." *Remote Sensing in Ecology and Conservation* 4 (2): 173–83. https://doi.org/10.1002/rse2.67.

Pigeon, Karine, Tracy McKay, and Laura Finnegan. 2019. "Targeting Alternate Prey to Understand Caribou and Moose Habitat Management Choices in a Regenerating Landscape: Increasing Functional Habitat for Caribou within West-Central Ranges." Hinton, Alberta, Canada.

Poole, Kim G, and K Stuart-Smith. 2004. "Winter Habitat Selection by Moose in the East Kootenay, British Columbia, Final Report." Cranbrook, British Columbia, Canada.

Poole, Kim G, and Kari B T - Alces Stuart-Smith. 2005. "Fine-Scale Winter Habitat Selection by Moose in Interior Montane Forests" 41 (November): 1+.

Potvin, François. 1981. "Constructing Dry Weight-Diameter Curves for Browsed Twigs." *The Journal of Wildlife Management* 45 (1): 276–79. https://doi.org/10.2307/3807903.

Potvin, François, Réhaume Courtois, and Louis Bélanger. 1999. "Short-Term Response of Wildlife to Clear-Cutting in Quebec Boreal Forest: Multiscale Effects and Management Implications." *Canadian Journal of Forest Research* 29 (7): 1120–27. https://doi.org/10.1139/x99-040.

Pybus, Margo J. 1999. "Moose and Ticks in Alberta: A Die off in 1998/99." Edmonton, Alberta, Canada.

Pybus, Margo J, Eric W Butterworth, and John G Woods. 2015. "AN EXPANDING POPULATION OF THE GIANT LIVER FLUKE (FASCIOLOIDES MAGNA) IN ELK (CERVUS CANADENSIS) AND OTHER UNGULATES IN CANADA." *Journal of Wildlife Diseases* 51 (2): 431–45. https://doi.org/10.7589/2014-09-235.

Ranta, W. B. 1998. *Selected Wildlife and Habitat Features : Inventory Manual for Use in Forest Management Planning*. Technical Series. Ontario Ministry of Natural Resources.

Rausch, Robert A., Bill Gasaway, and Charles Schwartz. 2008. "Moose." Alaska Department of Fish & Game. 2008. https://www.adfg.alaska.gov/static/education/wns/moose.pdf.

Raymond, Kevin S, Frederick A Servello, Brad Griffith, and William E Eschholz. 1996. "Winter Foraging Ecology of Moose on Glyphosate-Treated Clearcuts in Maine." *Journal of Wildlife Managment* 60 (4): 753–63.

Rea, Roy V, Chris J Johnson, Brent W Murray, Dexter P Hodder, and Shannon M Crowley. 2016. "Timing Moose Pellet Collections to Increase Genotyping Success of Fecal DNA." *Journal of Fish and Wildlife Management* 7 (2): 461–66. https://doi.org/10.3996/112015-JFWM-115.

Rempel, Robert S. 2012. *Effects of Climate Change on Moose Populations: A Vulnerability Analysis for the Clay Belt Ecodistrict (3E-1) in Northeastern Ontario*. Ontario, Canada: Queen's Printer for Ontario.

Rempel, Robert S, Philip C Elkie, Arthur R Rodgers, and Michael J Gluck. 1997. "Timber-Management and Natural-Disturbance

Effects on Moose Habitat: Landscape Evaluation." *The Journal of Wildlife Management* 61 (2): 517–24. https://doi.org/10.2307/3802610.

Renecker, Lyle A, and Robert J Hudson. 1986. "Seasonal Energy Expenditures and Thermoregulatory Responses of Moose." *Canadian Journal of Zoology* 64 (2): 322–27. https://doi.org/10.1139/z86-052.

Rippin, B. 2001. "Management Plan for Moose in Alberta (Draft)." Edmonton, Alberta.

RISC, Resources Information Committee. 1998. "Ground-Based Inventory Methods for Selected Ungulates: Moose, Elk, and Deer." Victoria, British Columbia, Canada. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/grndb.pdf.

———. 2002. *Aerial-Based Inventory Methods for Selected Ungulates: Bison, Mountain Goat, Mountain Sheep, Moose, Elk, Deer and Caribou*. Version 2. Victoria, British Columbia, Canada: British COlumbia Ministry of Sustainable Resource Management: Terrestrial Information Branch. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/unga_ml20_final.pdf.

Ritchie, Chris. 2008. "Management and Challenges of the Mountain Pine Beetle Infestation in British Columbia." *Alces* 44: 127–35.

Rodgers, Art. 2001. *Moose*. Stillwater, Minnesota, USA: Voyageur Press.

Rolandsen, Christer, Erling Johan Solberg, Ivar Herfindal, Bram Moorter, and Bernt-Erik Saether. 2011. "Large-Scale Spatiotemporal Variation in Road Mortality of Moose: Is It All about Population Density?" *Ecosphere* 2 (October): art113. https://doi.org/10.1890/ES11-00169.1.

Rolley, Robert E, and Lloyd B Keith. 1980. "Moose Population Dynamics and Winter Habitat Use at Rochester Alberta Canada 1965-1979." *Canadian Field Naturalist* 94 (1): 9.

Routledge, Robert G, and John B T - Alces Roese. 2004. "Moose Winter Diet Selection in Central Ontario" 40 (November): 95+. https://link.gale.com/apps/doc/A150584118/CPI?u=uvictoria&sid=CPI&xid=ebef9cb0.

Rovero, Francesco, Fridolin Zimmermann, Duccio Berzi, and Paul Meek. 2013. "'Which Camera Trap Type and How Many Do I Need?' A Review of Camera Features and Study Designs for a Range of Wildlife Research Applications." *Hystrix* 24 (August). https://doi.org/10.4404/hystrix-24.2-8789.

Safranyik, L, and A Carroll. 2006. *The Biology and Epidemiology of the Mountain Pine Beetle in Lodgepole Pine Forests.* Edited by L. Safranyik and W.R. Wilson. *The Mountain Pine Beetle: A Synthesis of Its Biology, Management and Impacts on Lodgepole Pine*. Victoria, British Columbia: Natural Resources Canada, Canadian Forest Service. https://doi.org/10.1016/j.giec.2010.09.011.

Samuel, W. M. 2004. *White as a Ghost: Winter Ticks and Moose*. Edited by Glen Semenchuk. Edmonton, Alberta, Canada: Federation of Alberta Naturalists.

Sattler, Renae L., Janna R. Willoughby, and Bradley J. Swanson. 2017. "Decline of Heterozygosity in a Large but Isolated Population: A 45-Year Examination of Moose Genetic Diversity on Isle Royale." *PeerJ*. DOI 10.7717/peerj.3584.

Sawyer, Hall, Matthew J Kauffman, Ryan M Nielson, and Jon S Horne. 2009. "Identifying and Prioritizing Ungulate Migration Routes for Landscape-Level Conservation." *Ecological Applications* 19 (8): 2016–25.

Schmidt, Jennifer I, Kris J Hundertmark, R Terry Bowyer, and Kevin G McCracken. 2008. "Population Structure and Genetic Diversity of Moose in Alaska." *The Journal of Heredity* 100 (2): 170–80. https://doi.org/10.1093/jhered/esn076.

Schmitz, Oswald J. 2005. "Scaling from Plot Experiments to Landscapes: Studying Grasshoppers to Inform Forest Ecosystem Management." *Oecologia* 145 (2): 225–34. https://doi.org/10.1007/s00442-005-0063-y.

Schneider, Richard R. 2013. "Alberta's Natural Subregions Under a Changing Climate: Past, Present and Future."

Schneider, Richard R, Andreas Hamann, Dan Farr, Xianli Wang, and Stan Boutin. 2009. "Potential Effects of Climate Change on Ecosystem Distribution in Alberta." *Canadian Journal of Forest Research* 39 (5): 1001–10.

Schramm, T., and N. Krogman. 2001. "Caribou Mountains Critical Wildlife Habitat and Traditional Ecological Knowledge Study."

Schwab, Francis E., and Michael D. Pitt. 1991. "Moose Selection of Canopy Cover Types Related to Operative Temperature, Forage, and Snow Depth." *Canadian Journal of Zoology* 69: 3071–77. https://doi.org/10.1139/z91-431.

Schwartz, CC, and AW Franzmann. 1991. "Interrelationship of Black Bears to Moose and Forest Succession in the Northern Coniferous Forest." *Wildlife Monographs* 113: 3–58.

Seaton, C Tom, Thomas F Paragi, Rodney D Boertje, Knut Kielland, Stephen DuBois, and Craig L Fleener. 2011. "Browse Biomass Removal and Nutritional Condition of Moose Alces Alces." *Wildlife Biology* 17 (1): 55–66. https://doi.org/10.2981/10-010.

Secretariat, CBFA. 2014. "Boreal Priority Species - Moose: Additional Considerations for Conservation Planning." CBFA Secretariat: Ottawa, Canada. https://www.fpac.ca/wp-content/uploads/BPS_Moose2015.pdf.

Seidl, Rupert, Werner Rammer, and Thomas Spies. 2014. "Disturbance Legacies Increase the Resilience of Forest Ecosystem Structure, Composition, and Functioning." *Ecological Applications* 24 (May): 140915094202006. https://doi.org/10.1890/14-0255.1.

Seiler, Andreas. 2005. "Predicting Locations of Moose–Vehicle Collisions in Sweden." *Journal of Applied Ecology* 42 (2): 371–82. https://doi.org/10.1111/j.1365-2664.2005.01013.x.

Serrouya, Robert, Robert G D'Eon, Sustainable Forest Management Network, and Knowledge Exchange and Technology Extension (KETE). 2004. *Variable Retention Forest Harvesting: Research Synthesis and Implementation Guidelines*. Edmonton, Alta.: Sustainable Forest Management Network.

Serrouya, Robert, Bruce N McLellan, Stan Boutin, Dale R. Seip, and Scott E. Nielsen. 2011. "Developing a Population Target for an Overabundant Ungulate for Ecosystem Restoration." *Journal of Applied Ecology* 48 (4): 935–42. https://doi.org/10.1111/j.1365-2664.2011.01998.x.

Serrouya, Robert, Bruce N McLellan, Harry van Oort, Garth Mowat, and Stan Boutin. 2017. "Experimental Moose Reduction Lowers Wolf Density and Stops Decline of Endangered Caribou." *PeerJ* 5: e3736. https://doi.org/10.7717/peerj.3736.

SFA, Silviculture and Applied Forest Ecology. 2019. "Siviculture Textbook." Austin State University. 2019. http://forestry.sfasu.edu/faculty/stovall/silviculture/index.php/silviculture-textbook-sp-9418.

Shanley, Colin, and Sanjay Pyare. 2011. "Evaluating the Road-Effect Zone on Wildlife Distribution in a Rural Landscape." *Ecosphere* 2 (February). https://doi.org/10.1890/ES10-00093.1.

Shave, Justin R, Andrew E Derocher, Seth G Cherry, and Gregory W Thiemann. 2019. "Chronic Stress and Body Condition of Wolf-Killed Prey in Prince Albert National Park, Saskatchewan." *Conservation Physiology* 7 (1). https://doi.org/10.1093/conphys/coz037.

Shenoy, Aditi, Jill Johnstone, Eric Kasischke, and Knut Kielland. 2011. "Persistent Effects of Fire Severity on Early Successional Forests in Interior Alaska." *Forest Ecology and Management* 261 (February): 381–90. https://doi.org/10.1016/j.foreco.2010.10.021.

Sheriff, Michael J., Ben Dantzer, Brendan Delehanty, Rupert Palme, and Rudy Boonstra. 2011. "Measuring Stress in Wildlife: Techniques for Quantifying Glucocorticoids." *Oecologia* 166 (4): 869–87. https://doi.org/10.1007/s00442-011-1943-y.

Singh, Navinder J, Luca Börger, Holger Dettki, Nils Bunnefeld, and Göran Ericsson. 2012. "From Migration to Nomadism: Movement Variability in a Northern Ungulate across Its Latitudinal Range ." *Ecological Applications* . United States : Ecological Society of America . https://doi.org/10.1890/12-0245.1.

Snaith, Tamaini, and Karen Beazley. 2004. "The Distribution, Status and Habitat Associations of Moose in Mainland Nova Scotia." *Proceedings Nova Scotian Institute of Science* 42 (November): 263–317. https://doi.org/10.15273/pnsis.v42i2.3608.

Snyder, John D, and Robert A Janke. 1976. "Impact of Moose Browsing on Boreal-Type Forests of Isle Royale National Park." *The American Midland Naturalist* 95 (1): 79–92. https://doi.org/10.2307/2424235.

Steinke, Julie. 2019a. "Beyond Beetle: Natural Regeneration after MPB Attack in Lodgepole Pine Forests of West-Central Alberta."

———. 2019b. "Understory Vegetation Responses to Simulated Mountain Pine Beetle Attack and Salvage Logging in Lodgepole Pine Forests in West-Central Alberta."

Stenhouse, G. B., Latour, P. B., L. Kutny, N. MacLean, and G Glover. 1994. "Productivity, Survival, and Movements of Female Moose in a Low-Density Population, Northwest Territories, Canada." *Arctic Institute of North America* 48 (1): 57–62.

Stent, Patrick, and Dennis Hamilton. 2007. "Ungulate Winter Range on Boundary TSA and TFL 8: Summary of Year-2 Ungulate Winter Snow Track Count Surveys & Summer Field Sampling Plan." Midway, British Columbia, Canada.

Stewart, Abbie, Petr E. Komers, and Darren J. Bender. 2010. "Assessing Landscape Relationships for Habitat Generalists." *Écoscience*. https://doi.org/10.2980/17-1-3284.

Stewart, Abbie, and Petr E. Kromers. 2012. "Testing the Ideal Free Distribution Hypothesis: Moose Response to Changes in Habitat Amount." *ISRN Ecology* 2012: 8. http://dx.doi.org.ezproxy.library.uvic.ca/10.5402/2012/945209.

Stockdale, Chris, Mike Flannigan, and Ellen Macdonald. 2016. "Is the END (Emulation of Natural Disturbance) a New Beginning? A Critical Analysis of the Use of Fire Regimes as the Basis of Forest Ecosystem Management with Examples from the Canadian Western Cordillera." *Environmental Reviews* 24 (3): 233–43. https://doi.org/10.1139/er-2016-0002.

Stocks, Brian J. 1993. "Global Warming and Forest Fires in Canada." *The Forestry Chronicle* 69 (3): 290–93. https://doi.org/10.5558/tfc69290-3.

Stone, C, D Spolc, and C A Urquhart. 1995. *Survey of Crown Dieback in Moist Hardwood Forests in the Central and Northern Regions of New South Wales State Forests: (Psyllid/Bell Miner Research Programme. Research Paper / State Forests Research Division*. Sydney: Research Division, State Forests of New South Wales.

Street, Garrett, Lucas Vander Vennen, Tal Avgar, Anna Mosser, Morgan Anderson, Art Rodgers, and John Fryxell. 2015. "Habitat Selection Following Recent Disturbance: Model Transferability with Implications for Management and Conservation of Moose (Alces Alces)." *Canadian Journal of Zoology* 93 (October): 813–21. https://doi.org/10.1139/cjz-2015-0005.

Street, GM, Arthur R. Rodgers, and John M. Fryxell. 2015. "Mid-Day Temperature Variation Influences Seasonal Habitat Selection by Moose." *Journal of Wildlife Management* 79 (3): 505–12. https://doi.org/10.1002/jwmg.859.

Stringham, Stephen. 1974. "Mother-Infant Relations in Moose (Alces Alces)." *Naturaliste Canadian* 101 (January): 325–69.

Strong, W.L., and C. C. Gates. 2006. "Herbicide-Induced Changes to Ungulate Forage Habitat in Western Alberta, Canada." *Forest Ecology and Management* 222 (1–3): 469–75. https://doi.org/10.1016/j.foreco.2005.10.036.

Sullivan, T P, and D S Sullivan. 2003. "Vegetation Management and Ecosystem Disturbance: Impact of Glyphosate Herbicide on Plant and Animal Diversity in Terrestrial Systems." *Environmental Reviews* 11 (1): 37–59. https://doi.org/10.1139/a03-005.

Sullivan, Thomas. 2018. "Influence of Nitrogen Fertilization on Forage Production for Native Mammalian Herbivores in Young Lodgepole Pine Forests." Summerland, British Columbia, Canada.

Sullivan, Thomas, and D Sullivan. 2003. "Vegetation Management and Ecosystem Disturbance: Impact of Glyphosate Herbicide on Plant and Animal Diversity in Terrestrial Systems." *Environmental Reviews - ENVIRON REV* 11 (March): 37–59. https://doi.org/10.1139/a03-005.

Sullivan, Thomas, Druscilla Sullivan, Pontus Lindgren, and Douglas Ransome. 2006. "Influence of Repeated Fertilization on Forest

Ecosystems: Relative Habitat Use by Mule Deer and Moose." *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere - CAN J FOREST RES* 36 (June): 1395–1406. https://doi.org/10.1139/X06-033.

Sweanor, Patricia Y, and F Sandegren. 1989. "Winter-Range Philopatry of Seasonally Migratory Moose." *Journal of Applied Ecology* 26 (1): 25–33. https://doi.org/10.2307/2403648.

T8FN, Treaty 8 First Nations Community Assessment Team. 2012. "Telling a Story of Change the Dane-Zaa Way." http://www.ceaa.gc.ca/050/documents_staticpost/63919/85328/Vol3_Appendix_B-Treaty_8.pdf.

Tarazona, Jose V, Daniele Court-Marques, Manuela Tiramani, Hermine Reich, Rudolf Pfeil, Frederique Istace, and Federica Crivellente. 2017. "Glyphosate Toxicity and Carcinogenicity: A Review of the Scientific Basis of the European Union Assessment and Its Differences with IARC." *Archives of Toxicology* 91 (8): 2723–43. https://doi.org/10.1007/s00204-017-1962-5.

Telfer, Edmund S. 1970. "Winter Habitat Selection by Moose and White-Tailed Deer." *Journal of Wildlife Management* 34: 553–59.

———. 1974. "Logging as a Factor in Wildlife Ecology in the Boreal Forest." *The Forestry Chronicle* 50 (5): 186–90. https://doi.org/10.5558/tfc50186-5.

———. 1981. "Browse Inventories: Techniques and Evaluation." In *Symposium on Census and Inventory Methods for Population and Habitats*, 220. Moscow, Idaho, United States.

———. 1984. "Circumpolar Distribution and Habitat Requirements of Moose (Alces Alces). In : Olson, R., R. Hastings and F. Geddes, (Eds.) Northern Ecology and Resource Management." University of Alberta Press. http://www.barbau.ca/content/circumpolar-distribution-and-habitat-requirements-moose-alces-alces-olson-r-r-hastings-and-f.

Telfer, Edmund S. 1969. "Twig Weight-Diameter Relationships for Browse Species." *The Journal of Wildlife Management* 33 (4): 917–21. https://doi.org/10.2307/3799325.

———. 1978. "Cervid Distribution , Browse and Snow Cover in Alberta." *Journal of Wildlife Management* 42 (2): 352–61.

Thompson, Dean G., and D.G. Pitt. 2011. "Frequently Asked Questions (FAQs) on the Use of Herbicides in Canadian Forestry." Sault Ste. Marie, Ontario, Canada: Canadian Forest Service. Great Lakes, Foresry Centre. http://epe.lac-bac.gc.ca/100/200/301/nrcan-rncan/cfs-scf/frontline_technical_rpt-e/112-ef/Fo123-1-112-eng.pdf.

Timmermann, H R, and R. Gollat. 1983. "Age and Sex Strcuture of Harvested Moose Related to Season Manipulation and Access." *Alces* 18: 301–28.

Timmermann, H R, and J G McNicol. 1988. "Moose Habitat Needs." *Forestry Chroniclehronicle* 64 (3): 238–45. https://doi.org/10.5558/tfc64238-3.

Timmermann, H R, and Arthur R Rodgers. 2017. "The Status and Management of Moose in North America – Circa 2015." *ALCES*.

Todesco, C J, H G Cumming, and J G McNicol. 1985. "Winter Moose Utilization of Alternate Strip Cuts and Clear Cuts in Northwestern Ontario: Preliminary Results." *Alces* 21: 447–74.

Toews, Mary. 2016. "Managing Human Footprint with Respect to Its Effects on Large Mammals: Implications of Spatial Scale, Divergent Responses and Ecological Thresholds." University Of Victoria. http://hdl.handle.net/1828/7586.

Tomm, H O, J A Beck Jr., and R J Hudson. 1981. "Responses of Wild Ungulates to Logging Practices in Alberta." *Canadian Journal of Forest Research* 11 (3): 606–14. https://doi.org/10.1139/x81-083.

Torres, R.T., A.M. Valente, T.A. Marques, and C. Fonseca. 2015. "Estimating Red Deer Abundance Using the Pellet-Based Distance Sampling Method." *Journal of Forest Science* 61 (10): 422–30. https://doi.org/10.17221/52/2015-JFS.

Triton. 2005. "Literature Review of Methodologies for Large Ungulate Habitat Enhancement Concurrent with Industrial

Development." British Columbia: Ministry of Water, Land and Air Protection. https://www.for.gov.bc.ca/hfd/library/documents/bib97172.pdf.

Trolliet, Franck, Marie Claude Huynen, Alain Hambuckers, and CéDric Vermeulen. 2014. "Use of Camera Traps for Wildlife Studies. A Review." *Biotechnology, Agronomy and Society and Environment*.

Wagner, Robert G, Michael Newton, Elizabeth C Cole, James H Miller, and Barry D Shiver. 2004. "The Role of Herbicides for Enhancing Productivity and Conserving Land for Biodiversity in North America." *Wildlife Society Bulletin 2004, 32(4):1028-1041*, November. https://www.fs.usda.gov/treesearch/pubs/8975.

Wall, Wayne B, Myriam Belisle, and Lindsay A Luke. 2011. "Moose Wildlife Habitat Decision Aid." *BC Journal of Ecosystems and Management* 11 (3): 45.

Wallgren, Märtha, Roger Bergström, Göran Bergqvist, and Markus Olsson. 2013. "Spatial Distribution of Browsing and Tree Damage by Moose in Young Pine Forests, with Implications for the Forest Industry." *Forest Ecology and Management* 305: 229–38. https://doi.org/https://doi.org/10.1016/j.foreco.2013.05.057.

Wam, Hilde, and Olav Hjeljord. 2010. "Moose Summer and Winter Diets along a Large Scale Gradient of Forage Availability in Southern Norway." *European Journal of Wildlife Research* 56 (October): 745–55. https://doi.org/10.1007/s10344-010-0370-4.

Wam, Hilde Karine, and Olav Hjeljord. 2010. "Moose Summer Diet From Feces and Field Surveys: A Comparative Study." *Rangeland Ecology and Management* 63 (3): 387–95. https://doi.org/10.2111/REM-D-09-00039.1.

Wang, Dongliang, Quanqin Shao, and Huanyin Yue. 2019. "Surveying Wild Animals from Satellites, Manned Aircraft and Unmanned Aerial Systems (UASs): A Review." *Remote Sensing* . https://doi.org/10.3390/rs11111308.

Wang, Xianli, Marc-André Parisien, Mike D Flannigan, Sean A Parks, Kerry R Anderson, John M Little, and Steve W Taylor. 2014. "The Potential and Realized Spread of Wildfires across Canada." *Global Change Biology* 20 (8): 2518–30. https://doi.org/10.1111/gcb.12590.

Wasser, Samuel K, Jonah L Keim, Mark L Taper, and Subhash R Lele. 2011. "The Influences of Wolf Predation, Habitat Loss, and Human Activity on Caribou and Moose in the Alberta Oil Sands." *Frontiers in Ecology and the Environment* 9 (10): 546–51. https://doi.org/10.1890/100071.

Wattles, David W, Katherine A Zeller, and Stephen DeStefano. 2018. "Response of Moose to a High-Density Road Network." *The Journal of Wildlife Management* 82 (5): 929–39. https://doi.org/10.1002/jwmg.21459.

Wearn, Oliver R, and Paul Glover-Kapfer. 2019. "Snap Happy: Camera Traps Are an Effective Sampling Tool When Compared with Alternative Methods." *Royal Society Open Science* 6 (3): 181748. https://doi.org/10.1098/rsos.181748.

Weber, Michael G, and Michael D Flannigan. 1997. "Canadian Boreal Forest Ecosystem Structure and Function in a Changing Climate: Impact on Fire Regimes." *Environmental Reviews* 5 (3–4): 145–66.

Weiskopf, Sarah R, Olivia E Ledee, and Laura M Thompson. 2019. "Climate Change Effects on Deer and Moose in the Midwest." *The Journal of Wildlife Management* 83 (4): 769–81. https://doi.org/10.1002/jwmg.21649.

Welsh, D A, K P Morrison, K Oswald, and E R Thomas. 1980. "Winter Utilization of Habitat by Moose in Relation to Forest Harvesting." In *Proc North Am Moose Conf Workshop*, 16:398–428.

Westfall, Joan, and Tim Ebata. 2014. "Predicting the Risk of Mountain Pine Beetle Spread to Eastern Pine Forests: Considering Uncertainty in Uncertain Times." Ministry of forests, lands and natural resource operations, British Columbia. https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/aerial-overview-survey-documents/2013-fh-bc-overview.pdf.

White, Kevin S, Neil L Barten, Stacy Crouse, and John Crouse. 2014. "Benefits of Migration in Relation to Nutritional Condition and

Predation Risk in a Partially Migratory Moose Population." *Ecology* 95 (1): 225–37. https://doi.org/10.1890/13-0054.1.

White, Kevin S, David P Gregovich, Neil L Barten, and Ryan Scott. 2012. "Moose Population Ecology and Habitat Use along the Juneau Access Road Corridor, Alaska." *Department of Wildlife Conservation, Editor. Juneau: Alaska Department of Fish and Game (See Supplemental Material, Reference S2, DOI: 10.3996/062014-JFWM-045. S13).*

Williston, P, and D Cichowski. 2006. "The Response of Caribou Terrestrial Forage Lichens to Mountain Pine Beetles and Forest Harvesting in the East Ootsa and Entiako Areas: Final Report - 2005 - Year 5. A Report to Morice-Lakes Innovative Forest Practices Agreement, Prince George, B.C." Smithers, BC.

Wilson, Robert E, Sean D Farley, Thomas J McDonough, Sandra L Talbot, and Perry S Barboza. 2015. "A Genetic Discontinuity in Moose (Alces Alces) in Alaska Corresponds with Fenced Transportation Infrastructure." *Conservation Genetics* 16 (4): 791–800. https://doi.org/10.1007/s10592-015-0700-x.

Witczuk, Julia, Stanisław Pagacz, Anna Zmarz, and Maciej Cypel. 2018. "Exploring the Feasibility of Unmanned Aerial Vehicles and Thermal Imaging for Ungulate Surveys in Forests - Preliminary Results." *International Journal of Remote Sensing* 39 (15–16): 5504–21. https://doi.org/10.1080/01431161.2017.1390621.

WRRC, Wildlife Roadsharing Resource Centre. 2017. "Wildlife-Vehicle Collisions: 2000-2014."