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Effects of Winter Ticks (*Dermacentor albipictus*) on the Reproduction of Utah Moose (*Alces alces shirasi*)

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EFFECTS OF WINTER TICKS (*DERMACENTOR ALBIPICTUS*) ON THE REPRODUCTION OF UTAH MOOSE (*ALCES ALCES SHIRASI*)

by

Samuel D. Robertson

A thesis submitted in partial fulfillment
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ABSTRACT

Effects of Winter Ticks (*Dermacentor albipictus*) on the Reproduction of Utah Moose (*Alces alces shirasi*)

by

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Utah State University, 2024

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In Utah, moose *(Alces alces shirasi*) are a relatively new species and they represent the southernmost naturally occurring moose population in the world. Recently the Utah Division of Wildlife Resources has been concerned about possible population declines. This prompted a collaboration with Utah State University to continue a study of Utah moose that began in 2013. My thesis research builds on that initial moose study. The objectives of my thesis were to 1) determine demographic rates in two Utah moose management units, and 2) collect body condition measurements and tick loads to determine how nutrition and parasites effect moose reproductive success.

To identify factors driving reproductive success for moose in Utah, my collaborators and I captured and recaptured 163 adult female moose in two northern Utah study areas (North Slope of the Uinta Mountains and Wasatch Mountains) in 2017-2019. We used ultrasonography to assess the nutritional condition of captured moose by measuring rump fat and loin thickness. We also assessed winter tick (*Dermacentor albipictus*) loads via eight 10-cm transects. Annual mean (±SE) rump fat varied from 2.38

(±0.34) mm to 4.91 (±0.71) mm, and annual mean tick load varied from 0.09 (±0.02) ticks/cm to 0.18 (±0.03) ticks/cm (N=39-80 individuals/year). We assayed pregnancy of 159 captured adult (>1 year-old) moose from 2017 to 2019, and the annual proportion pregnant varied from 66-79% (N= 37-80 individuals/year). I measured parturition of pregnant females from 2017-2019, and parturition rate varied from 50-67% (N= 26-49 individuals/year). The number of calves born was significantly less than the number of pregnant adult females. This suggests possible fetus resorption, aborted fetuses, and possible undetected calving. Each of four indices of reproductive success (mid-winter pregnancy, spring parturition, mid-winter calf-at-heel, and collared calf survival from mid-winter to summer) were negatively correlated with the mid-winter tick load of adult females. Moreover, the rate at which pregnancy and parturition declined with increasing tick load was mediated by female nutritional condition (rump fat), albeit in contrasting ways. Together, these results indicate that winter ticks are a potentially important constraint on the reproductive output and population growth of moose in Utah.

(111 pages)

PUBLIC ABSTRACT

Effects of Winter Ticks (*Dermacentor albipictus*) on the Reproduction of Utah Moose (*Alces alces shirasi*)

Samuel D. Robertson

Moose (*Alces alces*) are the largest and only solitary members of the deer family. The species can be found across many northern regions around the world. Moose are considered to have high intrinsic, recreational and ecological value. In recent years, there have been concerns about declining moose populations in portions of the species circumpolar range. Moose in Utah *(Alces alces shirasi*) belong to the Shiras subspecies, which is the smallest of the four subspecies found in North America. Utah moose are the southernmost naturally occurring moose population in the world. The Utah Division of Wildlife Resources (UDWR) has been concerned about possible moose population declines in Utah and with collaboration from Utah State University they initiated a study that began in 2013. The initial phase of the study estimated vital rates that included pregnancy, calving rates, calf recruitment and adult survival along with maternal age and body condition. This initial study found that adults had relatively high survival rates and maternal age and body condition influenced reproductive rates. In addition, fluctuating reproductive rates were identified a potential source of population instability.

The research reported in this thesis represents the second phase of the moose study. My UWDR colleagues and I continued to collect data on moose vital rates and body condition. We also initiated a new effort to measure winter tick (*Dermacentor albipictus*) loads on radio-collared moose because observations and analyses during

phase one of the study suggested that winter ticks were limiting population growth. In phase two of the study, I found evidence that winter ticks limited moose reproductive success. I found that poor body condition and high tick loads decreased rates of calving rates and calf survival. Pregnancy rates were affected but in unexpected ways.

Results from this study will help wildlife managers in achieving management objectives and help make future decisions. These results highlight the potential for winter ticks to limit the population growth of moose in Utah via reduced reproductive success. My results also suggest that the impact of winter ticks on reproductive success is mediated to some extent by maternal body condition, such that moose in excellent condition are more likely to overcome the harmful effects of winter ticks on reproduction.

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CHAPTER 1

INTRODUCTION

Moose (*Alces alces*) is the largest and only solitary species of the deer family (Cervidae). Bull (adult male) moose can weigh over 700 kg and stand over 1.8 m tall at the shoulder (Bubenik 2007). The species has a circumpolar distribution, inhabiting North America, Europe, and Asia (Telfer 1984). The species originated in Eurasia and first colonized North America by crossing the Beringia land bridge from Siberia into present day Alaska approximately 10,000-14,000 years ago (Hundertmark et al. 2002, 2003; Boyer et al. 2003). From there, moose have expanded southward and currently occupy Alaska, Canada, and northern portions of the lower 48 (Kelsall and Telfer 1974). Presently, there are four recognized subspecies of moose in North America: Eastern moose (*Alces alces americana*), northwestern moose (*Alces alces andersoni*), Alaskan moose (*Alces alces gigas*), and Shiras moose (*Alces alces shirasi*) (Bubenik 2007). My research as described here focused on the Shiras moose, the smallest of the four North American subspecies.

Moose history in Utah

Moose are a relatively new species in Utah; there is no fossil evidence indicating that moose were in Utah prior to the early 1900's (Wolfe et al. 2010). The first recorded sighting of a moose in Utah was in the mouth of Spanish Fork Canyon, just east of Spanish Fork City in 1906 or 1907 (Barnes 1927). It is believed moose first colonized the North Slope of the Uinta Mountains in northeastern Utah by natural dispersal from the Greater Yellowstone Ecosystem in the early 1900's (Wolfe et al. 2010). It was not until

1947 that a stable population was verified on the North Slope of the Uinta Mountains. Ten years later (1957) the Utah Division of Wildlife Resources (UDWR) conducted its first aerial survey on the North Slope and counted 59 moose. Utah's moose population is unique and significant in that it is the only well-established population in the Great Basin ecoregion, and Utah's moose population is the most southern naturally occurring population in the world (Wolfe et al. 2010).

Moose Management in Utah

Moose management is a difficult endeavor in most regions where moose are found, including Utah. Because moose are solitary and occur at low population densities, assessing population size and monitoring population trends is difficult (Timmerman & Buss 2007). UDWR began managing moose in 1958 when the agency allocated 10 bull moose permits in the first ever legal moose hunt in Utah. The UDWR has issued moose permits every year since. The UDWR held the first cow (adult female) moose hunts in 1977 when 20 cow permits were issued. Moose permits in Utah are drawn each year by hunters who apply and draw for the once in a lifetime permit. These permits are allocated between 12 different moose management units found throughout northern Utah. Moose hunting in Utah peaked in 2008 when over 400 bull/cow permits were issued to hunters. More recently, moose permits reached a low in 2014 when only 137 bull moose permits were issued. The UDWR discontinued cow moose permits in 2012-2015 and restarted in 2016 in a select number of units on a limited basis.

Currently, UDWR manages bull moose harvest by maintaining an age objective of 4-5 years on harvested bulls for each moose unit. This age structure is estimated by aging bull moose that are harvested annually. Currently, UDWR does not have an age objective on harvested cows. UDWR also monitors moose abundance by conducting aerial counts in each moose management unit on a rotational basis once every 3 years. These counts provide an index of population abundance (Ruprecht et al 2020) as well as provide information on cow/calf ratios and bull/cow ratios, which are vital for developing recommended harvest objectives. Cow/calf ratios are the proportion of adult cows to calves, and these ratios are often used as an index of moose productivity and population health. Bull/cow ratios are the proportion of bulls to adult cows and are often used to help set harvest objectives. UDWR managers adjust permit numbers annually according to the age of moose harvested during the previous year and by analyzing the most recent count data that includes cow/calf ratios and bull/cow ratios.

Moose in the Intermountain West have high intrinsic, recreational, and economic value throughout their range. Because they are valued so highly, there has been a great deal of concern over declining Shiras moose populations throughout its range. Declines have been noted in portions of Idaho, Montana, and Wyoming (Brimeyer and Thomas 2004, Harris et al. 2015, Monteith et al. 2015, DeCesare et al. 2016, Nadeau et al. 2017). According to the corrected counts from Ruprecht et al. (2020), Utah's moose population peaked in 2005 with a population of approximately 6,000 moose in northern Utah. Since 2005, the population decreased to approximately 3,000 moose in 2013 (Ruprecht et al. 2020). Since 2013, monitoring from the UDWR shows the moose population has remained fairly stable with populations at the management unit level variously increasing, decreasing, or remaining stable. Efficient and effective management of Utah's moose population requires information about the factors that affect its production and overall performance.

Limiting factors

There are several factors that can influence moose population dynamics. Two of the most important limiting factors are predators and parasites. The occurrence, prevalence and effects of these factors vary across moose populations (Nadeau et al. 2017). Wolves (*Canis lupus*), black bears (*Ursus americanus)*, grizzly bears (*Ursus arctos)* and cougars (*Puma concolor*) are the principal predators of moose (Ballard and Van Ballenberghe 1998). A wolf or grizzly bear population has yet to reestablish in Utah. However, the other two potential moose predators, cougars and black bears are found throughout Utah. Black bears have the potential to kill large numbers of neonatal moose calves in some locations (Ballard and Van Ballenberghe 1998). In Utah, the effect of black bears on moose is believed to be minimal. The current study as well as the preceding one (Ruprecht 2016) found no definitive evidence that black bears killed neonatal moose calves. This may be because most of the black bears in Utah are found in central and southern Utah which moose do not occupy and this likely limits the interaction between black bears and moose (Wolfe et al. 2010). A study in Utah looked at black bear diets by analyzing scat from three locations in Utah, one of these locations was in the Wasatch Mountains which was part of my study area. The scat analysis of (n=179) found no evidence of moose remains (Heward et al. 2004). Cougars on the other hand are predators that potentially target adult and calf moose. During my study, cougars killed two collared cows and two collared ten-month-old calves. One cow was an older moose (10 yrs.) and in poor shape. The other cow also appeared old (based on tooth wear) and in poor shape as well. One of the collared calves killed by cougars was heavily infested by winter ticks, which may have made it an easy target. When 26 adult moose were transplanted to the Manti National Forest in central Utah 4 of 7 radio-collared moose were killed by cougars. In addition, when moose were transplanted to the Fishlake Plateau two of nine known fatalities were attributed to cougars (Wolfe et al. 2010). Despite the evidence that cougars kill moose in Utah, other factors have been identified as limiting moose population growth (Ruprecht et al. 2020).

Parasites

Parasites have the potential to limit the population growth of Utah moose. Moose deal with multiple parasites including the arterial worm (*Elaeophora schneideri*), which can cause elaeophorosis characterized by restricted blood flow due to the presence of nematodes in the carotid arteries (Adcock and Hibler 1969, Worley and Anderson 1972, Pence 1991). This disruption in blood flow can lead to blindness: ischemic necrosis of the brain, ears and muzzle, poor antler growth, oral food impactions and in some cases death (Worley and Anderson 1972, Madden et al. 1991, Pessier 1998, Couvillion et al. 1986, Henningsen et al. 2012).

Winter ticks (*Dermacentor albipictus*) are another parasite that can have negative effects on moose populations. In the northeastern United States, researchers have found winter ticks cause high mortality in calves and reduce productivity in yearling and adult cows (Musante et al. 2010, Bergeron et al. 2013, Jones et al. 2017). In Utah, Ruprecht et al. (2020) found that moose population growth decreased in years when environmental conditions favored tick survival (reduced late winter snowpack). Reproductive female ticks drop off their hosts at the end of winter to lay eggs, and fewer ticks survive in years with abundant snow cover, which is known to reduce tick abundance the following year (Drew and Samuel 1986, Wilton, and Garner 1993, DelGiudice et al. 1997, Samuel

2007). However, there is no direct evidence of the effects of winter ticks on the demographic rates of moose in Utah. My study addressed this gap.

Winter ticks

The winter tick (*Dermacentor albipictus*) is a hard-bodied ectoparasite that is a member of the Ixodidae family of ticks. Entomologist Alpheus Spring Packard Jr. first described winter ticks from moose in Nova Scotia in 1869 (Samuel 1991). Winter ticks are a one-host tick with three parasitic life stages that all require a blood meal from the host. It infests wild and domestic ungulates including horses and cattle (Addison and Mclaughlin, 1988). The life cycle of the winter tick is predictable because its reproductive cycle relies on relatively constant environmental conditions such as temperature and photoperiod (Drew and Samuel 1986). The timing of the winter tick reproductive cycle is due to the nymphal and adult diapause (Drew and Samuel 1986). With nymphal diapause, larvae can attach at various times and still develop at the same time while on the host (Addison and McLaughlin 1988). Adult diapause allows for the synchrony of adult females falling off the host and laying eggs at roughly the same time (Drew and Samuel 1986). The strict cycle is thought to be driven by the cold northern climate. The heavy snow that is typical of the northern climate permits only a brief period for winter ticks to reproduce successfully (Samuel 2004).

From April to May, engorged females fall off their host after taking their last and largest blood meal. If conditions are right and late spring snow cover is minimal, these engorged female ticks are more likely to survive. If cold temperatures and snow cover last through late spring, the less likely the females will survive (Ruprecht et al. 2020). In June, these engorged females lay their eggs in layers of vegetation and leaf litter. The eggs hatch in late summer from August-September and ascend vegetation and begin questing for a host. They continue to quest until temperatures are too cold or snow covers the ground and impedes activity and survival (Drew and Samuel 1986, Samuel 2004). Larve will feed on the host from October-November and then molt into nymphs. Nymphs remain on the host from October to March, at which time they feed and molt into adults from January to March. Adults will remain and feed on a host until April-May and then drop from the host and repeat the cycle (Samuel 2004). The adult female winter ticks consume the most blood (1.70-2.55 g) and this happens during its last life stage (Addison et al. 1998). Intense feeding begins in early March and continues until all female winter ticks fall off several weeks to months later (Drew and Samuel 1989, Musante et al. 2007).

Winter ticks are found across North America with a distribution as far south as Baja, California (31° N) (Contreras et al. 2007) and as far north as the Yukon in Canada (62° N) (Samuel, 1989). There is also evidence that winter ticks can be found as far north as the Sahtu Settlement Area in the Northwest Territories (68° N) (Kutz et al. 2009). The distribution of winter ticks depends on the availability of their hosts, which are primarily large domestic and wild ungulates. The most common ungulate hosts are white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), woodland caribou (*Rangifer tarandus caribou*) and moose (Welch et al., 1991, Musante et al, 2007).

Moose are the host most affected by winter ticks (Lancaster and Samuel 1997, Samuel 2004, Musante et al. 2007) because moose grooming behavior is poorly adapted to counteract tick infestations. (Welch et al 1991, Samuel 2004). The grooming strategy of moose is believed to be a key reason why winter ticks affect moose more than other ungulates (Samuel et al. 2000, Samuel 2004). Deer, elk, and bison are what is known as "programmed groomers" (Samuel 2004); they groom in anticipation of ticks and other parasites and groom before larvae have a chance to molt into nymphs. Moose on the other hand are known as "stimulus groomers" and will groom only when they feel an irritation from feeding ticks (Mooring and Samuel 1998, Samuel 2004). This irritation from feeding ticks causes a moose to release histamine and this causes the host to begin grooming. This means moose delay aggressive grooming until ticks are developed into adults (Mooring and Samuel 1998).

The current hypothesis for poor grooming behavior in moose is that the relationship between moose and winter ticks is relatively recent and moose have yet to evolve an effective response to this parasite (Mooring and Samuel 1998). Moose are relative newcomers to North America, and as a result, they have acquired several parasites they did not evolve with, unlike the genus *Odocoileus* that coevolved with many of parasites like winter ticks (Anderson & Lankester 1974). Because moose have not co-evolved with these parasites, they have not acquired adaptations for effectively managing them. Problematic parasites for moose included meningeal worms (*Parelaphostrongylus tenuis*), liver flukes (*Fascioloides magna*) and winter ticks. All three of these parasites spread from hosts like white-tailed deer and mule deer that have co-evolved with and adapted to these parasites (Holmes 1982). All three of these parasites have minimal impact on deer, but they can be detrimental to moose and often cause mortality (Mooring & Samuel 1998, Samuel 2004).

Winter ticks have contributed to large moose die-offs (Delgiudice et al. 1997, Samuel 2004) and have been suspected of affecting population dynamics in the northeastern United States. It has been well documented in the northeastern United States that winter ticks cause moose population declines often by high mortality rates in 10–11-month-old calves and long-term effects by reducing adult female moose fitness and reproductive success (Musante et al 2010, Bergeron et al. 2013, Jones et al. 2017). Moose gestational and lactational costs are often greatest before spring green up and it is critical that moose minimize weight loss at this time for producing young (Jones et al. 2017). Winter tick infestations exacerbate a negative energy balance that already exists in late winter and early spring due to poor-quality forage resources (Schwartz and Renecker 2007). Winter ticks can also cause an additional protein deficit from blood loss (Musante et al 2007). Large tick loads can lead to anemia, restlessness, and intense and prolonged grooming from the constant irritation from biting ticks which can lead to decreased time feeding and hair-loss, which can lead to increased thermo-regulatory costs during cold wet winters (Samuel and Welch 1991, Addison et al. 1998, Samuel 2004).

The Shiras subspecies of moose found in the western Rockies has been documented having winter ticks (Becker et al. 2010, DeCesare 2014, Ruprecht et al. 2020) but little is known of the specific effects of winter ticks on the Shiras subspecies. It has been noted that impacts on moose populations from winter ticks in Montana are likely, but little is known (DeCesare et al. 2014). Winter tick loads have been measured on captured moose in Wyoming (Becker et al. 2010) but tick loads were small when compared to measurements from the eastern US. In 2013, when the UDWR started an extensive study of moose population dynamics, personnel began noticing troubling signs of winter ticks. Researchers found moose with extensive hair loss, and observed extreme grooming behavior, and they saw blood spattered around in numerous bedding sights. In

2017, researchers from UDWR began measuring tick loads on all captured moose and found evidence of substantial tick infestations. It was suspected that winter ticks may be having an impact on moose reproduction in Utah, similar to what has been observed in the northeast where ticks are having a significant impact on calf survival (Musante et al 2010, Bergeron et al. 2013, Jones et al. 2017). In chapter 2, I summarize these data and test the hypothesis that winter tick loads on adult female moose limit different aspects of reproduction in Utah moose.

Purpose

This study is a continuation of an ongoing study that began in 2013 and seeks to fulfill several new and ongoing objectives. The first objective was to continue to estimate vital rates for moose on the North Slope and Wasatch moose units. To accomplish this, UDWR captured and collared additional adult cow moose and calves in January 2017 to augment the 20 adult cow moose that were captured in 2013 that still had functioning collars in January 2017. Only adult cows were collared because the necks of adult bulls swell during the rut, and this can cause problems for bulls. It is also thought that female adult survival has the largest influence on population dynamics of ungulates (Gaillard et al. 1998). Calves were captured to improve understanding of calf survival, cause of mortality and timing of mortality. The vital rates of interest were annual adult survival, pregnancy, calving, calf survival and calf recruitment. At the conclusion of this study in 2019, my collaborators and I collected 7 years of data on these vital rates. Starting in 2017, we collected data on body condition, disease prevalence and parasite abundance on all captured moose.

The second objective, which is the focus of chapter 2, was to determine how the interaction of parasite loads and body condition affect female moose and their reproductive success. This data enabled me to evaluate how winter tick abundance impacts moose demographic performance, marking the first instance of such analysis for moose in Utah. A third objective was to examine how parasite loads, particularly winter ticks and body condition, change from year to year with varying climatic conditions. To accomplish this, we recaptured moose that were captured in 2017. In 2018 and 2019, moose were recaptured on both the North Slope and Wasatch units.

The recaptures allowed me to assess the changes in parasite loads and body condition with varying climate conditions. The captures in 2017 occurred after a mild winter and hot summer, providing insight into parasite loads and body conditions following a year of below-average precipitation. The captures in 2018 occurred after a year of high precipitation, while those in 2019 followed a historically low year for precipitation. These three years with differing climate conditions enabled me to compare parasite loads and body condition across different years.

CHAPTER 2

METHODS

Study Areas

The moose I studied occurred in two different mountain ranges in Northern Utah: the Wasatch Mountains (40.4° N, -111.3° W) and the North Slope of the Uinta Mountains (40.9° N, -110.5°). The Wasatch Mountain study area is approximately 4,000 km^2 and located in the Wasatch mountains moose management unit 17. The North Slope of the Uinta Mountains study area is approximately 1,700 km^2 and located in the North Slope, Summit moose management unit 8A and moose units 27 and 35 in Wyoming. The Wasatch study area is composed of National Forest lands, private lands, state wildlife management areas (WMA) and some bureau of land management (BLM). The North Slope is made up of High Uinta Wilderness area that was designated in 1984 by the Utah Wilderness Act. It also encompasses National Forest land along with privately owned land in Utah and Wyoming.

The Wasatch study area is made up of what is thought of as atypical moose habitat with a more heterogenous plant community than the North Slope study area. The elevation of the Wasatch study area ranges from 1,800-3,100 m. The lower elevations are made up of sagebrush steppe interspersed with gambel oak (*Quercus gambelii*), bigtooth maple (*Acer grandidentatum*), juniper (*Juniperus spp.*) and mountain mahogany (*Cercocarpus* spp.). At higher elevations vegetation transitions to quaking aspens, Douglas fir (*Pseudostuga menziesii*) and subalpine fir. Willows are found throughout the Wasatch Mountains but often in low densities. Most of the willows in the Wasatch study area are found in American Fork Canyon, Big and Little Cottonwood canyons, and the eastern part of the study area around Strawberry and Currant Creek reservoirs.

The North Slope study area ranges in elevation from 2,100-3,500 meters. Moose were studied from the low-lying agricultural fields in Wyoming up to the high peaks in the Uinta Wilderness Area of Utah. The agricultural fields in Wyoming were comprised of alfalfa (*Medicago spp.*) with streams surrounded by willows (*Salix spp.*) cutting through the fields. As the elevation increases the vegetation transitions into sagebrush steppe (*Artemesia spp*.) interspersed with pockets of quaking aspen (*Populus tremuloides*). As the elevation increases further, the sagebrush steppe gives way to montane forest dominated by lodgepole pine (*Pinus contorta*) quaking aspen and subalpine fir (*Albies lasiocarpa*). Roughly 50% of the lodgepole pine have been killed by mountain pine beetle (*Dendroctonus ponderosae Hopkins*) outbreaks. These forested areas are dissected by wide riparian drainages covered in willow communities. The higher elevations are also covered with many dispersed small lakes and marshes interspersed throughout the forests.

Climate data were available from the National Oceanic and Atmospheric Administration/National Climatic Data Center (NOAA/NCDC) nClimDiv dataset (Vose et al. 2014). Historical seasonal average temperatures for the study area (Utah Northern Mountains climate division) were -5.7°C, 3.2°C, 15.2°C and 5.1°C for winter, spring, summer, and fall. Historical seasonal precipitation totals averaged 18 cm, 17.5 cm,10.2 cm and 14.3 cm during the same seasons. Temperatures the year before and the years during our study period (winter 2015 - summer 2019) averaged -4.5°, 4.5°, 16.9° and

6.4°C respectively and precipitation averaged 20.9, 20.6, 5.6 and 15.9 cm for the same four seasons mentioned above.

Capture and handling

We captured moose via helicopter net-gunning, these captures occurred in January 2017-2019 and were completed within several days at each study site. Individual moose were restrained using hobbles and fit with a blind fold to limit stress. In January 2017, we captured 108 total moose, including 40 adult cows and 16 8-month-old calves (13 females and 3 males) on the North Slope study site and 40 adult cows and 12 8-month-old calves (9 females and 3 males) on the Wasatch study site. In 2018 we captured 67 total moose, including 22 adult females along with 12 calves (4 females and 8 males) on the North Slope and 22 adult cows and 11 calves (5 females 6 males) on the Wasatch. Of the 44 adult females captured in 2018 42 of them were recaptures from the 2017 captures and two were new moose that were opportunistically captured. In 2019 we captured 56 total moose, including, 19 adult cows, 1 yearling bull and 7 calves (6 females and 1 male) on the North Slope and 20 adult cows and 9 calves (6 females and 3 males) on the Wasatch. All the adults were recaptures that had previously been captured in 2013, 2017 and/or 2018.

The adult cow moose were fitted with Lotek Lifecycle GPS collars (Lotek Wireless INC., Newmarket, Ontario, Canada). These GPS radio collars collected GPS fixes every 13 hrs. and had a very-high-frequency (VHF) beacon that was active 24 hrs. a day; after 8 hrs. of nonmovement, a motion sensor triggered a “mortality message” via email and the pulse rate signal of the VHF increased. Each captured calf was fitted with an Advanced Telemetry Systems (ATS) expandable GPS collar (Advanced Telemetry

Systems, Isanti, Minnesota, USA). The calf collars gave locations every 4 hrs.; after 6 hrs. of nonmovement they would trigger a "mortality message" and the VHF signal would decrease. The male calf collars were designed to drop off after 6-8 months so they would not impede or constrict the bull during the rut when male moose necks tend to swell. In 2019 the recaptured adult cows had their Lotek collars replaced with ATS GPS collars because the older Lotek collars were beginning to fail. The ATS collars deployed in 2019 were programmed to take fixes every 2 hours; inactivity for >6 hours triggered a mortality switch that emailed a "mortality message" to researchers.

My collaborators and I determined winter tick loads of each moose captured from 2017-2019 by counting ticks along eight 10-cm randomly situated transects: 4 on the front shoulder and 4 on the rump (Sine et al. 2009). This was done by separating the hair using a 10-cm ruler and counting the number of ticks that intersected the 10-cm transect . Fecal samples were taken from each captured moose to assess endoparasite loads (Washington Animal Disease Diagnostic Lab, Pullman Washington, USA). Blood was also collected for serum chemical analyses to assess trace elements and conduct hematologic analyses to identify any disease found in the blood (Utah Veterinary Diagnostic Lab, Logan, Utah, USA). Hair was collected for later DNA analysis. We also took body measurements, neck circumference, chest girth, metatarsus length, and total body length of all adult cows and calves (Hundertmark & Schwartz 1998). Furthermore, we assigned body condition scores by palpating the rump, and we measured maximum rump fat depth and loin thickness for each captured adult using a portable ultrasound device (Stephenson et al. 1998; Cook et al 2010). Each moose was given an estimated age by looking at tooth eruption and tooth wear of the incisors. All moose captured and handled were done so by following the guidelines and protocols established by the American Society of Mammologists for care and use of wild mammals in research (Sikes 2011). The Institutional Animal Care and Use committee (IACUC) at Utah State University approved all animal handling (protocol # IACUC-2365).

Pregnancy

Pregnancy status of each adult cow moose captured was determined by using the pregnancy-specific protein B (PSPB) assay on serum collected from blood samples obtained from venipuncture (Sage Laboratories. LLC, Sweet, Idaho, USA) (Biotracking, Moscow, Idaho, USA-Sasser et al. 1986; Haigh et al. 1993; Huang et al. 2000).

Parturition

To determine if a cow moose produced 1 or 2 calves, we conducted calf searches of every collared female moose in the two study sites during May-June in 2017, 2018 and 2019. These calf searches were done from the ground using GPS locations and VHF telemetry. Every female was surveyed multiple times until we either observed her with a calf or calves, or we determined she had lost a calf or was not going to have one. To determine if a cow was non-parturient the cow had to be observed multiple times with clear unobstructed views. GPS data were also used to help determine if a cow moose had a possible calf by observing clustered points indicating a possible birth (McGraw et al. 2014). If a cluster of GPS points were observed, then a field visit was conducted as quickly as possible to determine if that cow in fact had a calf. Although all efforts were made to observe moose at peak calving time some cows may have had calves but lost them before we observed them.

Calf survival

For each year's calf survival estimates, ground surveys were conducted throughout the year and aerial surveys were conducted early spring (March-April). Sixty-five calves were also captured and collared with GPS collars to measure their survival from January until the end of their first year (31May; approximately 6-12 months). If the calf was observed in late April from the ground or by locations from its GPS collar it was considered surviving its first year and recruiting into the population.

Calf-at-heel

During captures in January 2017-2019, each cow that was captured was assessed for a calf at heel. A calf at heel is a calf that was born the previous spring. This was done by observing and capturing the cow and determining if the cow had a calf at this time. If the cow had a calf it was captured at the same time as the cow.

Statistical analysis

I used generalized linear mixed effects model (GLMMs) in STATA 15.1 (StataCorp LP 2017) to estimate the influence of tick load of the cow and rump fat of the cow one three aspects of reproduction: pregnancy, parturition, and calf-at-heel. All analysis were done using data collected in the field and the effects these data could have on reproductive success. I used GLMMs with a logit link to model pregnancy, parturition, and calf-at-heel because the response variables were binary. Moose identity was treated as the random effect and included as a random intercept, because some moose were captured and measured multiple times over the three period. The models included the standardized values of ticks per cm, and rump fat. Values were standardized to put variables at the same scale which allowed us to compare variables with varying measurements. I analyzed several models with different combinations of these variables to determine which of them, alone or in combination, affected pregnancy, parturition, and calf-at-heel. I compared these models using Akaike's Information Criterion (AICc) to determine the model with the best fit for these aspects of reproduction. To assess the effect of maternal tick load on the survival of radio-collared calves, I modeled survival as a function of age using a Cox proportional hazard model with staggered entry in STATA 15.1 (StataCorp LP 2017). I used a continuous time methodology whereby time-to-death was measured across uninterrupted timelines with survival time defined as calf age (number of days alive since date of capture). Survival estimates were conditional on calves surviving to the date of capture, which varied within and among years from January 7-30. I analyzed only natural mortalities (N = 15) and censored calves that went missing (N = 4) or were alive at the end of the study (N = 42). To evaluate the proportional hazards assumption, I tested the null hypothesis that the effect of maternal tick load on calf survival was constant over time. I found no evidence that the proportional hazards assumption was violated (χ^2_1=0.02, P=0.90).

CHAPTER 3

RESULTS

Winter ticks

Winter ticks were counted on 91 individual captured moose (> 1 year old) in 2017-2019. Fifty-two moose were measured multiple times during those three years which yielded a total of 163 total measurements. The fifty-two moose were measured multiple years to see how tick loads varied from year to year. Twenty moose were measured for ticks all three years, and we did observe variation in tick loads on individual moose from the different years (Figure 3.1). Winter ticks ranged from 0.00-0.94 ticks/cm in 2017 with a mean ± SE of 0.18 ± 0.03 ticks/cm (*N*=80*)*. In 2018, ticks/cm ranged from 0.00-0.68 ticks/cm with a mean ± SE of 0.09 ± 0.024 ticks/cm (*N*=44*)*. In 2019, ticks/cm ranged from 0.00-1.08 with a mean ± SE of 0.18 ± 0.05 ticks/cm (*N=39)*. Overall, during the three years of measuring ticks/cm ranged from 0.00-1.08 with a mean ± SE of 0.16 ± 0.012 ticks/cm (*N=163)* (Figure 3.2).

Rump fat

Rump fat depth was measured on the same 91 captured female moose (> 1 year old) in 2017, 2018 and 2019 captures and recaptures for a total of 163 measurements for rump fat (mm). Fifty-two moose were measured multiple years to see how rump fat varied from year to year. Rump fat ranged from 0-12 mm in 2017 with a mean ± SE of 4.35 ± 0.33 mm (*N=80*). In 2018 rump fat ranged from 0-17 mm with a mean ± SE of 4.91 ± 0.71 mm (*N=44*). In 2019, we saw the lowest rump fat totals of the three years with a range of 0-7 mm with a mean ± SE of 2.38 ± .34 mm (*N=39*). Overall, during the three years of measuring rump fat ranged from 0-17 with a mean ± SE of 4.0 ± .27 mm (*N=163*) (Figure 3.3). Twenty-four of the 163 moose measured from 2017-19 (15%) had 0 mm of rump fat measured.

Pregnancy

We acquired pregnancy results from 91 moose > 1 year old from 2017, 2018 and 2019 captures and recaptures for a total 159 pregnancy measurements. In 2017 we tested 80 moose for pregnancy; of those 66.3% (*SE* = 5.2%) were pregnant. In 2018 we tested 42 moose for pregnancy, of which 78.5% (*SE* = 6.3%) were pregnant. In 2019 we tested 37 moose for pregnancy and found 75.6% (*SE* = 7.0%) were pregnant. Pregnancy rate across the 3-year period was 73.5% (*SE* = 3.5%) (Figure 3.4).

Parturition

We determined parturition rates of female moose who tested pregnant in 2017, 2018 and 2019. In 2017 67.3% (33 of 49) of cows who tested pregnant had at least 1 live calf when surveyed. In 2018 the number dropped 61.3% (19 of 31). In 2019 the rate dropped further to 50% (13 of 26). (Figure 3.5). We know some calves were still born, died shortly after birth, or died before being surveyed, six calves were found dead during surveys in 2017 and appeared to have been stillborn or died shortly after birth. Two calves were also found dead in 2018 during surveys and both were likely stillborn or died shortly after birth. We determined that 38.6% of cows who tested pregnant over the 3 years (2017-2019) did not have a calf. Parturition rates among all moose surveyed, known pregnant, known not pregnant and unknown varied in 2017, 46.9% (39 of 83) in 2018, 54.7% (40 of 73) and 2019 43.4% (16 of 37). Over the 3-year period parturition rates of all surveyed moose who had at least 1 live calf averaged 48% (*SE* = 3.5%, N=194).

Calf survival

We determined calf survival by monitoring 61 GPS collared calves that were captured in 2017-2019. These calves were 8-9 months old at the time of captures. In 2017, 61.9% (13 of 21) of calves collared in January survived until June. In 2018, 90.0% (18 of 20) of calves collared in January survived until June. In 2019, 68.8% (11 of 16) of calves collared in January survived until June (Figure 3.6). Two calves were censored in 2017 and 2018 because their fates were unknown.

I modeled the probability of pregnancy as a function of winter tick load (ticks/cm) and rump fat (mm) of 91 moose from which we obtained 159 pregnancy measurements from captures in January 2017-2019. The best-fit model with the lowest AICc (Table 3.1) included the interaction of tick load and rump fat (Table 3.2) such that the probability of pregnancy increased as tick load increased at low rump fat measurements, but pregnancy decreased as tick load increased at higher rump fat measurements (Figure 3.7).

We surveyed 67 moose from May-June in 2017-2019 for a total of 105 observations of moose, for which we had tick load and rump fat (mm) measurements. These moose were monitored at this time to determine parturition. Similar to the pregnancy model, the best-fit parturition model (Table 3.2), which measured the probability of a calf-at-heel in May-June, included an interaction between tick load and rump fat (mm) (Table 3.2). The probability of a calf-at-heel decreased as maternal tick load increased, and the severity of the decrease was greatest among mothers with the least amount of rump fat (Figure 3.8). However, the 95% confidence interval for the interaction coefficient overlaps zero, which indicates that the interactive effect of tick load and rump fat was not significant. Although the curves in figure 3.8 suggests the interaction is significant.

The Cox proportional hazard ratio indicates for each additional tick on the cow moose the likelihood of its calf dying increases 10% (Figure 3.9) This might seem high but one must realize that a 1 tick increase in the total number of ticks from the eight-10cm transects could represent thousands of more ticks when looking at the whole surface area of an adult moose. The first model I ran included maternal tick load (total number of ticks from the eight-10cm transects), calf tick load (total number of ticks from the eight-10cm transects), cow rump fat and calf sex. Likelihood ratio tests revealed that the best-fit model was the one that included only a main effect for maternal tick load (Table 3.3).

I modeled the probability of having a calf-at-heel during captures in January-February as a function of winter tick load (ticks/cm) of 91 moose from which we obtained 163 calf-at-heel measurements from captures in January 2017-2019. The probability of a calf-at-heel decreased as the ticks/cm increased (Figure 3.10) The best-fit model with the lowest AICc included tick loads (ticks/cm) and rump fat (mm) (Table 3.3). The probability of a calf-at-heel decreased as the ticks/cm increased (Figure 3.10).

Table 3.1 AICc comparison of the best fit model for pregnancy of female moose from the North Slope and Wasatch study areas.

				AICc Comparison for Pregnancy				
Response Variable	**#_constants**	**#_covariates**	**K**	**LogLike**	**AICc**	**ΔAICc**	**exp(-0.5*Δ)**	**Wi**
Ticks/cm x Rump fat (mm)	2	3	5	-79.730	169.851	0	1	0.920
Rump Fat (mm)	2	1	3	-85.024	176.203	6.352	0.042	0.038
Ticks/cm, Rump fat (mm)	2	2	4	-84.538	177.337	7.490	0.024	0.022
Ticks/cm	2	1	3	-94.384	194.923	25.072	0.000	0.000

Table 3.2 Parameter estimates for the best-performing mixed effects logistic regression model predicting reproductive rates as a function of winter ticks/cm, rump fat (mm) and the interaction of winter ticks/cm and rump fat (mm).for a moose population sampled in northern Utah in 2017, 2018 and 2019.

Response Variable	**Parameter**	**Estimate**	***SE***	***z***	***P***	**95% Lower**	**95% Upper**
Pregnancy	Ticks/cm	0.160	0.258	0.62	0.534	-0.345	0.667
	Rump fat (mm)	1.12	0.370	3.03	0.002	0.395	1.84
	Ticks/cm × rump fat (mm)	-0.962	0.335	-2.87	0.004	-1.62	-0.305
	Intercept	1.34	0.330	4.07	0.000	0.670	1.99
Parturition (Calf-at-heel in May-June)	Ticks/cm	-2.02	1.00	-2.02	0.044	-3.99	-0.059
	Rump fat (mm)	2.18	1.05	2.07	0.038	0.120	4.24
	Ticks/cm × rump fat (mm)	2.46	1.30	1.89	0.059	-0.090	5.01
	Intercept	0.518	0.642	0.81	0.420	-0.741	1.78

Table 3.3 AICc comparison of the best fit model for parturition of the North Slope and Wasatch study areas.

				AICc Comparison for Parturition				
Response Variable	**#_constants**	**#_covariates**	**K**	**LogLike**	**AICc**	**ΔAICc**	**exp(-0.5*Δ)**	**Wi**
Ticks/cm x Rump fat (mm)	2	3	5	-53.699	118.005	0	1	0.723
Ticks/cm, Rump fat (mm)	2	2	4	-57.080	122.561	4.557	0.102	0.074
Ticks/cm	2	1	3	-60.718	127.674	9.670	0.008	0.009
Rump fat (mm)	2	1	3	-59.345	124.928	6.924	0.031	0.023

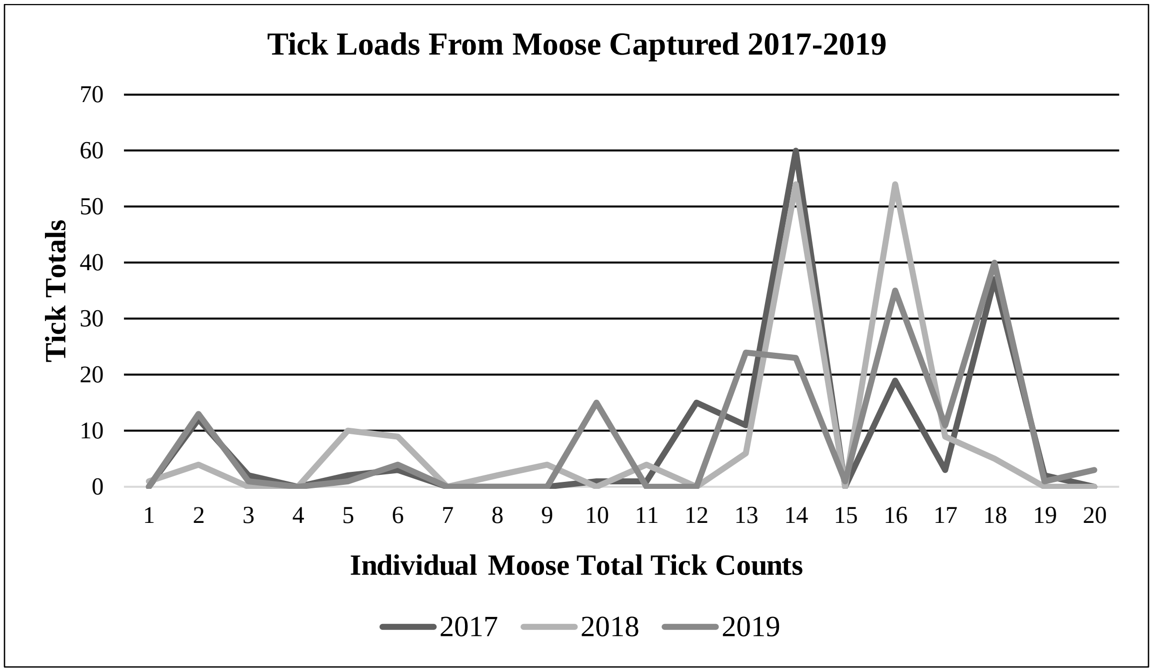

Figure 3.1 Tick loads from twenty individual moose that we captured and measured all three years of the study in 2017-2019. This graph shows overall tick counts from the eight-10cm transects. It shows how total tick counts from the eight-10cm transects fluctuated each year for these moose that were captured for 3 consecutive years.

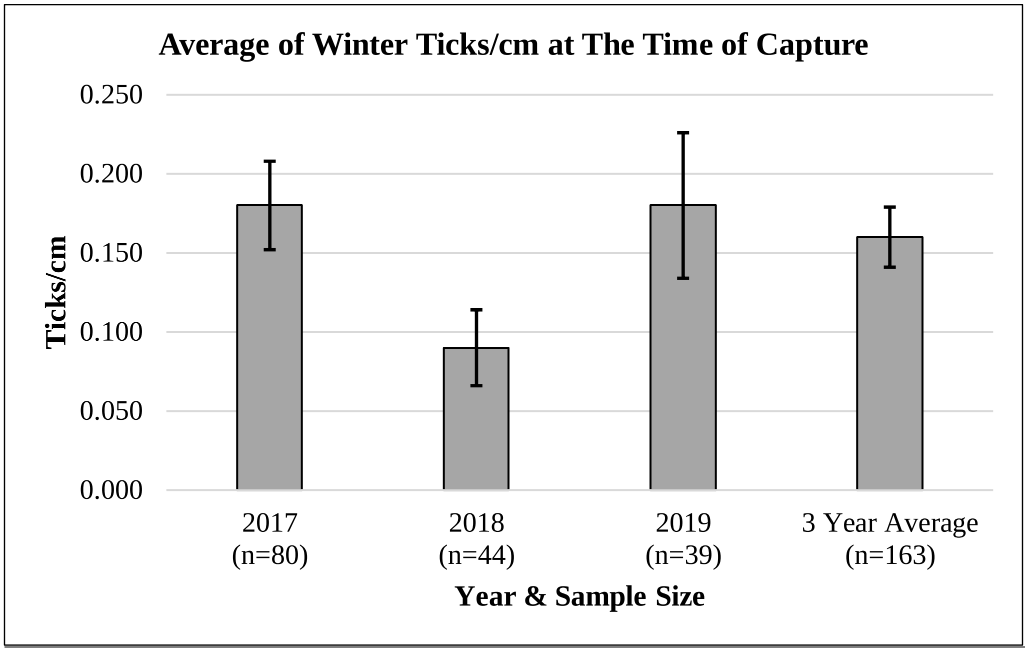

Figure 3.2 Average number of winter ticks/cm ± SE of adult female moose at the time of capture in January 2017-2019 and the three-year average. Sample size represents the total number moose that we measured eight-10cm transects. From these eight transects we calculated the average ticks/cm per year.

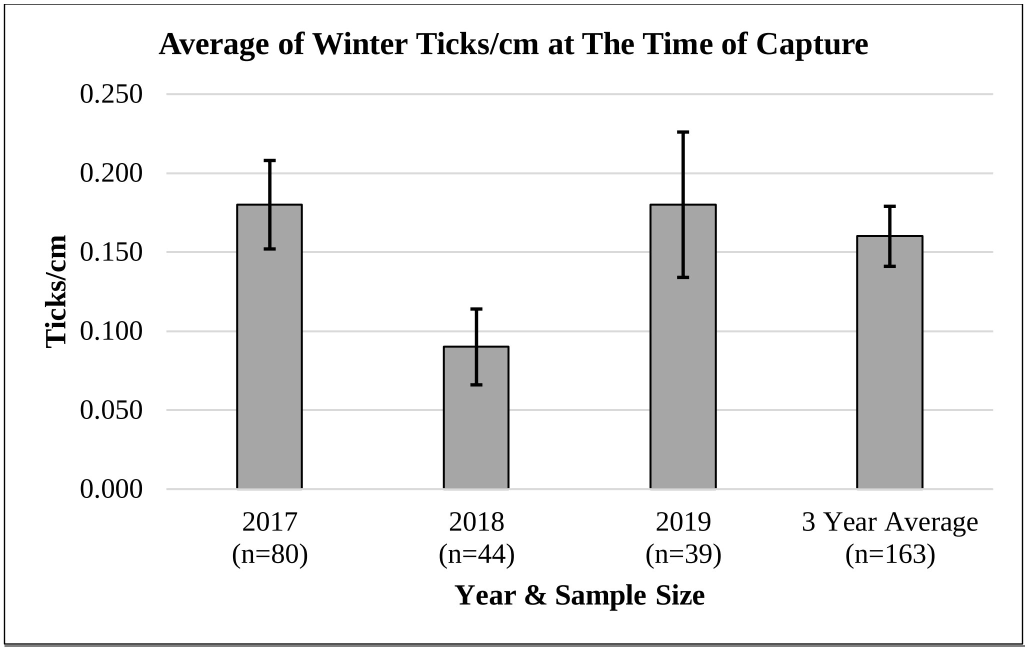

Figure 3.3 Average rump fat (mm) ± SE per adult female moose at the time of capture in January 2017-2019 and the three-year average. Sample size represents the total number of moose that were measured for rump fat (mm) per year.

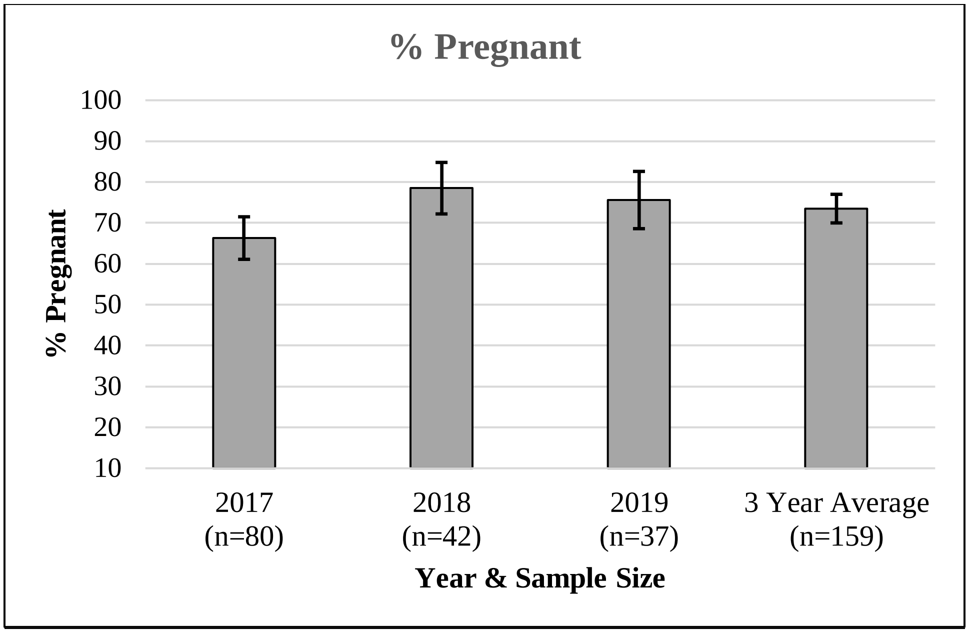

Figure 3.4 Percentage ± SE of pregnant adult female moose that tested pregnant at the time of captures. Determined by the pregnancy-specific protein B (PSPB) in January 2017, 2018, 2019 and the three-year average. Sample size represents the number of measurements for pregnancy.

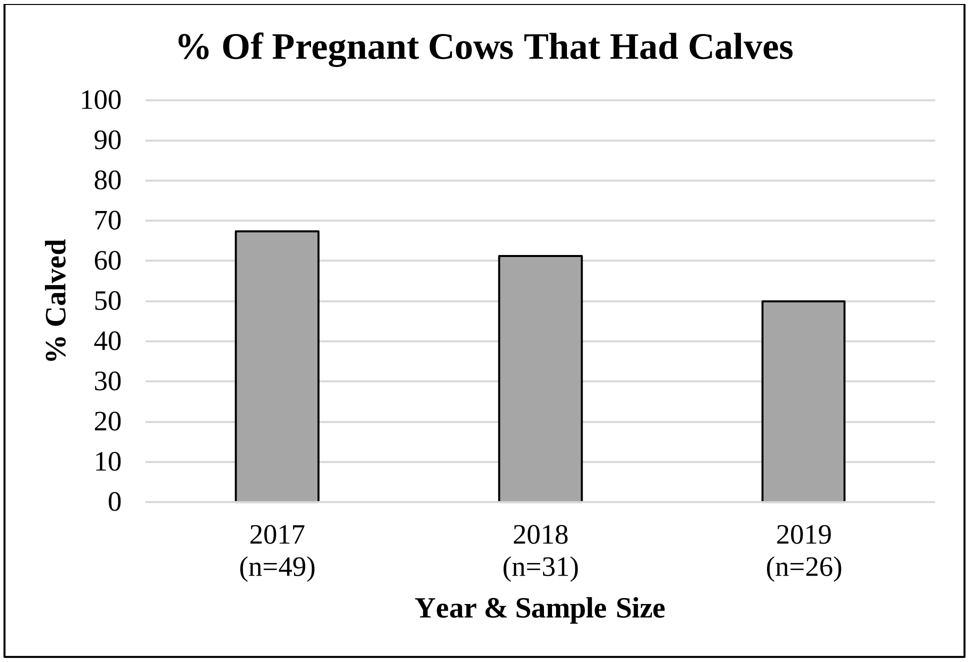

Figure 3.5 Percentage of calves born to adult female moose who tested pregnant at the time of captures. May-June 2017-2019. Sample size is how many individual moose tested pregnant per year.

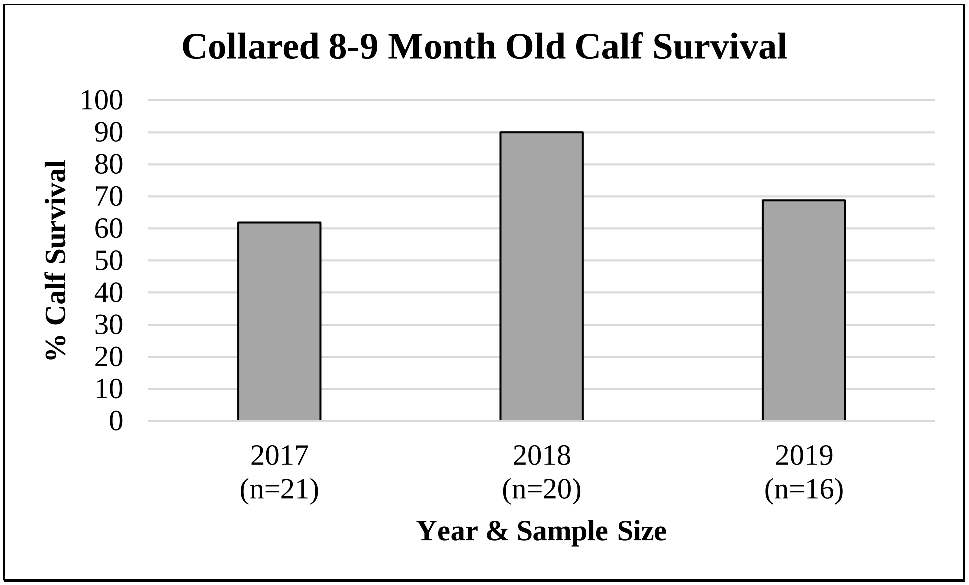

Figure 3.6 Percentage of 8–9-month-old calves that were captured, collared, and survived their first year of life (June 1st).

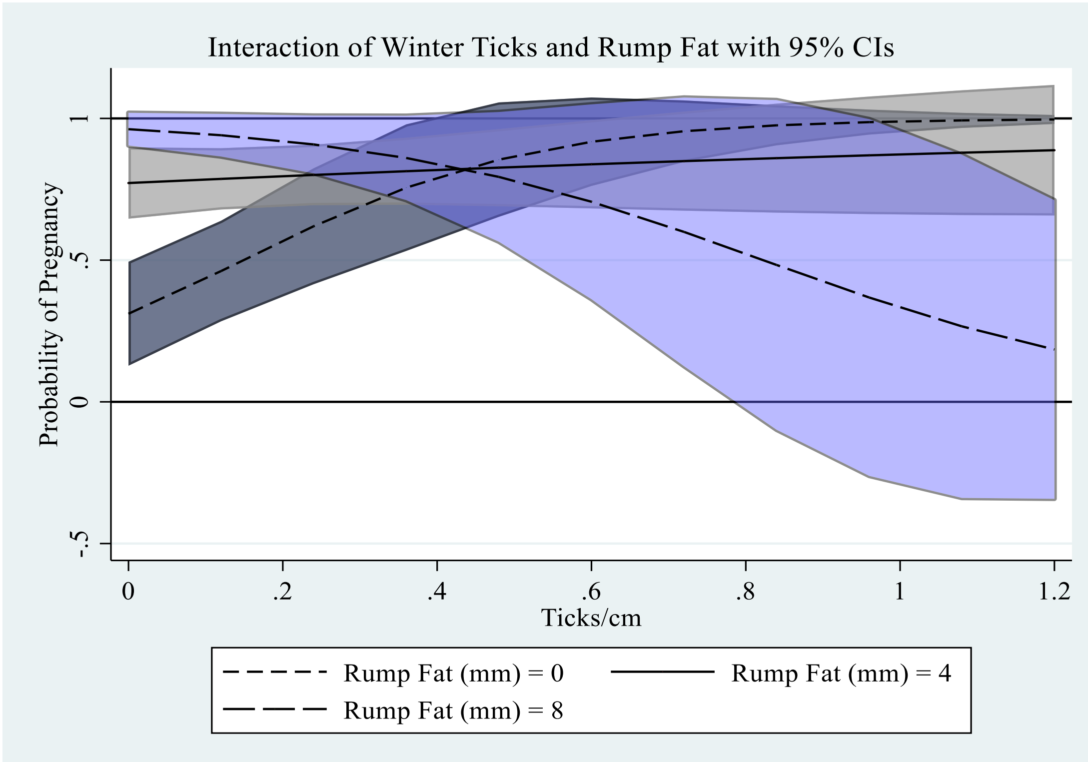

Figure3.1 Probability of pregnancy given ticks/cm and rump fat of 0, 4 and 8 mm.

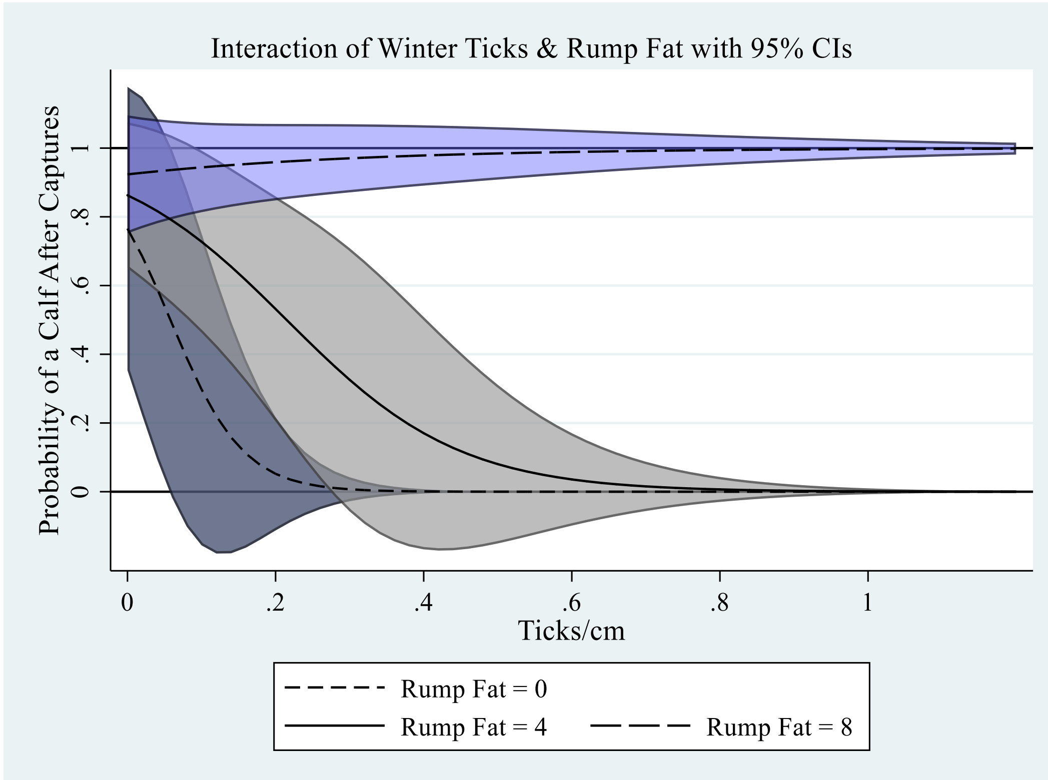

Figure 3.2 Probability of parturition (calf-at-heel in May-June) versus ticks/cm for rump fat measurements of 0, 4 and 8 mm.

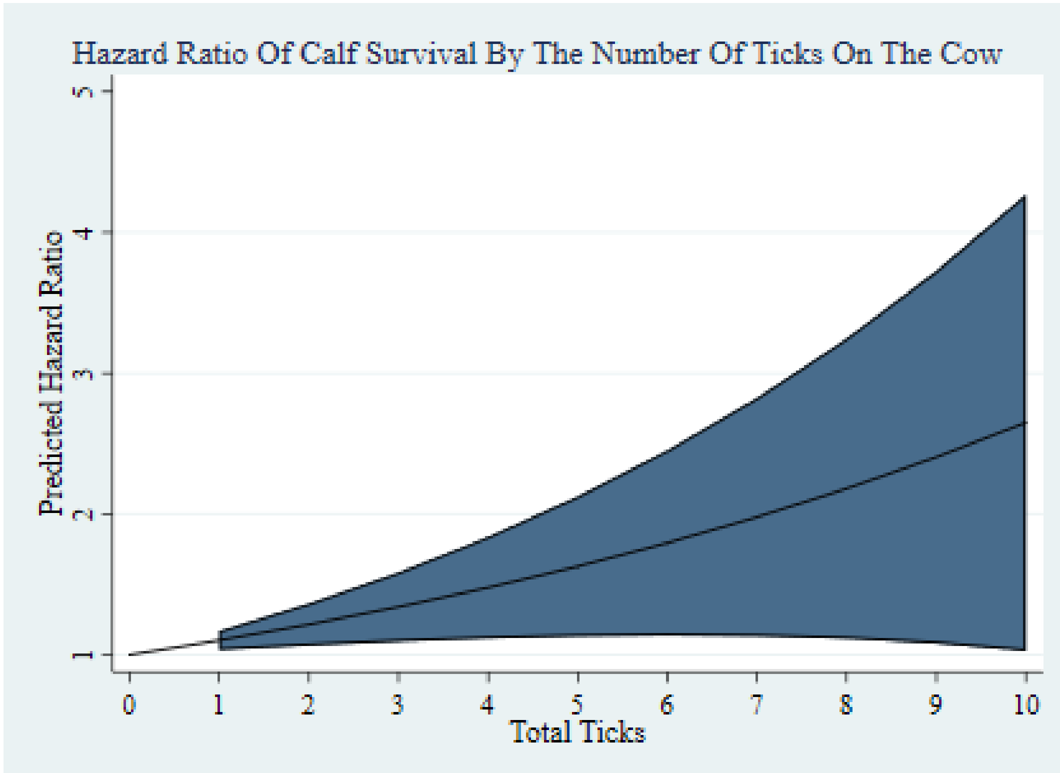

Figure 3.3 Hazard ratio of calf survival when compared to the number of ticks measured from the eight-10cm transects on the cow. The graph indicates that an increase of measured ticks on a cow decreases its calf survival.

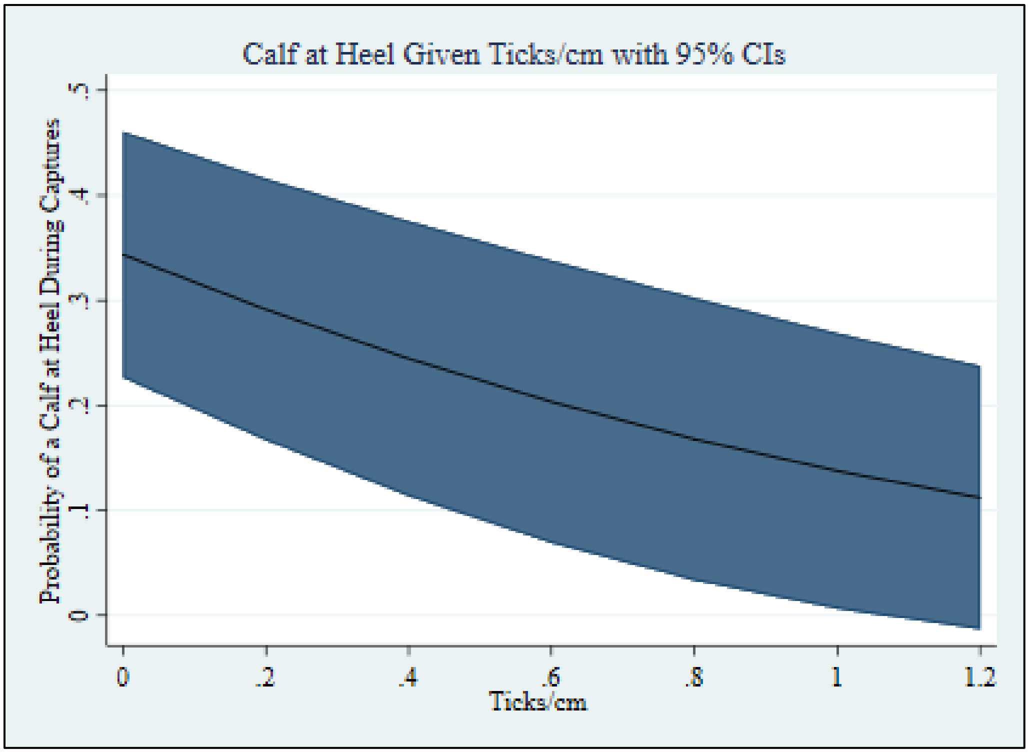

Figure 3.4 The probability an adult female moose had a calf-at-heel at the time of capture in mid-winter decreased as the female's tick load (ticks/cm) increased.

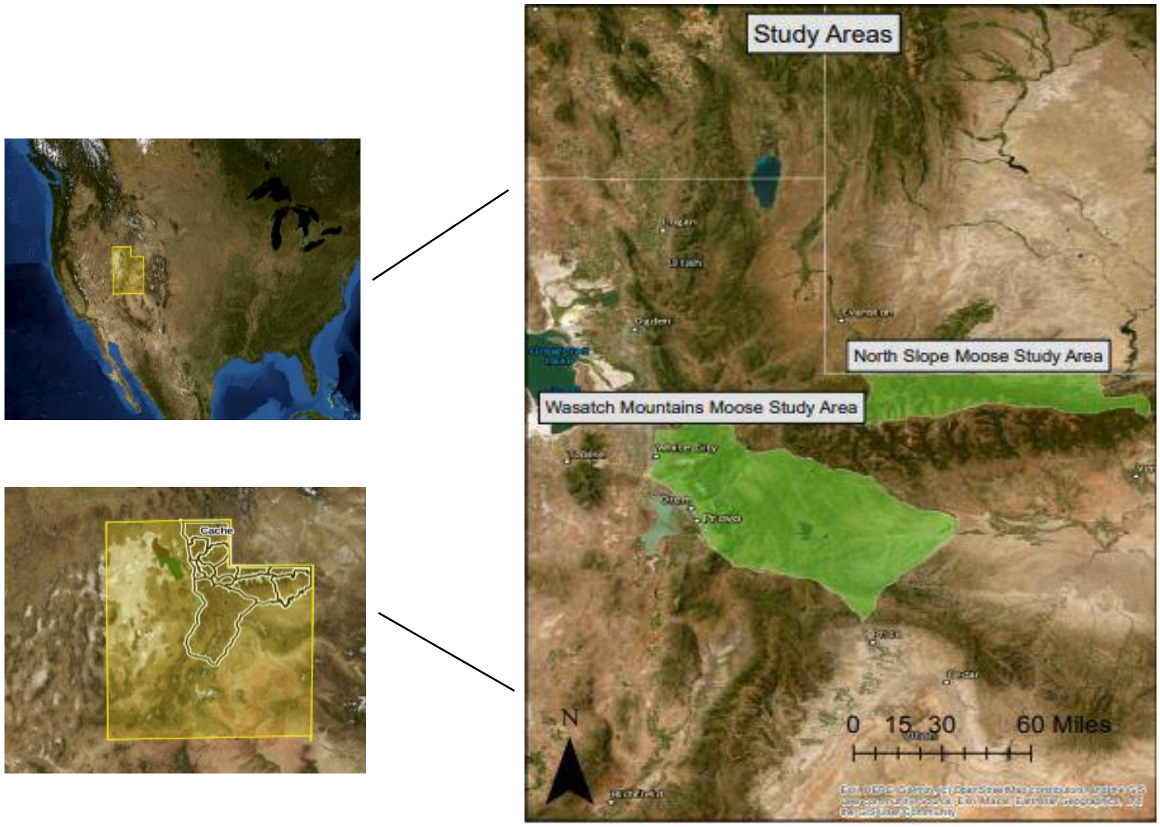

Figure 3.11 The areas represent the two study areas, North Slope and Wasatch moose management areas in northeastern Utah, USA.

CHAPTER 4

DISCUSSION

Productivity of moose is dependent on cow and calf nutritional condition, and this can dictate the number of calves that are recruited into the population (Jones et al. 2017). Populations with high reproductive success tend to be more resilient to mortality factors, which is why we give consideration to reproductive success in our study (Jones et al. 2017). Reproductive success in Shiras moose and other moose subspecies is related to maternal fat stores (Heard et al. 1997; Testa and Adams 1998; Keech et al. 2000; White et al. 2014). We know from previous work with moose from Utah that rump fat levels are critical in determining the reproductive success of moose (Ruprecht et al. 2016). It has been more difficult to assess how winter ticks effect Shiras moose reproduction until recently.

Winter ticks are known to cause declines in moose populations by causing high mortality rates in calf moose and they can also cause long term effects by reducing adult cow body condition and overall productivity (Musante et al 2010, Bergeron et al. 2013, Jones et al. 2019). Moose body condition is relative to season; moose often experience a negative energy balance during winter and often suffer weight loss even when they are in optimal habitat (Schwartz and Renecker 2007, Jones et al. 2017). Moose gestational and early lactational costs often occur in early spring before green up, so it is critical that female moose try to limit weight loss to optimize production (Jones et al. 2017). Reduced cow body condition from blood loss, irritation and reduced feeding caused by winter ticks may result in lower fertility, delayed age of first reproduction, lower calving, and twinning rates (Musante et al. 2010); all of these factors have been observed during this study (Appendix 1).

Key findings

Our results indicate that the probability of a cow moose becoming pregnant increased as winter tick load increases, as long as the rump fat remains below 8 mm; at rump fat levels over 8 mm, higher tick loads had a negative impact on pregnancy. These are non-intuitive results with several possible explanations. The first is measuring winter tick loads the same year as conception is too late to determine if winter tick loads will impact pregnancy. This is because winter ticks are accumulated at the same time female moose conceive, which means the winter tick loads a moose accumulates at the same time as conceiving have not had time to have any impact on that cow. Therefore, the tick loads we measured at the time of capture could not impact a cow's ability to get pregnant. It could however influence its ability to remain pregnant. This does not mean that moose that are repeatedly exposed to high tick loads year after year do not experience long term health problems like disease that can have implications on the ability of a moose to become pregnant (Musante 2010).

The next explanation may lie in the difference of our two study areas which we combined to increase sample size. Moose in the Wasatch area had much higher pregnancy rates than moose in the North Slope area (Table 4.1). The Wasatch moose also had much higher tick loads than the North Slope, which may indicate that pregnancy rates on the Wasatch are not likely affected by the interaction of tick load and rump fat; this could suggest that winter ticks do not affect pregnancy rates, but rump fat likely does as was found by Ruprecht et al. (2016). With most of the moose on the Wasatch testing pregnant with all levels of winter tick loads and rump fat measurements vs. the North Slope where rump fat measurements were similar to Wasatch, but both winter tick loads and pregnancy rates were lower. I do believe this non-intuitive effect does come down to me combining the two areas and the difference in tick loads and pregnancy rates between the two areas (Table 4.1). My results are from a small sample size and a small window in time. I suspect that some moose in the study area that have been exposed to high tick loads year after year are seeing negative effects on pregnancy rates from winter ticks, but the sample size is too small to make this conclusion at this time. This is something that needs to be studied more in the future.

It has been suggested that moose can still conceive even with poor body condition, but they may terminate pregnancies if winter conditions become too strenuous for survival (Milner et al. 2013). We estimated 38.6% of cows that tested pregnant over the 3 years (2017-2019) did not have a calf at heel in May-June when surveyed. The large discrepancy between pregnancy rates and parturition rates suggests that some of these moose births were not detected or possibly had in-utero fetal losses occur. Body condition is often cited as an important factor affecting moose parturition (Ruprecht et al. 2016). Our results show that body condition with respect to rump fat is critical, but it does not tell the whole story. Parasites like winter ticks likely add to the degradation of body condition, and poor body condition can be limiting when it comes to a female moose producing a calf. Our study results suggest that winter ticks are having negative effects on a cow moose's ability to produce a calf. The moose with lower rump fat measurements are more likely to be affected by winter ticks and thus reducing the likelihood of producing a calf and cow moose with higher levels of rump fat are more likely to overcome tick loads that have been recorded in Utah and the likelihood of having a calf increases. This is significant in Utah because 49% of the moose for which we recorded rump fat from this study and the previous study have had < 4 mm of rump fat. (Figure 4.1). There is still some uncertainty to these results given that the 95% CI for the coefficient describing the interaction overlaps 0, (Table 3.1)

My results suggest that winter tick loads on adult female moose likely have a significant impact on whether their calf that was born the summer before captures survived its first year. Even though my results suggest this, I believe this result would be even more significant if we could have collared moose calves when they were first born, instead of collaring 8–9-month-old calves. Like the results on parturition suggest, the interaction of winter ticks and rump fat have a negative impact on calf production. This interaction also has an impact on a cow moose's ability to have a calf at the time captures took place. My analysis on calf survival is missing that critical period when calves are first born. This is likely the time when winter ticks are having the most impact on cows, while they are lactating or in the last stage of gestation. We observed still born calves while surveying cows for calves, which could have been due to high tick loads on the cow. It was observed that adult female moose that were captured in the areas of these stillborn calves had high tick loads. Without having collars on the calves shortly after birth it makes it difficult to assess this. It has also been observed in Utah that calf moose with higher tick loads die and it is believed that winter ticks were part of the cause if not the entire cause. The problem is we do not have a lot of cows with high tick loads producing calves, which makes it difficult to look at calf survival and tick loads. This fits into my results that winter ticks are influencing a cow moose ability to have a calf, moose with higher tick loads are less likely to produce a calf. We believe if our adult cow moose had good body condition with high amounts of rump fat. They would still be able to produce calves even with higher tick loads which would allow us to see a stronger association with tick loads and calf survival like has been found in other studies in the northeast (Musante et al. 2010, Bergeron et al. 2013 and Jones et al. 2017). The calf at heel result that we observed during this study suggests captured adult cow moose that had a calf at the time of captures in January were also the moose that had lower tick loads (Figure 3.10). The average tick load on cows without a calf was 0.22 ticks/cm compared to those with a calf at 0.06 ticks/cm. This finding of ticks/cm having an impact on the probability of a cow having a calf at the time of capture is good supporting evidence that aligns with our findings that ticks influence calf production. With this observation I make the assumption that moose likely have similar tick loads year after year due to their strong site fidelity (Morrison et al. 2021).

Many moose populations are currently declining at their southern range in North America, including in Minnesota, Manitoba, Novia Scotia, Vermont, New York, New Hampshire, Wyoming, and Montana (Brimeyer and Thomas 2004, Harris et al. 2015, Monteith et al. 2015, DeCesare et al. 2016, Jones et al. 2017, Nadeau et al. 2017). The cause of the declines varies but, in many cases, it has been associated with a warming climate that can have an indirect influence by increasing parasites and diseases (Jones et al. 2017). As the climate warms in the intermountain west the is predicted to switch from snow to rain which will reduce spring snowpack (Safeeq et al. 2016). If the springtime snowpack is reduced winter ticks will likely increase if hosts are available. Snow cover in early spring reduces the survival and reproduction of winter ticks; this is because when winter ticks fall off a host in early spring and fall onto snow their survival and reproduction is reduced. This is because winter ticks are susceptible to cold temperatures (Samuel 2007, Ruprecht et al. 2020). Also, if springtime snowpack is reduced it could lead to summertime forage being diminished and less plentiful. This could cause moose to have reduced rump fat the next fall and leave them more susceptible to the negative effects of winter ticks.

My results suggest winter ticks are impacting Utah moose populations by negatively influencing certain aspects of reproduction. Our results show Winter ticks are having negative effects on calf production and calf survival. Other studies that have found negative impacts from winter ticks have found they are causing high calf mortality. My study is one of the first to show winter ticks are likely having a negative impact on calf production. This could be because moose in Utah live in sub optimal habitats and have reduced body condition compared to other moose populations. Because moose in Utah live at the southern extent of the moose range where winters are milder than further north means moose in Utah can have reduced body conditions (lower rump fat) and still survive. This reduced body condition could be the reason we see the impacts of winter ticks on calf production instead of calf survival. If Utah moose were in better shape, we would likely see more calf production, but we would also see reduced calf survival due to winter ticks, as has been found in other moose populations at their southern edge.

Table 4.1 Hazard ratio estimated from a Cox proportional hazard model of calf survival describing the effect of maternal moose tick load on calf mortality risk. For each additional tick on a cow moose at the time of capture in mid-winter, the mortality risk of its radio-collared calf at any time following capture increased by 10% (95% confidence interval = 4-17%).

Hazard	**Hazard Ratio**	**Standard Error**	**z**	**P>|z|**	**95% Conf. Interval**	
Total # Ticks on Cows	1.102	.034	3.12	0.002	1.037	1.172

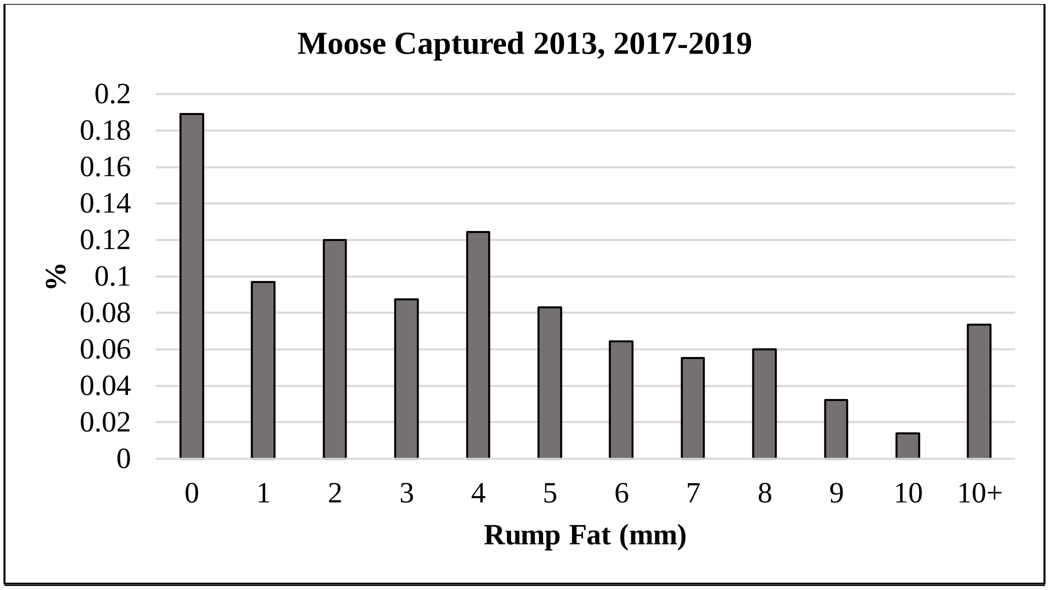

Figure 4.5 Percentage of moose that measured a certain amount of rump fat 2013, and 2017-2019.

CHAPTER 5

CONCLUSION

This thesis advances understanding of moose reproductive rates and the factors that affect them in Utah. It provides a better understanding of how body condition and winter tick loads affect reproduction. Although the effects of winter ticks on moose have been studied in detail across much of their distribution. Most of the research to date has focused on the effects of winter ticks on calf survival. In this study, I investigated the impacts of winter ticks and maternal body condition on the reproductive success of female moose. This research focused on the understudied Shiras subspecies, which has received limited attention regarding winter ticks as a potential constraint on population growth. I hope that this research will provide valuable insights for wildlife managers in Utah, enabling them to effectively manage moose populations across the state.

Results of this study will provide Utah wildlife managers and moose managers across the western US a better understanding of several factors that limit moose reproduction in Shiras moose. This study also points out the importance of understanding the implications of a changing climate and its potential impacts on species at their southern range limit, whether through direct climate change effects or climate-mediated effects like increased parasite loads. Consequently, managers will not need to monitor not only moose numbers but also short-term and long-term weather patterns.

The results of this thesis indicate that winter ticks reduce the reproductive success of moose in Utah by limiting calf production and calf survival. This thesis also shows that moose can potentially mitigate the reproductive cost of a heavy tick load by maintaining high levels of rump fat. Recognizing the critical role of habitat in maintaining healthy moose populations, managers should consider habitat treatments tailored specifically for moose conservation. Although managers cannot control the weather, which has a direct impact on winter tick survival, they do have control on how to improve habitat through habitat projects.

Management implications

Utah's moose population is fairly stable at the time of this writing. However, with the possible proliferation of winter ticks induced by climate change, my study suggests that winter ticks will likely impact the health and reproduction of the moose populations in the future. Should the snowpack in Utah continue to form later and melt earlier, it could provide a longer window for winter ticks to reproduce, potentially leading to exponential population growth. One management practice that could be implemented to minimize the impact of ticks on moose population growth is to increase moose harvest and reduce moose density. Reducing moose densities would reduce the number of hosts for winter ticks and possibly reduce the number of winter ticks on the landscape. A potential problem with this approach is that moose in Utah share habitats with high densities of mule deer and elk. So, if managers reduce moose densities it is possible that winter ticks could still survive and reproduce at high densities if they use the other ungulates as hosts. It is known that ticks use these other hosts, but the degree of use is unknown. The combination of reduced calving and calf survival could have detrimental effects on Utah's moose population and ultimately change how moose are managed. One unique aspect about moose in the western United States is they live in a mountainous environmental and therefore have the option to move to higher elevations. By doing so, they may minimize exposure to winter ticks by staying up higher where snow comes earlier and persists longer. It is therefore possible that higher elevations could serve as a type of refuge from winter ticks for moose. This is unknown and could be the next phase of assessing the impacts of winter ticks on Utah moose.

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Appendix

Utah Moose Study Final Report, 2013-2019

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SUMMARY OF RESEARCH CONDUCTED 2013-2019

- Moose captures were conducted in 2013 and 2017-2019. In Jan-Feb. 2013, 120 adult females were captured 60 on the North Slope and 60 on the Wasatch. Each moose was fitted with a VHF radio collar. In January 2017 we captured 108 moose. 40 adult females and 16-8-month-old calves (13 females and 3 males) were captured on the North Slope and 40 adult females, and 12-8-month-old calves (9 females and 3 males) were captured on the Wasatch study site. These moose were fitted with Lotek GPS collars. In 2018 we captured 44 adult females and 23 calves, 22 adult females along with 12-8-month-old calves (4 females and 8 males) were captured on the North Slope and 22 adult females and 11-8-month-old calves (5 females and 6 males) were captured on the Wasatch. Of the 44 adult females captured 42 of them were recaptures from the 2017 captures. In 2019 we captured 39 adult females and 17 calves; 19 adult females and 8-8-month-old calves (6 females and 2 males) were captured on the North Slope and 20 adult females, and 9-8-month-old calves (6 females and 3 males) were captured on the Wasatch. All the adults in 2019 were recaptures that had previously been captured in 2013, 2017 and 2018.
- Recaptures have been conducted in 2018 & 2019 to look at how tick loads and body condition vary from year to year under different climatic conditions. The winter conditions during 2015-16 and 2017-18 were different from the winter conditions in 2016-17 and 2018-19. Snowpack was significantly higher in the winter of 2016-17 and 2018-19 vs. that of 2015-16 and 2017-18. The snowpack in 2017-18 was one of the worst in recent history. Because of these different conditions it allowed for researchers to compare tick loads and body conditions of moose during captures following four different climatic years.
- Data collected included blood samples for pregnancy tests, and mineral analysis. Fecal pellets were collected for analysis of parasite loads. Hair was collected for future DNA analysis. Body condition scores (BCS) were assessed through palpation. Rump fat and loin thickness were measured using an ultrasound machine. Also starting in 2017 tick loads were measured to assess winter tick abundance as well as an anemia analysis to check for blood loss. All samples and measurements collected provided an overall health assessment for each moose.
- Starting 2017 calves captured were given the same health assessment as adults minus the body condition scores and ultrasound of rump fat and loin thickness. They were also collared with ATS, GPS collars to obtain survival estimates, calf recruitment and cause of mortality. The bull calf collars are designed to expand and release (breakoff) after several months. The cow calf collars are fitted with an expandable insert developed by ATS that allows the collar to expand as the cow calf grows allowing the collar to remain on for several years. This allows researchers to gather the data needed and to ensure the safety of the animal as it continues to grow past 1 year of age.
- In May and June of each year ground searches of all radio & GPS-collared cow moose were conducted to estimate calving rates.

- From 2013-2019 every functioning collared moose was monitored year-round from the ground, air, and GPS collars to document their survival rates.
- All mortalities were necropsied to determine cause of death and all viable tissue samples were delivered to the Utah State University veterinary diagnostic lab for examination. The incisors of all adult mortalities were sent to the lab for aging.
- Data collected during 2013-2019 was utilized to calculate annual survival rates of female adults and calves and to estimate calving rates, twinning rates, and calf recruitment. Data collected was also used to develop and further quantify analyses of the effects of winter ticks on reproduction and recruitment. This data will also help in constructing a model to predict population estimates going forward.

STATUS OF RADIOCOLLARS

At the end of December 2019, there were 4 functional VHF radio-collars being monitored and 41 GPS collars (26-Wasatch, 20-North Slope) for a total of 45 monitored moose. 3 Wasatch cows and 1 North Slope cow that had VHF collars from 2013 were recaptured and released with GPS collars in January of 2019. All the Lotek GPS collars that were deployed in Jan-Feb. 2017 had quit working and transmitting locations by the beginning of 2019 (10-Wasatch, 12-North Slope). Therefore, all recaptured adult females in 2019 had their Lotek GPS collars replaced with ATS GPS collars this helped us from losing contact with most of the collared moose. There are 2 calves that were collared in Jan. 2018 still on air and have been monitored in 2019 as adults. Most of the bull calf GPS collars have been released and have been retrieved; 1 calf GPS collar, on the Wasatch, malfunctioned (quit transmitting signals) and likely released, but unfortunately, we were not able to retrieve it. There were 7 calf collars still on air and working at the end of 2019. 6 calves are females, and 1 calf is a male and will likely drop his collar any day. These 7 calves are considered adults now and will be monitored as such in the following year.

BODY CONDITION

The body condition of each moose captured in 2013, 17 18 & 19 was assessed by measuring rump fat, and loin thickness using ultrasonography. Rump fat is a good indicator of overall ingesta-free body fat in moose (Stephenson et al. 1998). It is also important for a female moose to become pregnant and produce young (Ruprecht et al. 2016). Rump fat depths in 2013 ranged from 0 to 21mm, with a mean maximum rump fat depth of 4.47 mm (n=51). 17 of 51 moose (33%) had a rump fat depth of zero (Figure 1). Rump fat depths in 2013 between the Wasatch and North Slope herds were very similar (Figure 2).   Rump fat depths in 2017 ranged from 0 to 12mm (Figure 3). In 2017 both units combined had a mean maximum rump fat depth of 4.08 mm (n=80). In 2017 both units once again had similar rump fat (Figure 4). The rump fat in 2018 ranged from 0 to 17mm (Figure 5). The rump fat in 2018 was higher with a mean maximum rump fat depth of 5.11 mm (n=44). The Wasatch had higher rump fat than the North Slope in 2018 (Figure 6). Rump fat depths in 2019 ranged from 0 to 7mm (Figure 7). Rump fat depths in 2019 were the lowest measured during the study with a mean rump fat depth of 2.3 mm (n=39). The North Slope had slightly higher rump fat in 2019 but both units were down from previous years (Figure 8). The lower rump fat could be due to the historically dry year in 2018 which could have limited the quality and quantity of food available.

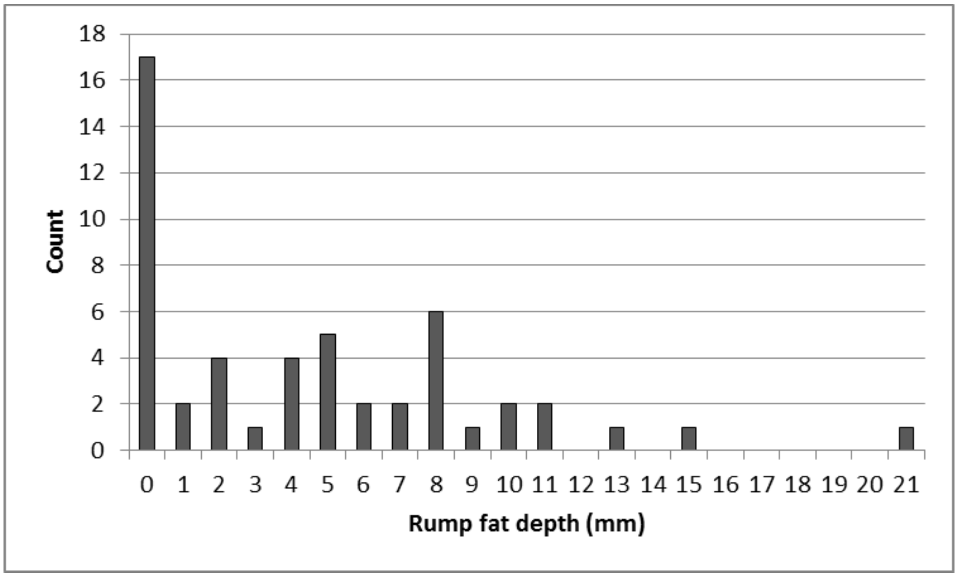

Figure 1: Histogram of rump fat depths in both units, 2013 (n=51) (Ruprecht 15).

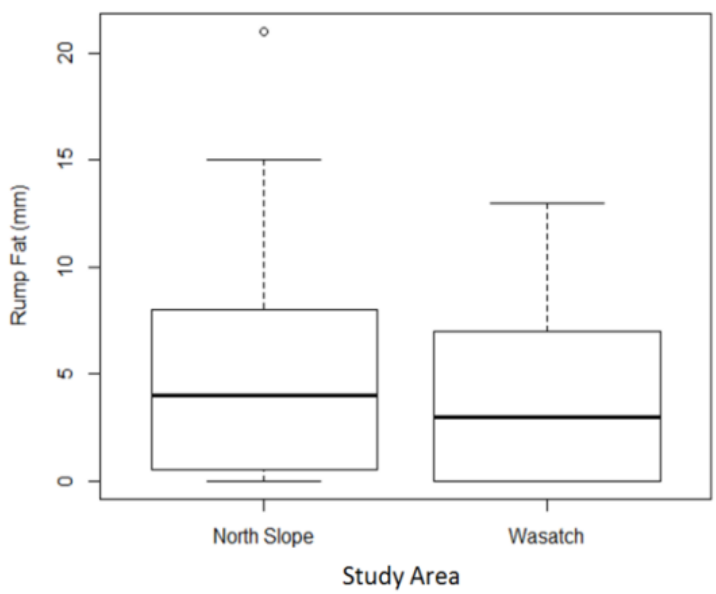

Figure 2: Moose winter rump fat depths in 2013 measured using ultrasonography (n=51) (Ruprecht 15).

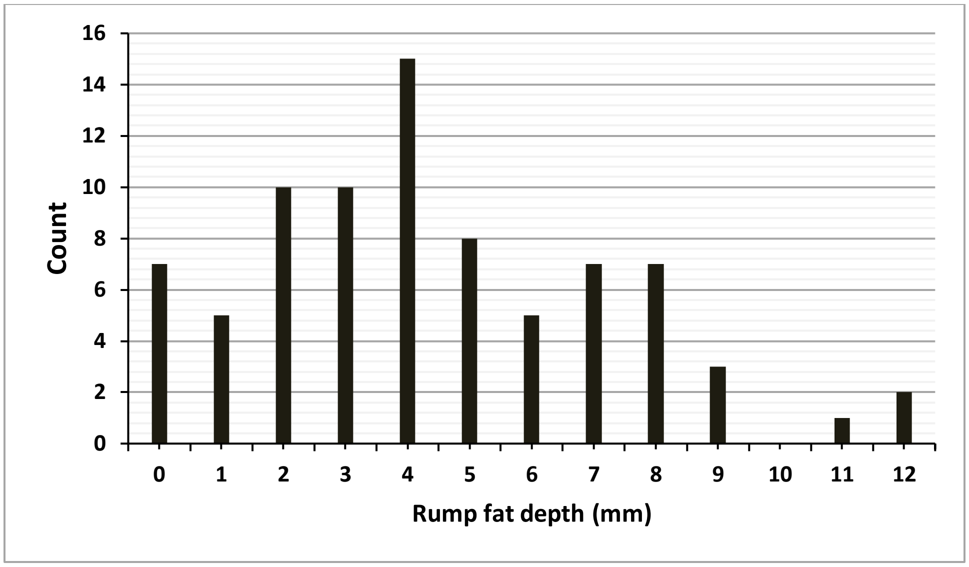

Figure 3: Histogram of rump fat depths in both units, 2017 (n=80)

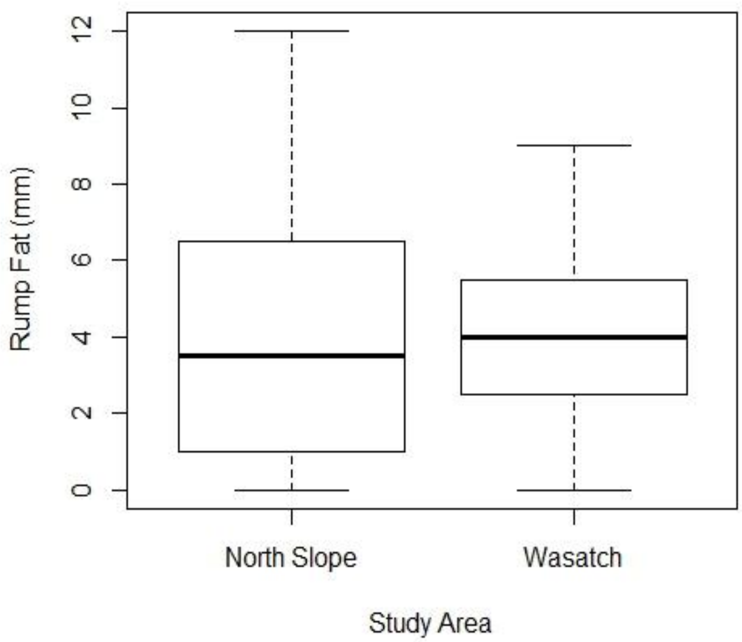

Figure 4: Moose winter rump fat depths in 2017 measured using ultrasonography (n=80).

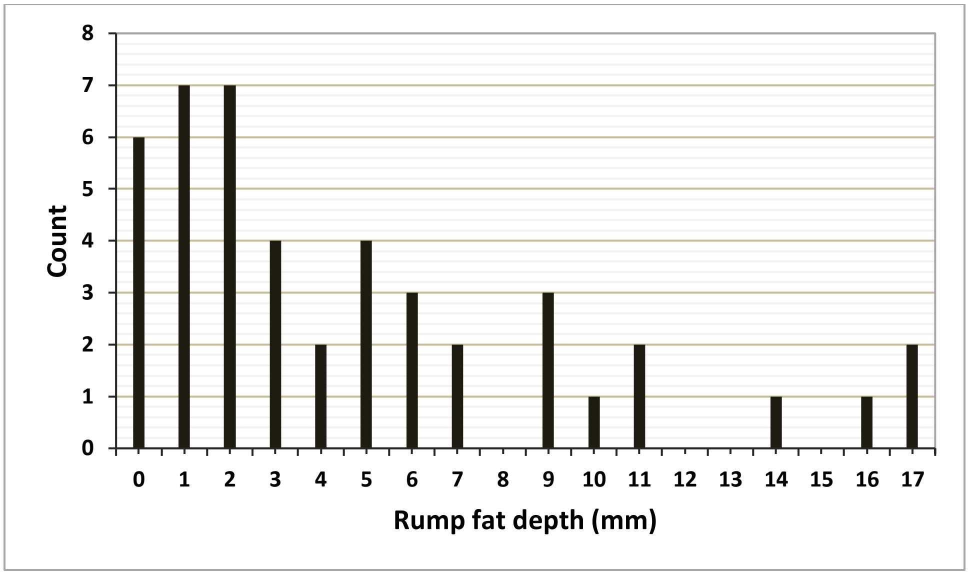

Figure 5: Histogram of rump fat depths in both units, 2018 (n=44)

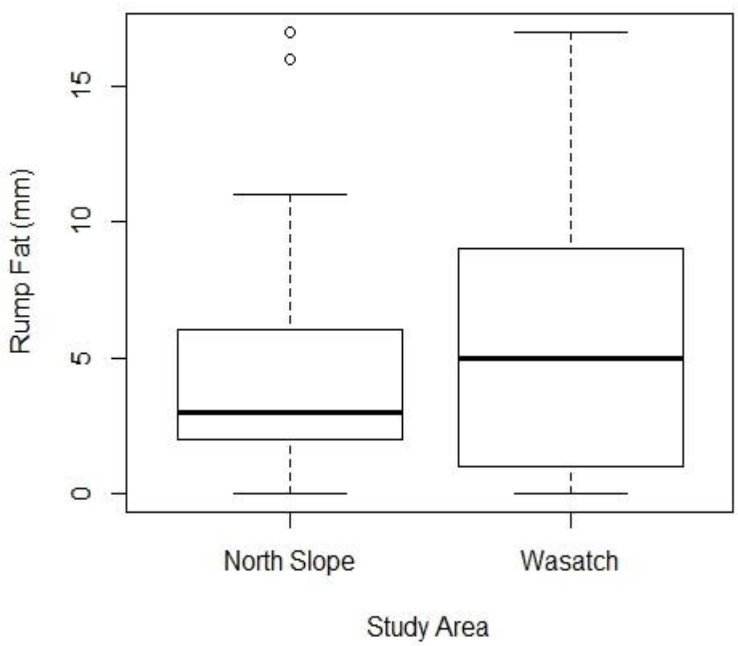

Figure 6: Moose winter rump fat depths in 2018 measured using ultrasonography (n=44).

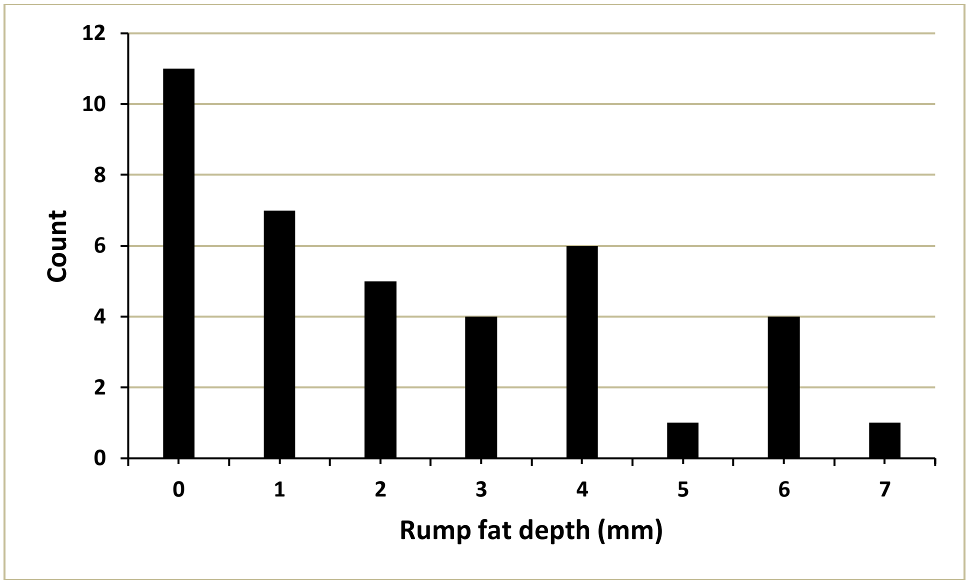

Figure 7: Histogram of rump fat depths in both units, 2019 (n=39)

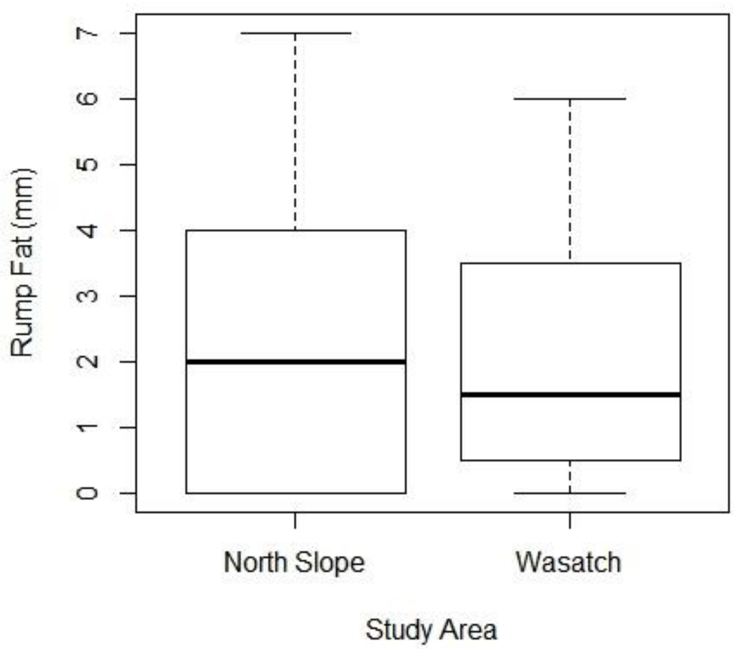

Figure 8: Moose winter rump fat depths in 2019 measured using ultrasonography (n=44).

PREGNANCY RATES

Blood was drawn during capture in 2013, 17, 18, and 19 to determine pregnancy using the standard Pregnancy-Specific Protein B (PSPB) assay. The pregnancy rates (Table 1) have changed each year in both areas. The Wasatch has increased each year and the North Slope dropped significantly in 2017 from 2013 but rebounded slightly in 2018 and 2019. This could be due to a shift in age distribution; we know that pregnancy is age-specific in our two study populations (Ruprecht et al. 2016). This means it could be the study population on the North Slope in 2017, 2018 and 2019 was older than the study population on the North Slope in 2013, which could be an explanation for the decreased pregnancy rates. It could also be due to a change in body conditions from 2013 to 2017, 2018 and 2019. It has been found that the amount of rump fat a cow moose has influences its likelihood of being pregnant (Ruprecht et al. 2016). An increase in rump fat on the Wasatch moose could be why there has been an increase in pregnancy rates in 2017 and 2018. While the decrease in pregnancy rates on both units in 2019 could be due to an older population along with reduced body condition from a historically dry year in 2018.

Table 1: Summary of pregnancy rates of captured moose, Utah 2013, 2017, 2018 and 2019

Year	*Area*	*# Sampled*	*# Pregnant*	*(%) Pregnant*
2013	North Slope	58	44	75.8
	Wasatch	56	41	73.2
	Total	114	85	74.6
2017	North Slope	40	17	42.5
	Wasatch	40	36	90.0
	Total	80	53	66.3
2018	North Slope	21	13	61.9
	Wasatch	21	20	95.2
	Total	42	33	78.5
2019	North Slope	18	12	66.7
	Wasatch	19	16	84.2
	Total	37	28	75.6

Age Specific Pregnancy

In this analysis we wanted to get an understanding of how age may influence pregnancy and overall pregnancy rates. All known aged moose from 2013-2019 were used in this analysis (n=95). From these 95 known aged moose we had 110 pregnancy results. Ages came from pulling the incisors and having them aged (Matson's Laboratory, Brigham Young University) some moose were also aged by the eruption of new teeth, most of these were yearlings and two-year-old moose. We used splined models in R to locate age specific thresholds in pregnancy, reproductive maturity, and senescence. This analysis shows that most Utah moose do not become pregnant until they reach 3 years of age, and they begin to senesce at 7 years of age (Figure 9).

This is important because if you have a majority of older or younger moose in your population, pregnancy rates may increase or decrease. It is known from previous research that body condition (rump fat) is also critical for a female moose to become pregnant (Ruprecht et al. 2016). It has also been found in other studies (Sand 1996; Heard et al. 1997; Ericsson et al. 2001) that maternal age was a critical determinant in moose pregnancy rates.

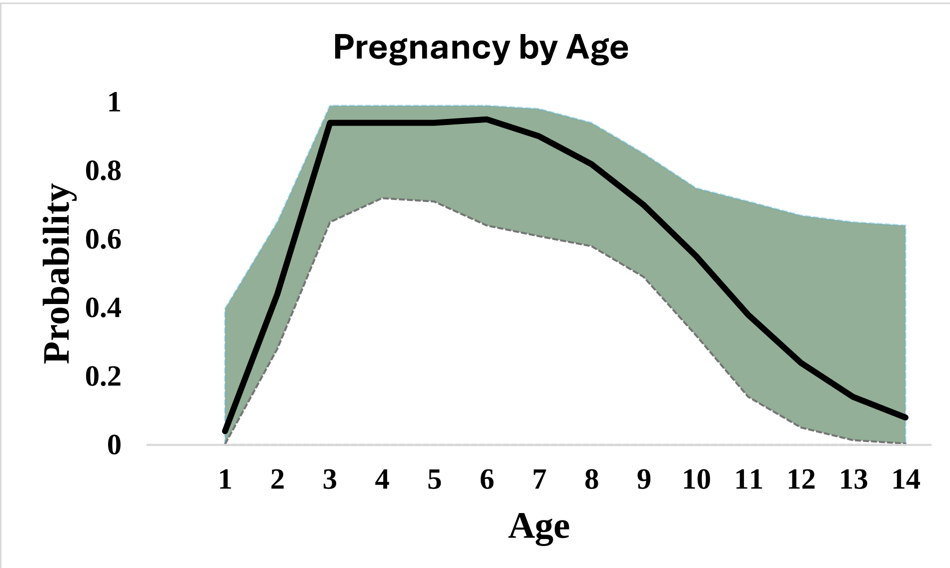

Figure 9: The probability of being pregnant at a certain age.

CALVING RATES

To determine calving rates (Table 2), we conducted calf searches on all radio-collared adult female moose during May-June 2013-2019. In 2016 we calculated calving rates two ways: first we calculated it using our traditional methods from ground calf surveys from May-June, and the second way it was calculated was by taking the number of cows that had calves during captures in 2017 and divided them by the number of cows who did not have calves (Table 2 *2016). All the calves that were captured in 2017, 2018 and 2019 were fitted with GPS collars. This was done so that those collared calves could be used to calculate the calf survival and recruitment with greater accuracy. There is a difference in the calving rates on the Wasatch in 2016 between surveyed calves and calves collared in Jan-Feb. 2017. This difference could be due to smaller sample size or possibly some portions of calves were lost before January. Because not all moose could be surveyed during the peak calving period, it is possible that some moose calves were born but died before surveys took place - these should be regarded as *minimum* calving rates. The calving rate on the North Slope is the lowest we have seen during the seven years of the study. This could be due to poor body condition which we observed while measuring rump fat during captures in January 2019. These poor body conditions could be from the extremely dry previous year and or an older cohort of moose. It could also be due to density issues. The Wasatch calving rate is also down, this also could be due to the reduced body condition we observed in 2019

(Figure 8). It also could be due to an increase in tick loads which are likely due to the lack of moisture in 2018. The mean calving date was June 3 (range: May 14–June 21).

Table 2: Summary of calving rates of radio collared moose, Utah 2013–2019.

Year	***Area***	***Calving Rate (%)***	***95% CI***	***N***
2013	North Slope	55.1	41.1–69.0	49
	Wasatch	33.3	20.0–46.6	48
	Total	44.3	34.7–53.9	97
2014	North Slope	42.4	25.5–59.2	33
	Wasatch	44.1	27.4–60.8	34
	Total	43.3	31.3–55.2	67
2015	North Slope	72.7	53.7–91.7	22
	Wasatch	52.0	32.0–72.0	25
	Total	61.7	47.7–75.7	47
2016	North Slope	50.0	21.7–78.3	12
	Wasatch	52.3	31.0–73.1	21
	Total	51.5	34.5–68.6	33
*2016	North Slope	45.0	30.0–60.0	38
	Wasatch	30.0	16.2–45.8	40
	Total	37.2	26.5–47.9	78
2017	North Slope	41.0	25.6–56.4	39
	Wasatch	61.3	46.9–75.7	44
	Total	50.6	35.4–65.8	83
2018	North Slope	54.5	37.8–71.2	34
	Wasatch	65.0	50.1–79.9	39
	Total	60.3	49.1–71.5	73
2019	North Slope	37.5	13.7–61.2	16
	Wasatch	47.6	27.1–68.0	21
	Total	43.2	28.2–58.1	37

*2016 was estimated on calves that survived to be collared in Jan-Feb 2017.

Age Specific Calving Rates

Just like the pregnancy by age analysis, we used the same known aged moose from our study to predict the probability of having a calf (Figure 10). Like pregnancy being affected by age, the ability to have a calf is also related to age. This makes sense because a moose must be pregnant to have a calf, these two things should be linked. It makes sense that we see the same shaped curves for the probability of pregnancy and calving. What is concerning is the probability of calving is significantly lower than the probability to become pregnant. This likely means cows are losing calves earlier than they can be observed, or they are aborting pregnancies in favor of their own survival. We know from previous studies (Ruprecht et al.) that body condition is important for calving. We have also found that tick loads in relation to body condition can also affect the likelihood of a cow moose having a calf. It has been suggested that cow moose can produce a calf even in poor condition but may terminate pregnancies if winter conditions are poor (Milner et al. 2013). This could also be true if weather permits (lack of snow) tick loads to become extreme which may cause the cow to terminate pregnancy to preserve her own survival. These factors could explain why we are seeing such discrepancies in pregnancy rates and calving rates.

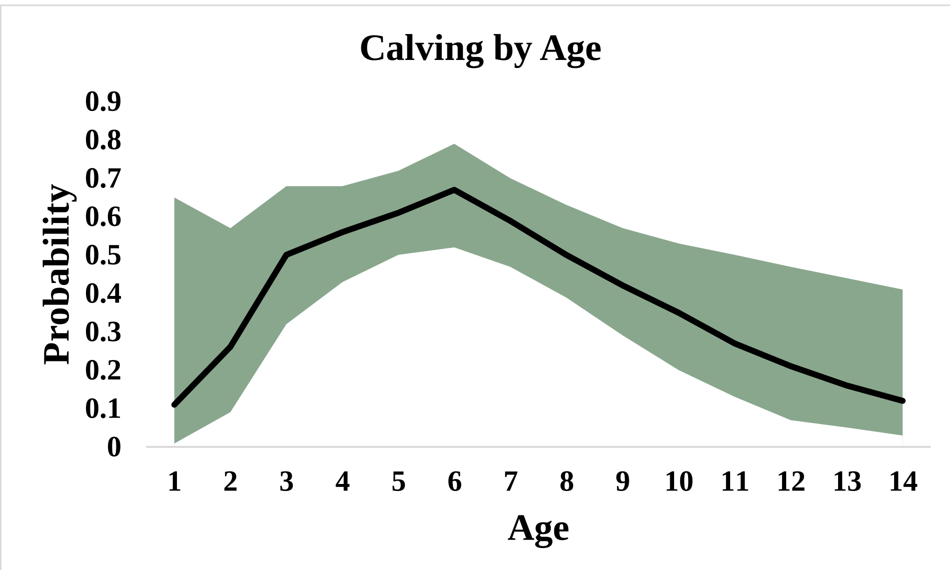

Figure 10: The probability of having a calf at a certain age.

TWINNING RATES

Twinning Rates of radio-collared moose were determined during calving surveys (Table 3). Twinning rates were calculated as the number of twins divided by total number of births of all collared cows. One set of twins was documented on the Wasatch and none on the North Slope in 2019. Twinning rates this year are more typical of what we have seen in previous years, the exception being 2018 when 4 sets of twins were born between the Wasatch and North Slope.

Table 3: Summary of twinning rates of radio collared moose, Utah 2013–2019.

Year	***Area***	***Twinning Rate (%)***	***95% CI***	***N***
2013	North Slope	3.7	0.0–11.1	27
	Wasatch	6.3	0.0–18.8	16
	Total	4.7	0.0–14.4	43
2014	North Slope	0.0	–	13
	Wasatch	6.7	0.0–19.7	15
	Total	3.6	0.0–16.4	28
2015	North Slope	0.0	–	16
	Wasatch	0.0	–	13
	Total	0.0	–	29
2016	North Slope	0.0	–	17
	Wasatch	9.1	0.0–26	11
	Total	3.5	0.0–10.3	28
2017	North Slope	6.6	0.0–19.1	15
	Wasatch	3.8	0.0–11.1	26
	Total	4.8	0.0–11.3	41
2018	North Slope	5.9	0.0–17.1	17
	Wasatch	13.0	0.0–26.7	23
	Total	10.0	0.7–19.3	40
2019	North Slope	0.0	–	6
	Wasatch	11.1	0.0–31.4	9
	Total	6.67	0.0–18.8	15

CALF SURVIVAL RATES

Calf survival for 2013-2016 (survival of calves born to radio-collared cows) was estimated for a 10-month interval from the time after calving to the end of the following winter (~June year *t* to March year *t*+1, (Table 4). Ground and aerial surveys were conducted in late March to determine if each calf identified with a radio-collared cow during the spring calving surveys in year *t* survived until spring year *t*+1. Survival rate equaled the proportion of these calves that survived to spring year *t*+1. Calf survival rate during 2016-2017 was calculated from calves' radio-collared in Jan-Feb 2017, and it may not be comparable to other years. Although we missed 6-8 months that these calves could have died, we were able to track and monitor calf survival through the critical spring months. This could overestimate survival for 2016-2017 because some calves may have died as neonates before the start of surveys. Additionally, in 2013-2016 some calves may have died in April or May prior to being recruited into the adult population. As such, the estimates presented here should be considered *maximum* calf survival rates. In 2017-2018 & 2018-2019 we used both methods mentioned above. We used the calves that were collared during captures in 2018 & 2019, and we also tracked uncollared calves using the collars of their mothers from the ground in April. Using both methods allowed us to have a larger sample size and follow each calf that was born in June until the following April. Estimates were calculated using the Kaplan-Meier survival estimator.

Table 4: Summary of calf survival rates, Utah 2013–2018.

Year	*Area*	*Calf Survival Rate (%)*	*95% CI*	*N*
2013-14	North Slope	84.6	67.1 – 100	13
	Wasatch	100	–	10
	Total	91.3	80.5 – 100	23
2014-15	North Slope	83.3	64.7 – 100	12
	Wasatch	30.8	13.6 – 69.5	13
	Total	56.0	39.6 – 79.3	25
2015-16	North Slope	40.0	18.7 – 85.5	10
	Wasatch	50.0	31.8 – 93.6	12
	Total	45.5	30.4 – 74.6	22
2016-17	North Slope	53.8	32.6 – 89.1	13
	Wasatch	60.0	36.2 – 99.5	10
	Total	56.5	39.5 – 80.9	23
2017-18	North Slope	71.4	51.3 – 99.5	14
	Wasatch	53.8	32.6 – 89.1	24
	Total	60.5	46.8 – 78.2	38
2018-19	North Slope	27.3	10.4 – 71.6	11
	Wasatch	47.4	29.5 – 76.1	19
	Total	40.0	25.8 – 62.0	30

Calf Kaplan Meier Survival Estimates

We took 85 calves from 2016-2018, North Slope (n=37) and the Wasatch (n=48) and calculated their survival estimates through the first year of life. There was no statistical difference between the North Slope and the Wasatch calf survival estimates ($P = 0.84$; Figure 11). These calculations only used calf moose that we knew the approximate date of death. We know calves died throughout the year by following the mothers and checking their calf status, the problem is we do not know when those calves died so we left them out of the analysis. These estimates show that there is mortality happening within the first couple of days of life and in early and late spring. The smoothed hazard estimates used the same calf moose and calculated the probability of a calf moose dying at a certain time during their first year (Figure 12). On the North Slope a calf is more likely to die early on in life and after winter during early spring. On the Wasatch the probability of dying at a certain age is like the North Slope with calves dying within the first couple of days and later in the spring. The Wasatch however has a smoother curve in the spring which indicates the probability of dying on the Wasatch is more constant during the year than the North Slope that has a higher probability of dying in the spring.

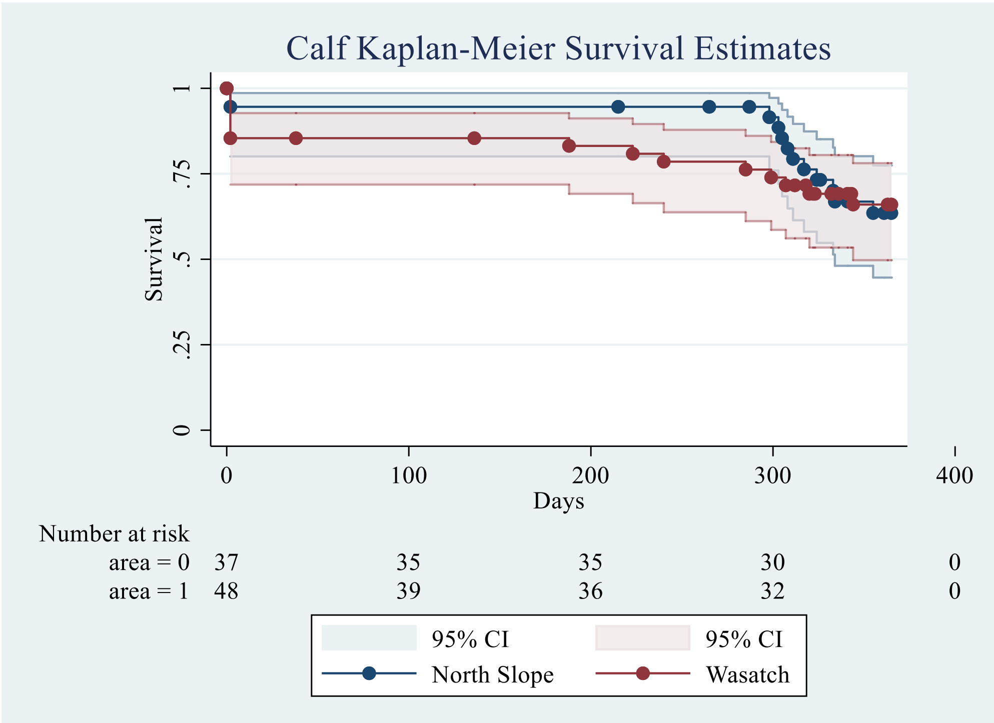

Figure 11: Kaplan-Meier survival rates for the first year of calf moose the North Slope (blue) and the Wasatch (red). Shaded areas represent 95% confidence intervals for survival estimates. There was no statistical difference in survival rates between units.

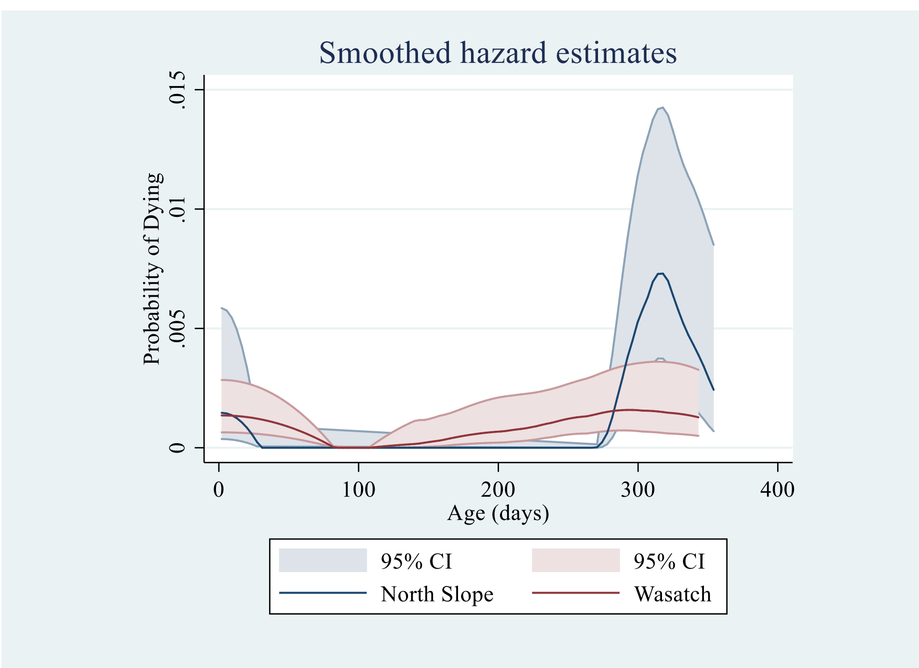

Figure 12: Smoothed hazard estimates for calf moose in the North Slope (blue) and the Wasatch (red). Shaded areas represent 95% confidence intervals for smooth hazard estimates.

RECRUITMENT RATES 2013–2018

Recruitment rates represent the ratio of calves surviving their first year per adult female moose. Because survival rates of calves are generally lower than those of adults, recruitment is a more robust measure of productivity. Recruitment rates were calculated as the product of calving rates and calf survival (Table 5).

Table 5: Summary of recruitment rates of radio collared moose, Utah 2013–2019.

Year	*Area*	*Recruitment Rate (%)*	*95% CI*	*N*
2013-14	North Slope	46.6	27.6–69.0	49
	Wasatch	33.3	20.0–46.6	48
	Total	40.5	31.7–53.8	97
2014-15	North Slope	35.5	16.5–59.2	33
	Wasatch	13.6	3.7 –42.3	*34*
	Total	24.2	12.4–43.8	67
2015-16	North Slope	29.4	11.1–47.0	22
	Wasatch	28.3	10.2–46.4	25
	Total	29.1	18.4–40.4	47
2016-17	North Slope	24.2	10.7–37.8	38
	Wasatch	18.0	6.1 –29.9	40
	Total	21.1	12.0–30.2	78
2017-18	North Slope	29.3	15.0–43.6	39
	Wasatch	31.8	18.0–45.6	44
	Total	30.6	20.7–40.5	83
2018-19	North Slope	14.8	3.9 –50.9	34
	Wasatch	30.8	14.7–60.8	39
	Total	22.8	12.6–44.3	72

ADULT SURVIVAL RATES

Adult female moose were monitored year-round to estimate annual survival using a Kaplan-Meier survival estimator (Table 6). Some moose collars emitted mortality signals, but collar failures precluded visual confirmation of deaths. The estimates below have censored all such instances, i.e. they only represent confirmed mortalities. 2019 adult survival is down from years past, but it is likely due to the age of moose in both areas. The moose that died in 2019 have mostly been older moose over 10 yrs. (Table 9 & 10). These are moose that have been monitored for at least 3 years some as long 6 years which means they are getting older and likely driving down survival rates.

Table 6: Summary of adult female survival rates, Utah 2013–2019.

Year	*Study Area*	*Adult Survival Rate*	*95% CI*
2013	North Slope	87.1	78.6–96.5
	Wasatch	89.2	81.4–97.8
	Total	88.0	82.1–94.4
2014	North Slope	91.0	81.6–100
	Wasatch	85.7	74.8–98.1
	Total	88.0	80.4–96.2
2015	North Slope	91.5	80.8–100
	Wasatch	90.0	77.7–100
	Total	91.3	83.6–99.8
2016	North Slope	71.3	53.3–100
	Wasatch	90.2	78.2–100
	Total	82.9	71.3–96.4
2017	North Slope	84.4	74.5–95.7
	Wasatch	86.3	77.3–96.3
	Total	85.4	78.6–92.8
2018	North Slope	86.5	76.2–98.2
	Wasatch	85.4	75.2–96.9
	Total	86.0	78.6–94.0
2019	North Slope	82.1	67.5–99.8
	Wasatch	83.3	69.6–99.7
	Total	82.8	72.6–94.5

Adult Kaplan Meier Survival Rates

We took the known ages of 87 moose from the North Slope (n=50) and the Wasatch (n=37) and calculated their survival rates through time. There was no statistical difference between the North Slope and the Wasatch adult survival estimates (P = 0.09; Figure 13). Ages were determined from pulling incisors from moose in 2013-2019 and having them aged (Matson's Laboratory, Brigham Young University). This analysis allows us to see the percentage of moose that will survive to a certain age. The oldest moose that has been aged was 14.5 and it does not appear Utah moose reach ages much past 14. The smoothed hazard estimates used the same known aged moose and calculated the probability of a moose dying at a certain age (Figure 14). The older a moose gets the more likely it will die. During this analysis we also calculated the mean survival time and median survival time for each area, the mean survival time for the North Slope is 9.83 yrs. (95% CI 8.73-10.93) and the Wasatch is 8.62 yrs. (95% CI 7.65-9.68). The median survival time for the North Slope is 10 yrs. (95% CI 8-12.83) and the Wasatch is 8.92 yrs. (95% CI 7.5-10.08). This means that 50% of the moose on the North Slope are dead by age 10 years old and on the Wasatch 50% are dead by age 8.92 years.

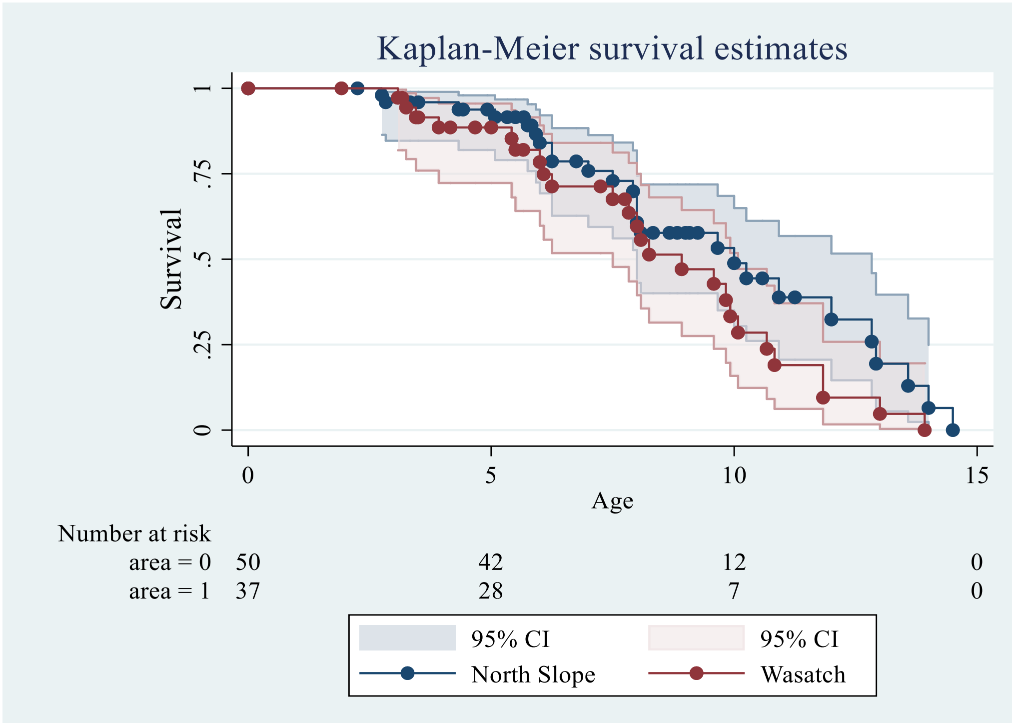

Figure 13: Kaplan-Meier survival rates for moose in the North Slope (blue) and the Wasatch (red). Shaded areas represent 95% confidence intervals for survival estimates. There was no statistical difference in survival rates between units.

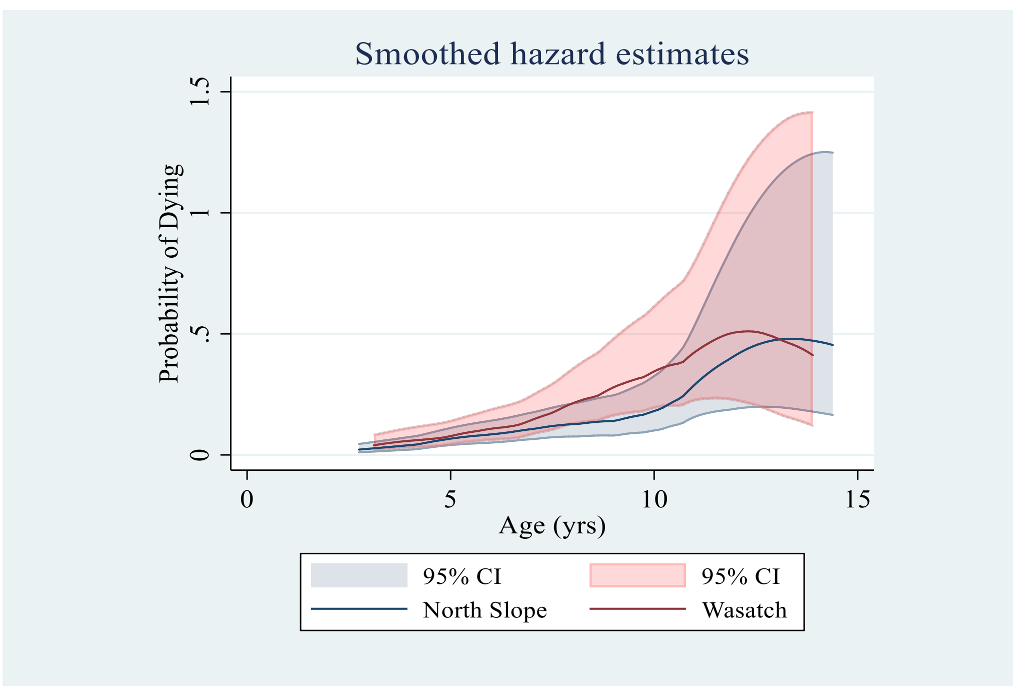

Figure 14: Smoothed hazard estimates for moose in the North Slope (blue) and the Wasatch (red). Shaded areas represent 95% confidence intervals for smooth hazard estimates.

AGE CLASS DISTRIBUTION

Age structure of any population is important when it comes to understanding population dynamics. When age structures deviate from the hypothetical stable distribution which is often used to make management decisions, it can be difficult to determine which vital rates are contributing to temporal variation in population growth (Hoy et al. 2019). Obtaining age structure of any wild population is difficult and often impossible. Changing environments can result in changes in age structures. For example, moose in Utah we now know that winter ticks, body condition and ultimately climate conditions along with age can impact reproductive success for moose. If you have several years of poor conditions that reduce reproductive success you could have a shift in age distribution towards older individuals. A shift in age structure will likely affect future age structures by reducing reproductive success and overall survival estimates, because older individuals often have lower reproductive output and are more sensitive to environmental stress (Hoy et al. 2019). We have tried to get an understanding of age structures of moose on our two study areas through captures in 2013 and 2017-2019 using known ages from cementum annuli and estimated ages from tooth wear. Only 2013 and 2017 were random captures, 120 and 80 adult females respectively. 2018 and 2019 were recaptures and may not give a true representation of age structure shifts. By looking at age structures of our captured moose from the four years captures were conducted, it does appear that both study area populations are getting older (Figure 15). It appears the North Slope has an older population than the Wasatch this could be part of the reason we have seen slightly lower adult survival in both areas the last three years and reduced pregnancy rates on the North Slope. Although our understanding of age distribution is not perfect, we do know from the data that both populations are not likely to always have a stable population distribution and this needs to be considered when making management decisions.

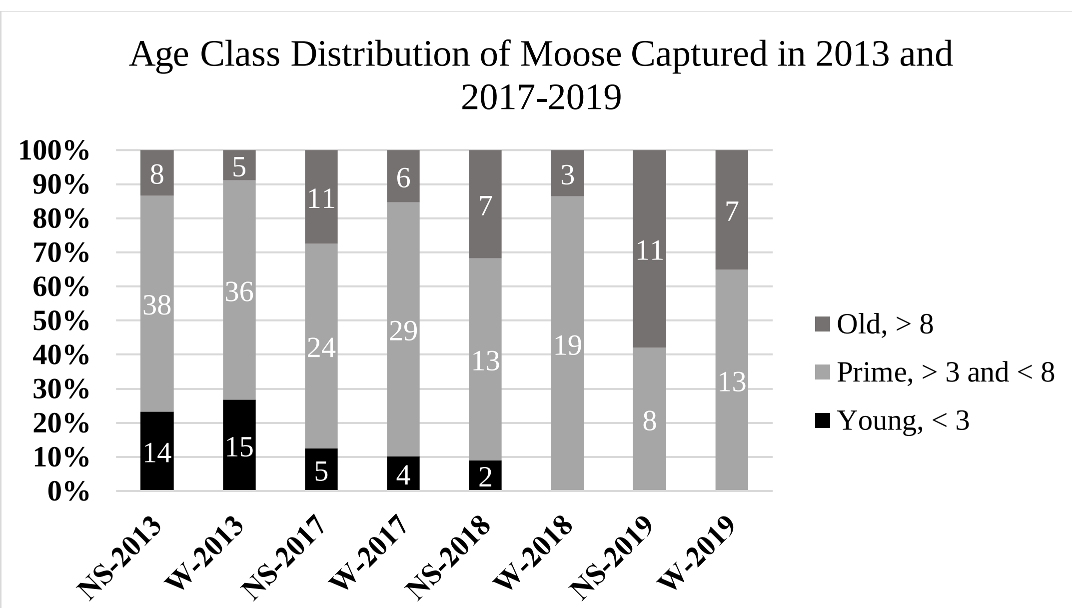

Figure 15: Age class distribution of captured moose during the four years captures were conducted.

MATRIX MODELING OF POPULATION GROWTH RATE

We expanded a female only, pre-birth Lefkovitch matrix population model (Caswell 2001) that was created by Joel Ruprecht using the 2013-2015 data. This model now includes the years 2013-2018 and has 3 stage classes (i.e. calf, yearling, adult) to estimate growth rate (λ) for each unit. Matrix elements were populated using vital rate estimates from both units from 2013-2018 as well as the 2013-2018 overall estimates of both units. Top row (i.e. productivity elements) were calculated as the product of parturition rate and calf survival then divided by two to assume calf sex ratio was at parity. Because calf moose are not sexually mature, they are not allowed to breed in the model. Survival rates were assumed to be equivalent between yearlings and adults. A schematic diagram and matrix of the 2013-2018 overall element values are provided in Figures 16 and 17, respectively.

Overall, lambda from 2013-2018 was estimated at .99352 indicating the overall population from both units decreased slightly after 6 years (Table 7). This decrease has been happening mostly during these last three years. Lambda for the North Slope from 2013-18 was estimated at 0.99867 which means the population has neither decreased nor increased (Table 7). In the Wasatch, lambda from 2013-18 was estimated at 0.98838, indicating a 1% annual population decline (Table 7). The North Slope had good population growth 2013-2015 but has had a decreasing population in 2016-2018. This could indicate a density issue, all the growth early on may have caused negative density dependence. The vital rates on the North Slope may indicate this with lower adult survival and lower calf recruitment. The Wasatch population has been consistent and stable, the population has slightly decreased in 6 years and has not had any major fluctuations in vital rates.

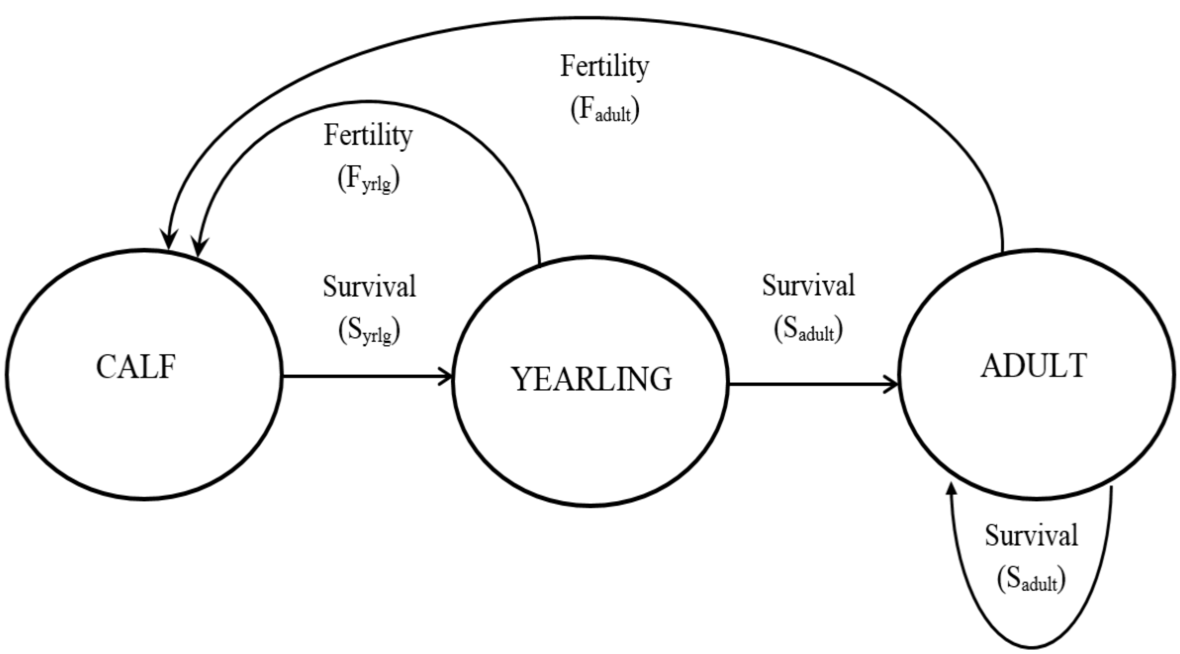

Figure 16: Schematic diagram representing vital rates used to populate a Lefkovitch matrix population model. Created by Joel Ruprecht

$$\text{Matrix Elements} = \begin{pmatrix} \mathit{Fcalf} & \mathit{Fyrlg} & \mathit{Fadult} \\ \mathit{Syrlg} & \mathit{0} & \mathit{0} \\ \mathit{0} & \mathit{Sadult} & \mathit{Sadult} \end{pmatrix}$$

$$\text{Overall} = \begin{pmatrix} 0 & 0.08 & 0.144 \\ 0.8804 & 0 & 0 \\ 0 & 0.8804 & 0.8804 \end{pmatrix}$$

$$\text{North Slope} = \begin{pmatrix} 0 & 0.08 & 0.1637 \\ 0.878 & 0 & 0 \\ 0 & 0.878 & 0.878 \end{pmatrix}$$

$$\text{Wasatch} = \begin{pmatrix} 0 & 0.08 & 0.125 \\ 0.8828 & 0 & 0 \\ 0 & 0.8828 & 0.8828 \end{pmatrix}$$

Figure 17: Matrices populated with the overall 2013-2018 vital rate estimates used in a Lefkovitch population model to estimate population growth rates.

Table 7: Summary of annual growth rates from 2013-2018.

Year	***Study Area***	***Lambda (λ)***	***Growth Rate (%)***
2013	North Slope	1.04418	4.4
	Wasatch	1.02678	2.7
	Total	1.03621	3.6
2014	North Slope	1.05213	5.2
	Wasatch	0.92104	-7.9
	Total	0.98907	-1.0
2015	North Slope	1.03764	3.8
	Wasatch	1.01868	1.9
	Total	1.02816	2.8
2016	North Slope	0.95384	-4.7
	Wasatch	0.98375	-1.7
	Total	0.96914	-3.1
2017	North Slope	0.96060	-3.9
	Wasatch	0.99295	-0.7
	Total	0.97683	-2.4
2018	North Slope	0.93394	-6.4
	Wasatch	0.98011	-2.0
	Total	0.96074	-4.0
2013-18	North Slope	0.99867	0
	Wasatch	0.98838	-1.0
	Total	0.99352	-0.6

MORTALITY

Since 2013 we have had 69 collared adult female moose die. 34 on the North Slope (Table 8) and 35 on the Wasatch (Table 9), many of them have been malnourished, some with high parasite loads of eleaophora and winter ticks. We had several hit by vehicles, some caught in fences, several with wounds and infections. Some have died of old age. Several have been killed by hunters on the North Slope. One fell through the ice and drowned, one got stuck in a beaver pond and died. We also had one adult killed by a mountain lion (Table 8 & 9). In 2017 we started collaring 6-8-month-old calves to assess calf survival and since then we have had 17 collared calves die. On the Wasatch 6 have died (Table 10) and 11 on the North Slope (Table 11). Most have been malnourished with high parasite loads, two were killed by mountain lions. It is difficult to pinpoint cause of death of adults and calves because many times they have had several factors that could have contributed to their mortality. To say one thing caused their death would be a large assumption when most likely it was a combination of several factors. The new GPS collars continue to allow us to inspect dead moose more quickly than in the past, allowing us to collect many tissue samples and have a better understanding on cause of death. Age at death of adult female moose during 2013-2019 ranged from 1- to 14-years-old (Figure 18.) The ages of most of the moose captured in 2017 and 2018 have not been determined yet. Mortality of adult and calf moose was concentrated at end of winter and before green-up (Figure 19).

Table 8: Summary of adult Wasatch moose mortalities 2013-2019

2013-2019 Adults Moose ID	*Approximate Date of Death*	*Age at Death (yrs.)*	*Comments*
152.649	04/01/2013	9	Malnourished with gelatinous bone marrow.
152.700	04/15/2013	6	Unknown only hair and bones left; she did have poor bone marrow.
152.170	04/16/2013	8	Malnourished with high tick loads.
152.561	05/13/2013	1	Malnourished with poor bone marrow.
152.501	06/10/2013	3	Tangled in a barb wire fence.
152.100	06/27/2013	6	Unknown badly decomposed.
152.160	07/12/2013	6	Unknown badly decomposed.
152.661	07/24/2013	2	Unknown badly decomposed.
152.341	04/10/2014	14	Malnourished with high tick loads. Old age.
152.821	04/25/2014	12	Malnourished with high tick loads, elaeophora and jaw infection.
152.750	06/14/2014	8	Unknown, no obvious cause of death.
152.580	10/14/2014	2	Hit by a vehicle.
152.410	11/25/2014	5	Hit by a vehicle.
152.460	12/01/2014	9	Unknown, badly decomposed
151.721	03/20/2015	3	Carcass mostly decomposed. No cause of death available
152.231	02/15/2016	11	Carcass mostly decomposed. No cause of death available.
152.370	03/21/2016	8	Very high tick load, severe ear cropping, very malnourished. Gelatinous bone marrow.
152.321	11/01/2016	7	Carcass mostly decomposed. No cause of death available. Gelatinous bone marrow.
150.740	02/20/2017	NA	Fell through the ice on a small pond and drowned.
152.361	04/05/2017	12	Killed by a mountain lion.
150.970	04/10/2017	NA	Very high tick load. Elaeophora in carotid arteries. Gelatinous bone marrow.

150.760	04/11/2017	NA	Very high tick load. Ear cropping and malnourished with gelatinous bone marrow.
150.660	05/06/2017	NA	Moose had severe pneumonia and was malnourished with gelatinous bone marrow
150.830	05/23/2017	6	Hit by a Vehicle on highway 6 in Spanish Fork Canyon.
150.640	10/22/2017	5	Elaeophora in carotid arteries, and severely malnourished
151.100-W	03/18/2018	NA	Malnourished with gelatinous bone marrow. High tick load. Elaeophora in the carotid arteries. Liver failure.
152.762	03/25/2018	9	Carcass mostly decomposed, no obvious cause of death.
150.820-W	04/21/2018	NA	Malnourished with gelatinous bone marrow. High tick load. Elaeophora in the carotid arteries. Had unborn fetus inside.
150.540-W	06/23/2018	9	Possibly human caused, had what appeared to be a bullet hole in left side. No bullet was ever found. Also had Elaeophora in carotid arteries.
150.720	08/05/2018	8	Malnourished with gelatinous bone marrow. Severe emaciation. Elaeophora in the carotid arteries. Cysts on kidneys and liver.
150.860	08/20/2018	NA	Hit by a vehicle in Park City.
148.249-19	02/17/2019	11	Malnourished with gelatinous bone marrow. High loads of elaeophora in the carotid arteries. Deformed hooves
150.100-19	03/7/2019	12	Malnourished with gelatinous bone marrow. High tick load. Elaeophora in the carotid arteries. Infected ear. (old age)
152.551	06/10/2019	10	Malnourished with gelatinous bone marrow. Had extensive grooming and hair loss.
150.290-19	11/9/2019	NA	Possibly human caused, had several wounds on neck and side. Died in a strange location.

Table 9: Summary of adult North Slope moose mortalities 2013-2019

2013-2019 Adult Moose ID	***Approximate Date of Death***	***Age at Death (yrs)***	***Comments***
152.031	03/15/2013	2	Malnourished with poor bone marrow.
151.928	03/25/2013	13	Leg caught in a Barb wire fence.
151.700	04/15/2013	6	Unknown only hair and bones left; she did have poor bone marrow.
151.570	05/16/2013	9	Malnourished with poor bone marrow.
151.802	08/06/2013	6	Unknown, badly decomposed.
151.772	08/08/2013	6	Unknown, possibly from bad infection on leg.
152.129	11/19/2013	7	Malnourished with poor bone marrow.
151.780	02/15/2014	7	Unknown, badly decomposed.
151.821	03/15/2014	5	Unknown, badly decomposed.
152.092	09/22/2014	3	Hunter found dead, badly decomposed.
151.971	05/12/2015	12	Unknown, badly decomposed.
152.052	1/30/2016	NA	Only bones and hide left. No obvious cause of death. No teeth for aging.
151.642	4/30/2016	6	Only bones and hide left. No obvious cause of death. Gelatinous bone marrow.
151.852	05/01/2016	7	Carcass mostly decomposed. No cause of death available.
151.042	06/06/2016	10	Malnourished, gelatinous bone marrow.
151.150	09/28/2016	6	Possible human caused death had a compound fractured right humorous.
151,360	04/12/2017	NA	Stuck in the mud in a beaver pond. Gelatinous bone marrow.
151.678	04/15/2017	10	Carcass mostly decomposed. No cause of death available.
151.290	05/02/2017	NA	High tick load, Elaeophora in carotid arteries. Malnourished with gelatinous bone marrow.
151.050	05/16/2017	NA	Malnourished with gelatinous bone marrow. All four lower legs missing hair.
151.922	06/01/2017	8	Carcass mostly decomposed. No cause of death available.
151.330	08/18/2017	10	Malnourished with gelatinous bone marrow. Left front hoof was badly infected.

151.270	01/15/2018	NA	Moose frozen in a stream. No obvious cause of death. Elaeophora in carotid arteries.
151.300	02/17/2018	NA	Only bones and hide left. No obvious cause of death.
151.340	04/07/2018	NA	Malnourished with gelatinous bone marrow. Very high tick loads.
152.071	04/18/2018	NA	Moose died in a stream. Malnourished with gelatinous bone marrow.
152.061	09/16/2018	NA	Killed legally by a cow moose hunter
150.420	11/07/2018	14	Malnourished with gelatinous bone marrow. Had coronary ulcers on both eyes. Completely blind
151.929-19	02/24/2019	13	Malnourished with gelatinous bone marrow. Elaeophora in carotid arteries. (old age)
148.110-19	05/31/2019	8	Only bones and hide left. Likely malnutrition/winter kill, moose was in poor condition during January captures
150.270-19	04/27/2019	13	Malnourished with gelatinous bone marrow. Elaeophora in the carotid arteries. (old age)
148.129-19	11/10/2019	NA	Moose died in a stream. Malnourished with gelatinous bone marrow. Moose was completely consumed by scavengers. (likely old age)

Table 10: Summary of Wasatch calf moose mortalities 2017-2019

2017-2019 Calf Moose ID	***Approximate Date of Death***	***Comments***
149.254	03/15/2017	Unknown, badly decomposed.
149.332	03/25/2017	Very high tick load and malnourished with gelatinous bone marrow.
149.352	03/26/2017	Killed by a mountain lion. Malnourished with gelatinous bone marrow.
149.312	04/17/2017	Killed by a mountain lion. Very high tick loads with gelatinous bone marrow
148.310-W	05/11/2018	Malnourished with gelatinous bone marrow. No other obvious cause of death.
148.060-19	03/13/2019	Malnourished with gelatinous bone marrow. Very high tick load, completely covered in ticks.

Table 11: Summary of North Slope calf moose mortalities 2017-2019

2017-2019 Calf Moose ID	*Approximate Date of Death*	*Comments*
149.553	04/05/2017	Completely scavenged by coyotes. Gelatinous bone marrow.
149.653	04/06/2017	Completely scavenged by coyotes. Gelatinous bone marrow.
149.462	04/14/2017	Malnourished with gelatinous bone marrow.
149.523	04/21/2017	Completely scavenged by coyotes. Gelatinous bone marrow.
149.643	04/30/2017	Carcass mostly decomposed. No cause of death available.
149.483	05/19/2017	Malnourished with gelatinous bone marrow.
149.580-NS	5/11/2018	Only Bones and hide left. No obvious cause of death
151.809-19	3/26/2019	Calf was mostly scavenged. Malnourished with poor bone marrow.
149.180-19	3/31/2019	Malnourished with poor bone marrow. Moderate tick load.
148.269-19	4/2/2019	Only hair and bones left. Malnourished with poor bone marrow.
148.320-19	4/30/2019	Calf was submerged in mud/water, possibly got stuck and was too weak to get out. Malnourished with poor bone marrow

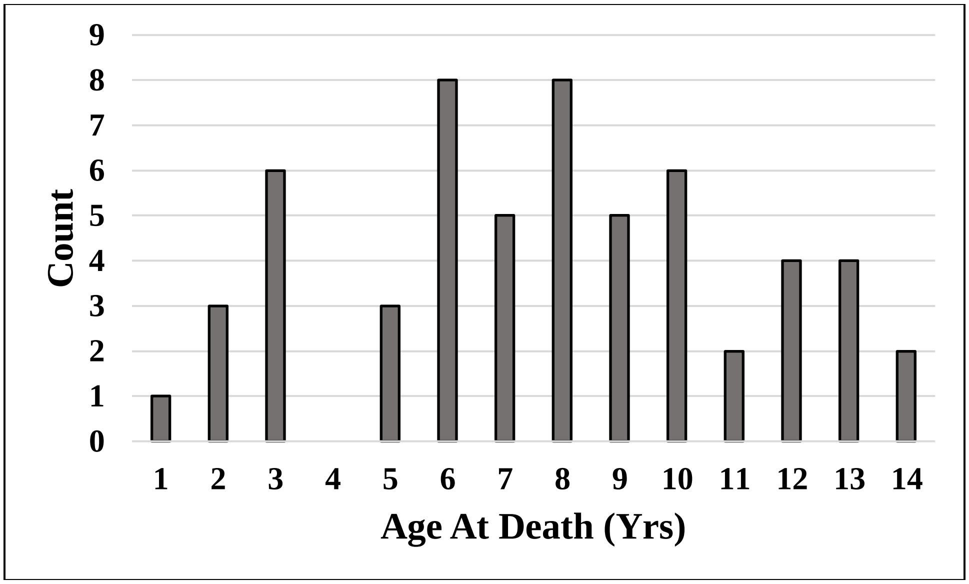

Figure 18: Ages of adult female moose at the time of death, 2013-2019 (n=58).

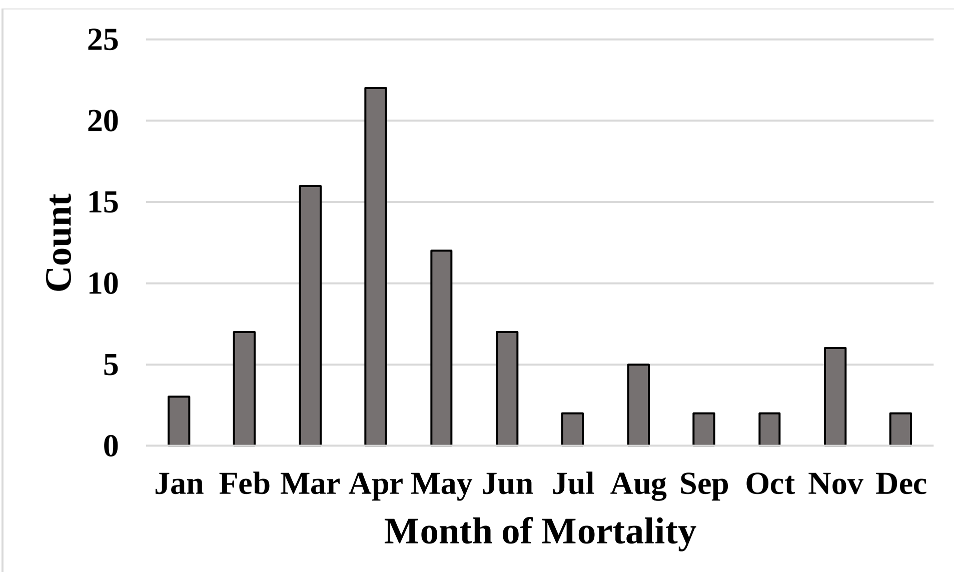

Figure 19: Numbers of moose deaths by month, Utah 2013–2019. This includes all collared moose, adults, and calves (n=86).

MOOSE TOXICOLOGY REPORTS

The use of GPS collars has made it possible to get to mortalities fast enough to collect viable samples. Since January 2017, 21 moose livers have been collected from mortalities of GPS collared moose in both the Wasatch and North Slope units. The liver samples along with many other samples are taken to the Utah State Veterinary Diagnostic Lab in Logan Utah for analysis. This lab does not have a full set of normal mineral reference ranges of moose liver; however, the mineral ranges that it lacks for moose it compares them to other ungulates for reference. The lab does have normal references for five minerals that show fluctuation in moose liver that have been collected from this study (Figure 20). The sample size is small; however, it does give an idea of the mineral deficiencies from the two study areas. Over 60% of the moose that were analyzed were deficient in Manganese which may be associated with reduced conception rates (Ojha et al. 2018). It is also important for the maintenance of growth, pregnancy, and lactation (Ojha et al. 2018).

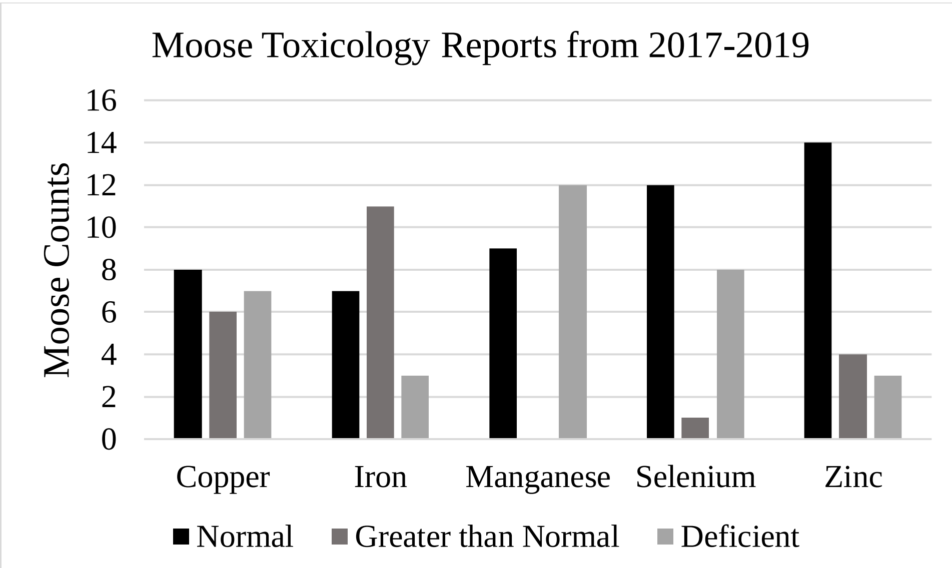

Figure 20: The five minerals from 21 moose liver toxicology reports that fluctuated between moose. All other minerals were in the normal ranges.

MOOSE MOVEMENT

Since January 2017 every moose captured both adult females and calves have been fitted with GPS collars. This has allowed us to track moose movement more closely. Although most of our study moose tend to move very little and have high site fidelity, there have been some interesting movements taken place. On the North Slope we have had some of our GPS collared moose moving up and down the drainages from the high valleys in the wilderness area to the sage brush steppe areas down below (Figure 21). We even had a moose cross over from the North Slope to the South Slope for several days before making its way back to the North Slope (Figure 22). These movements are seasonal movements with these moose summering high and wintering low. Some moose on the North Slope have been making some interesting movements at interesting times. We have several moose summering down low in the farmlands of Wyoming and in late fall are moving up to the wilderness area and then back down to lower areas for winter. Some of the North Slope moose also move from one drainage to the next and even across multiple drainages.

Most of the Wasatch moose move very little, but we did have 5 GPS collared moose who wintered in the Cascades spring area and then summer in Little Cottonwood Canyon (Figure 23).

This journey for them is only about 16 miles but they cross deep snow-covered peaks in the spring to get there. I believe the habitat that Big and Little Cottonwood Canyons provide is critical summer moose habitat and should be protected where and when it can.
Most of the calf collars fall off before or shortly after their first year of life and most of the calves stay close to where their mother has been. Although we have had a couple of yearlings make some long movements. One yearling bull on the North Slope moved from Gilberts Creek to Sheep Creek Lake nearly making it to Flaming Gorge before the collar fell off (Figure 24), approx. 30 miles. Another female yearling moose on the Wasatch moved from the Timber Lakes area East of Heber City all the way north to Wyoming before settling in the Boyer Lake area north of Weber Canyon (Figure 25).

The movement data that has been collected will be very valuable for continuing research on moose. Movement data could be used to analyze habitat selection, parasite loads and body condition. Does a place a moose calls home affect its parasite load and overall health? These are a few examples of things that this GPS location data will help answer in the future.

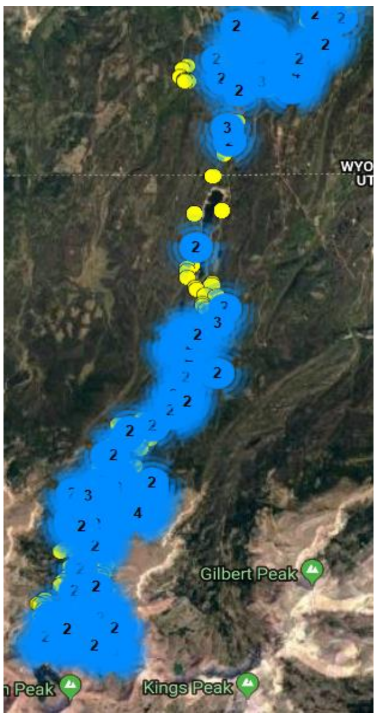

Figure 21: Moose 148's approx. 25-mile movement from her summer range in the wilderness to her winter range in the sagebrush steppe.

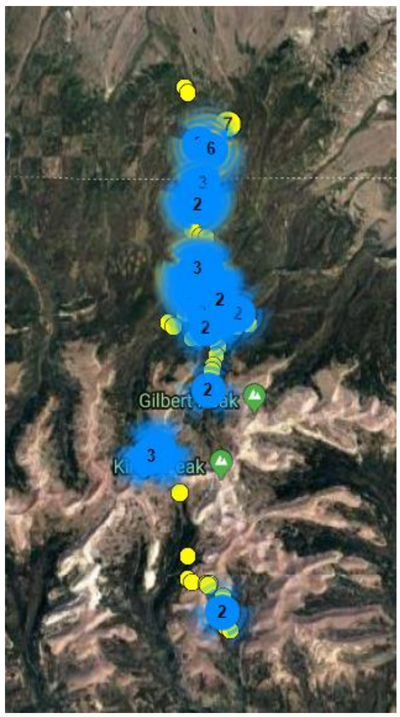

Figure 22: Moose 128's movement from the North Slope to the South Slope and back.

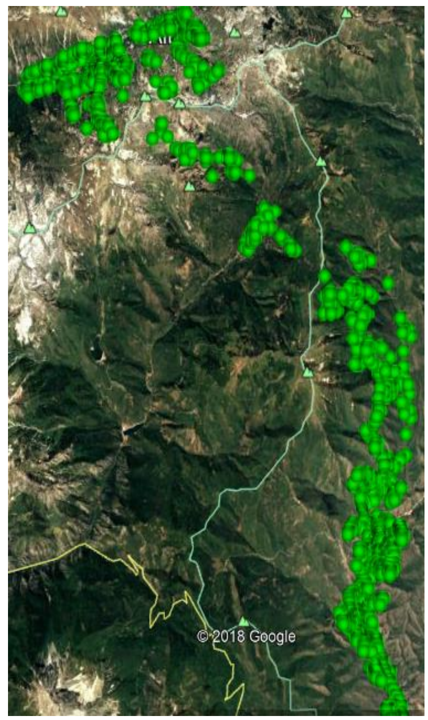

Figure 23: Moose 198's movement back and forth from her summer range in Little Cottonwood Canyon to her winter range in Cascades Springs. 5 GPS collared moose have had this seasonal movement pattern.

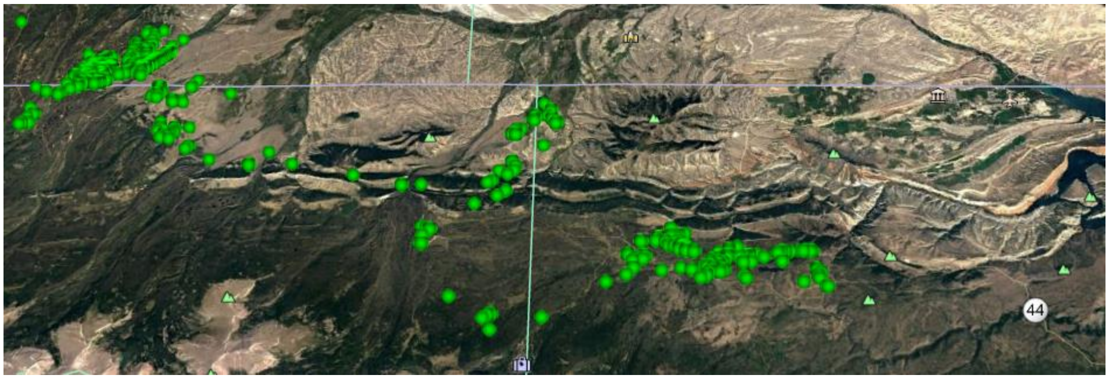

Figure 24: Yearling bull 270’s movement from Gilbert’s Creek to Sheep Creek, approx. 30 miles.

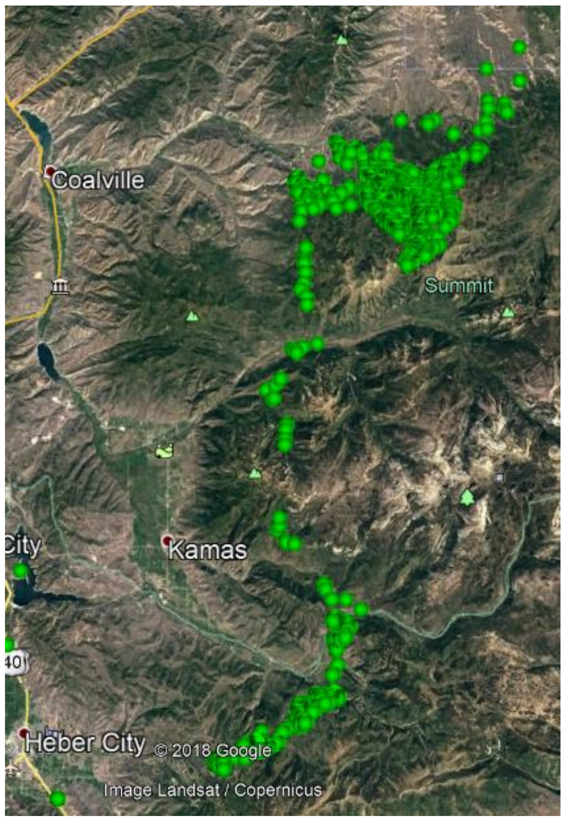

Figure 25: Yearling female 239’s movement from the Timber Lakes area North to Boyer Lake, approx. 45 miles

HABITAT

Although this was not a habitat study, and we did not measure any vegetation indices we spent countless hours in the field on both units and made several observations. We felt it was important to make note of these observations. While on the North Slope it was noted what the condition of the willow communities (*Salix spp*.) were we hiked. We noticed the willows were very large with most well over 12 feet tall, while most were alive, they had a lot of dead portions in each plant and did not appear to be healthy. We did notice some new growth, but it was limited to certain areas, most of the main drainages are full of willows that are old and senescent. Areas that used to have beaver ponds have been taken over with grasses and are mostly void of browse like willows. Willows are very important to moose on the North Slope it was observed from a study in 1971 that the key browse species for moose were Salix drummondiana and S. geyeriana (Wilson 1971). These two species made up 92% and 4.7% respectively of all the observed moose browsing from this study (Wilson 1971). Also, the areas below live and dead lodgepole pines (*Pinus contorta*) are almost completely void of any kind of forage and the ground is mostly covered by bare ground. There does seem to be some positive things happening, aspen (*Populus tremuloides*) stands seem to be increasing, because the Lodgepole pine stands have been opened from the beetle kill, thus allowing for new stands of aspen to generate. With these different observations it appears the North Slope needs some habitat improvement projects.

On the Wasatch vegetation is made up of more heterogenous communities and this makes it difficult to make observations of possibly poor habitat. One thing that was noticed was the lack of Mountain mahogany (*Cercocarpus spp*.) recruitment which is a favorite wintertime browse of moose in northern Utah. Most of the mountain mahogany is old, very large and has been high marked by browsers, thus most have been browsed up to where live vegetation can't be reached. It was also noted that some aspen stands throughout the Wasatch were lacking new growth and the old trees seemed old and in a lot of cases dying. Although these are only observations they should be noted and considered when contemplating habitat improvement projects.

ELAEOPHORA SCHNEIDERI

Elaeophora schneideri is a common filarioid parasite and in Utah mule deer (*Odocoileus hemionus)* are the definitive hosts (Wolfe et al. 2010). Transmission typically occurs from the bite of tabanid horse fly or deer fly (Dipters: Tabanidae). Larvae migrate from the fly mouthparts and into the hosts circulatory system and end up in the carotid or lemtomeningeal arteries (Grunenwald et al. 2018). E. schneideri can cause elaeophorosis which is characterized by restricted blood flow due to the presence of E. schneideri in these arteries. This disruption in blood flow can lead to blindness: ischemic necrosis of the brain, ears and muzzle, poor antler growth, oral food impactions and in some cases death (Grunenwald et al. 2018). Moose from this study from both the Wasatch and North Slope have been found to carry E. schneideri. In 17 moose that were necropsied during this study E. schneideri was prevalent in the carotid arteries. There were likely more moose that died that had E. schneideri but could not be necropsied in time because they had been either scavenged or were too decomposed for sampling. Although some moose did show physical signs of E. schneideri by having cropped ears and cloudy eyes it was not clear how much E. schneideri contributed to the death of these moose. Several live moose were observed in the field with severely cropped ears but seem to be functioning fine. Even though we do not know how this parasite may have affected these moose it should be noted that it is quite prevalent in both areas and likely having some impact on moose in the state of Utah.

CONTINUED WINTER TICK RESEARCH

Tick Transect Sampling Methods

In 2018 Undergraduate technician Talon Jeppson conducted winter tick (*Dermacentor albipictus*) transects to try and get a better understanding of where winter ticks were on the ground. The sampling took place in the fall from early October to mid-November in the Wasatch Mountain range in Utah in areas where moose density is highest. Sampling ended after permanent snowpack and prolonged freezing temperatures occurred. Winter ticks were collected by dragging a 1m^2 white flannel sheet in 100-meter-long transects (Bergeron and Pekins 2014). The white flannel sheets were tied to two thin ropes each 1 meter long, which were then fed and tied through a screw eye that was attached to each end of a dowel. The transects were completed by standing in the open space between the ropes positioning the dowel out in front while dragging the white flannel sheet behind. The person conducting the drag would walk a 100 meter transect through various vegetation types and elevations.

For each transect sampled the date, time, location, elevation, detection of ticks, and weather conditions were recorded. After each transect sampled the white flannel sheet was inspected on both sides for the presence of winter ticks (Bergeron and Pekins 2014). If winter ticks were present, then the ticks were removed from the white flannel sheet using tweezers and placed in a vial with the correlating transect number. The completed transect vials with ticks were then placed in the freezer until all transects were collected. The transects with no tick's present were counted and collected as part of the data. After 53 transects were completed the vials were removed from the freezer and each vial had their ticks counted individually. The ticks were emptied into a petri dish and then each individual tick was counted and placed into a separate petri dish to avoid double counting.

Findings

We found that elevation seemed to play a role in tick presence. The 53 transects were taken between 6,000 ft up to 8,500 ft in elevation. From elevations between 6,000 ft to 7,500 ft 29 transects were conducted and 432 ticks were collected. The elevations between 7,000 and 7,500 ft showed to have the highest number of ticks present which was 326 with 6 transects conducted. Elevations from 7,500 ft to 8,500 ft had 23 transects conducted and 0 ticks were counted (Figure 26). There is likely many other factors effecting tick abundance like vegetation, precipitation, and snowpack but from this small sample of transects it appears elevation is important.

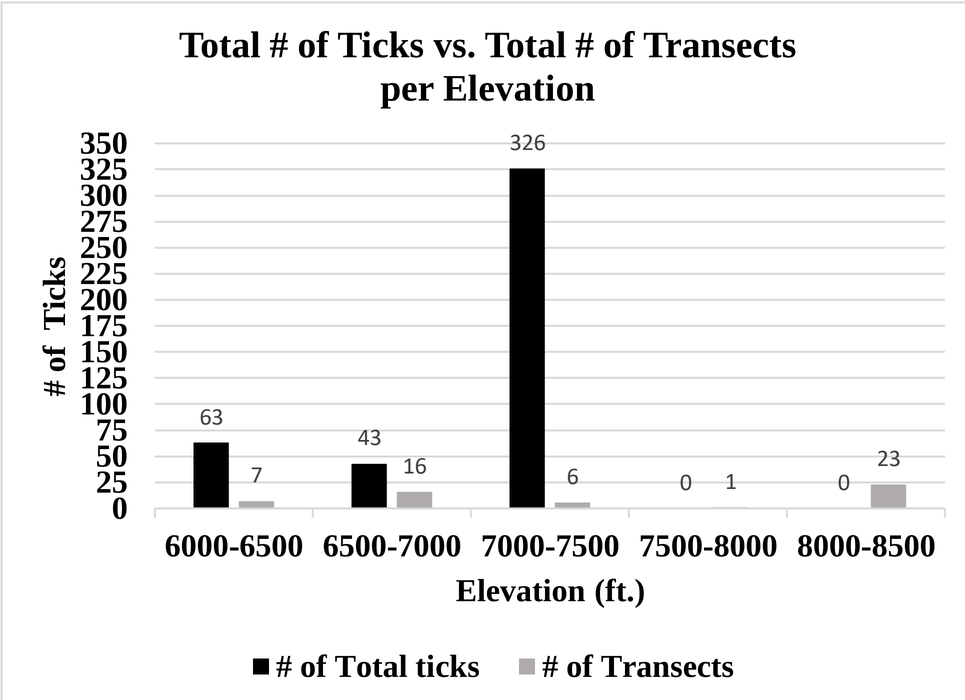

Figure 26: Total number of ticks counted in different elevation ranges along with the number of transects ran at that elevation range.

WINTER TICK COUNTS 2017, 2018 & 2019

Tick counts were conducted on recaptured moose in January 2018-19 to try an observe differences in tick counts from one year to the next. Researchers predicted the tick counts in January 2018 would be lower than that of January 2017. The suspected reason for the decrease in the number of ticks was there was an increased snowpack in the winter of 2016-17 vs. the snow conditions in the winter 2015-16. Winter ticks do not reproduce as well when snow last longer into the spring as they do when snow diminishes in the spring (Samuel 2007, Rodenhouse et al. 2009). Our hypothesis was correct the overall tick counts on the Wasatch were almost cut in half in January 2018 vs. January 2017. (Figure 27). Researchers then predicted we would see an increase in ticks during captures in 2019 because of the historically dry 2017-18 winter. Our hypothesis was correct once again and tick numbers were even higher than in 2017 (Figure 27).

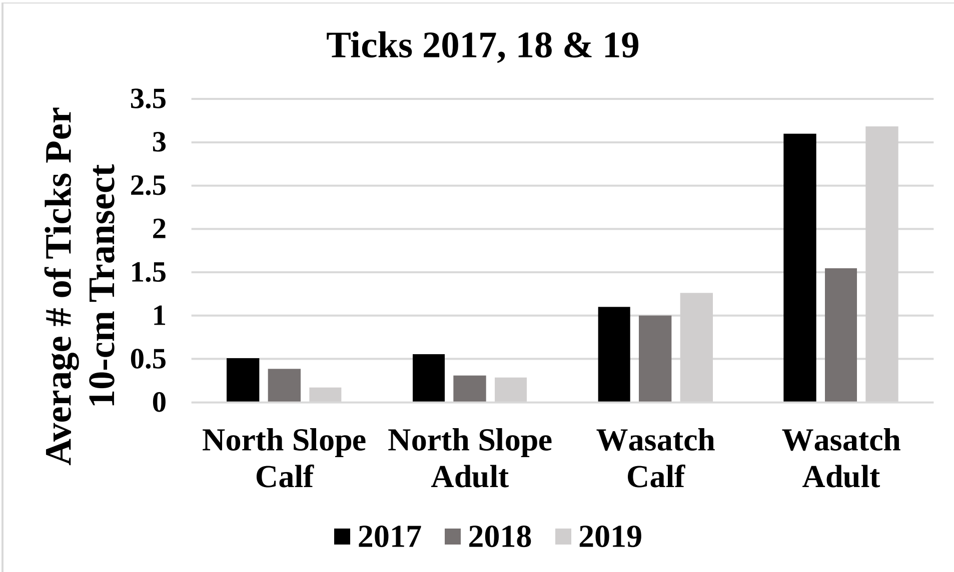

Figure 27: Average number of ticks per 10 cm. transect for the North Slope and Wasatch for 2017, 18 & 19.

WINTER TICKS IMPACTS ON CALVING

There is substantial evidence that winter ticks have a negative impact on calf moose survival and thus calf recruitment (Jones et al. 2017). In Utah it is also believed that winter ticks are having an impact on calf survival however the sample size of captured calves with high tick loads is small which makes it difficult to prove statistically. The reason sample size is small is because the moose with calves are those with lower tick loads and there is significant correlation between cow and calf tick loads. This makes sense because the calves follow their mother closely so if the cow picks up many or few ticks the calf, or calves will likely do the same. From the data collected it appears that winter ticks in Utah are having the greatest impact on cow moose and their ability to produce a viable calf that survives to be recruited. High tick loads can affect a cow's fitness and ability to reproduce because of the high protein deficit caused from large amounts of blood loss (Musante et al 2010). The lack of fitness and the ability to carry a pregnancy full term could be due to the loss of body condition in the spring from winter ticks (Musante et al 2010). This could be leading to abortions or stillbirths, which we observed on the Wasatch in 2017, 2018 and possibly in 2019 where we suspect several cows had calves that were aborted or lost shortly after birth from cows that had high tick loads. This may help explain why calving rates on the Wasatch have been approximately 30% lower than the pregnancy rates in 2017, 18 and 19.

We know from previous work that body condition - specifically rump fat, is a good indicator of a moose's health and its ability to reproduce (Ruprecht et al. 2016). In Stata (Statistical Data Analysis) we ran several logistic regression models looking at different variables affecting a moose having a calf. The one with the lowest AIC was the model with tick loads interacting with rump fat. This model suggests that moose with low to moderate rump fat (0-4 mm) and high tick loads have a reduced probability of having a calf (Figure 28 & 29). Only when a moose has 8 mm of rump fat or more can it overcome the effects of high tick loads impeding its ability to have a calf (Figure 30). This is encouraging suggesting that if a moose is healthy enough tick levels that we see in Utah will not affect a moose's ability to have a calf. The problem is 62% of the moose captured or recaptured have had rump fat levels at or below 4 mm (Figure 31). Tick loads are likely to increase with the effects of climate change where warmer shorter winters favor winter ticks and their reproduction (Samuel 2004). It is critical that wildlife managers develop a management plan to grow healthier moose in the state of Utah if we want to overcome the negative effects of winter ticks.

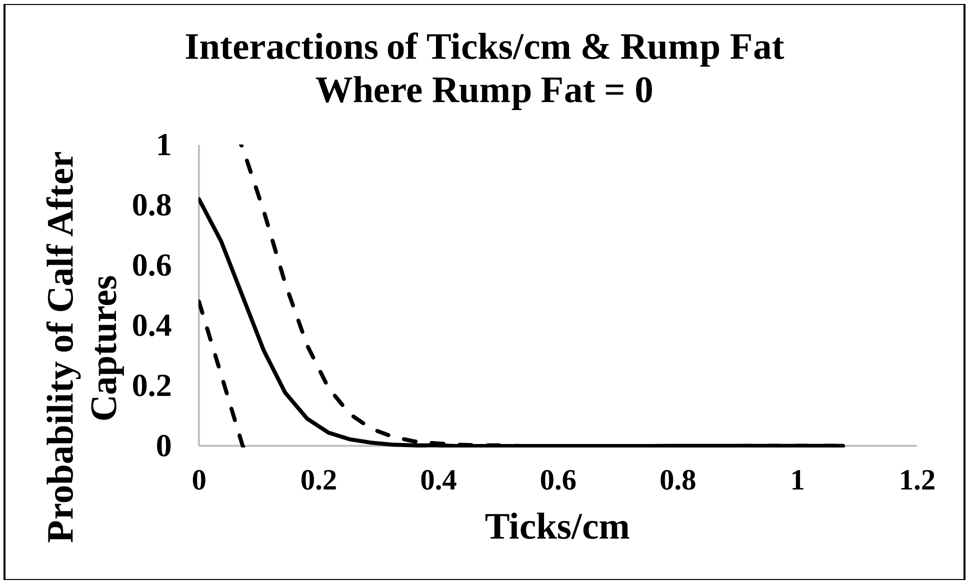

Figure 28: Probability of a cow moose having a calf with 0 mm rump fat with varying number of ticks per cm.

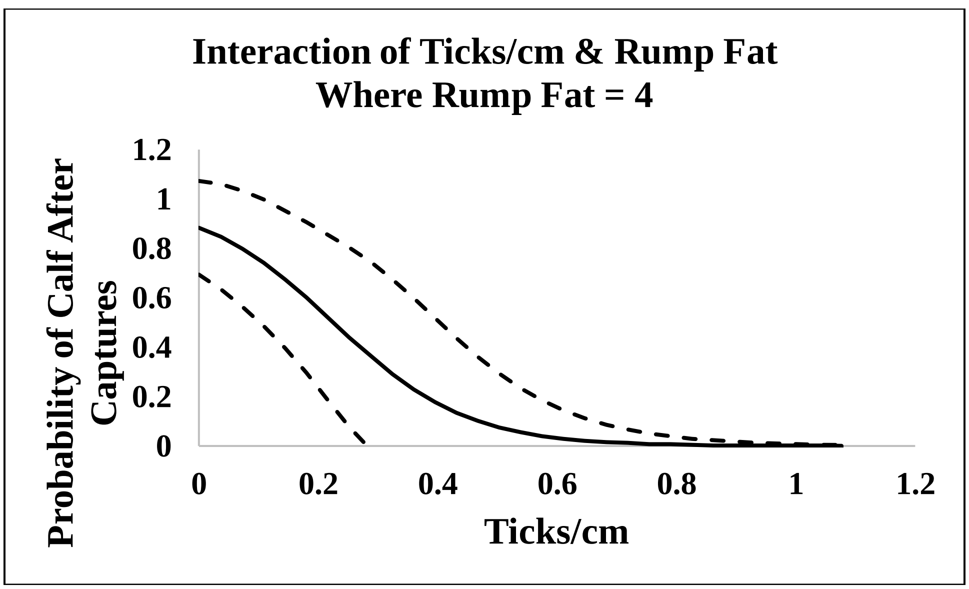

Figure 29: Probability of a cow moose having a calf with 4 mm rump fat with varying number of ticks per cm.

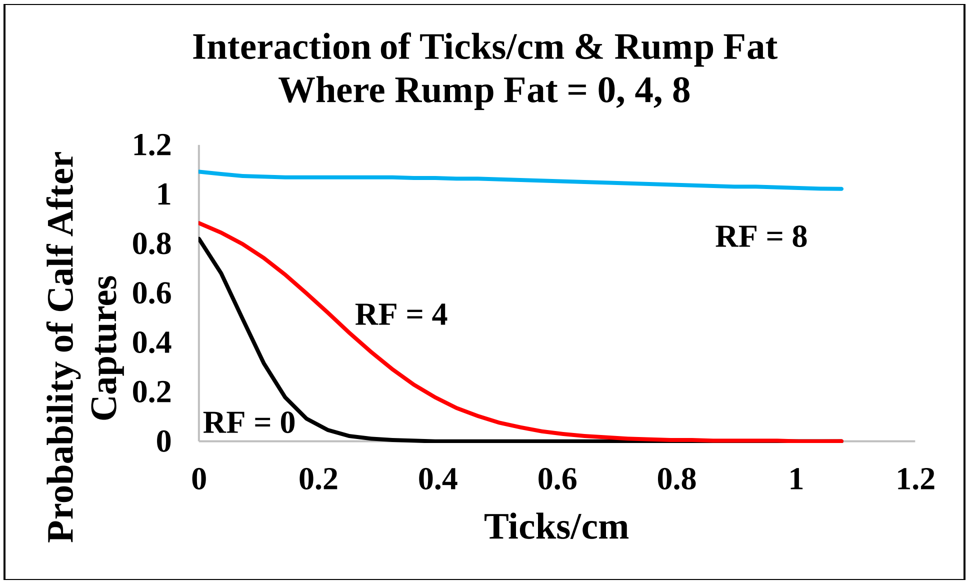

Figure 30: Probability of a cow moose having a calf with 0, 4 and 8-mm rump fat with varying number of ticks per cm.

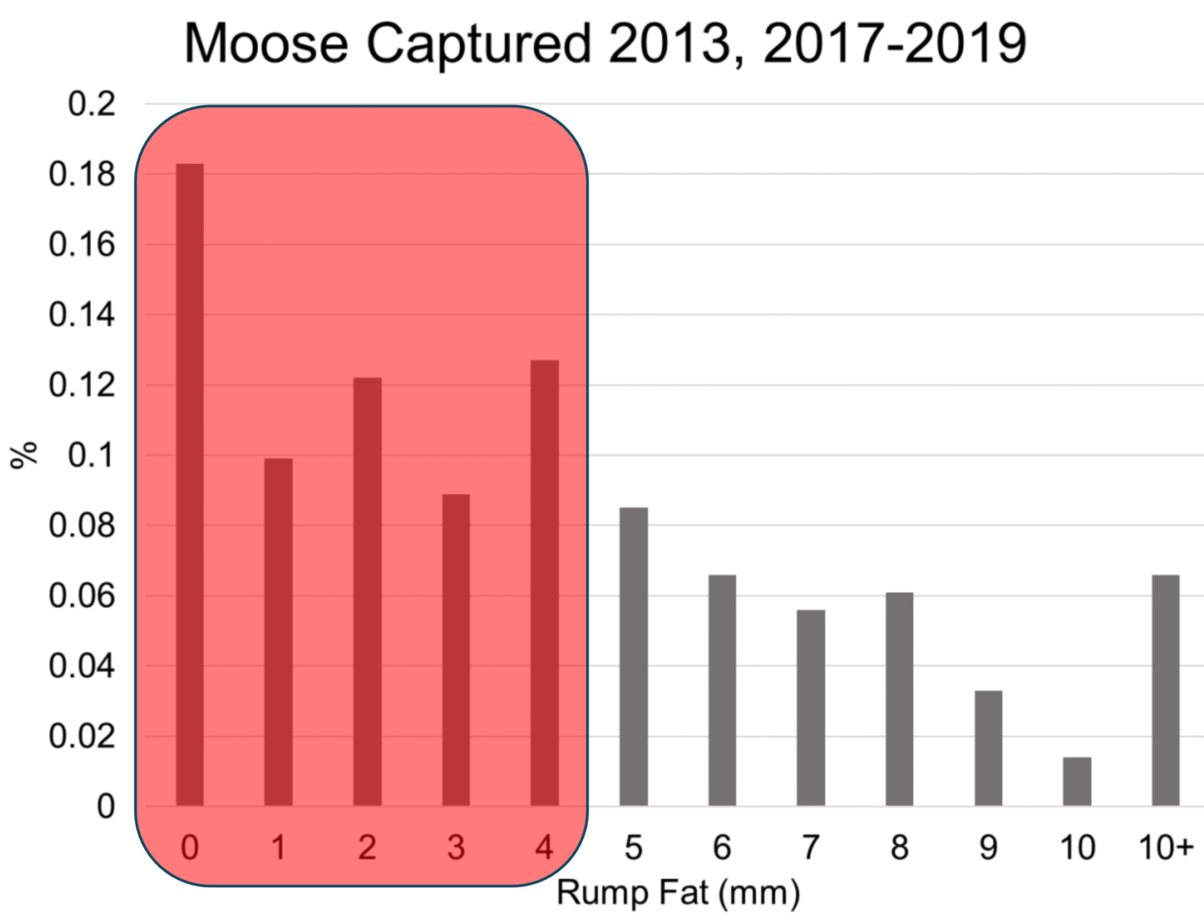

Figure 31: Amount of rump fat of each moose captured in 2013, 17, 18 & 2019.

CONCLUSION

As this study comes to an end our understanding of moose in Utah has grown exponentially since the beginning in 2013. We now have collected and have knowledge of moose vital rates for seven years on two moose management units in the state. These rates include pregnancy, calving, calf survival, calf recruitment and adult survival. We know that body condition and age can have a significant impact on reproductive success (Ruprecht et al 2016). Reproductive success also is being impacted by winter ticks and winter ticks may be limiting moose population growth more than previously thought. Our understanding of cause of mortality of calves and adults has improved substantially. In this study it has been shown that our moose die from a host of things, and it is difficult to pinpoint any one thing causing any one moose mortality. From the body condition assessments at captures we now know that many moose in Utah are in poor shape and many that die appear to be malnourished. Migration patterns of moose have been recognized with the help of GPS collars with moose on the North Slope wintering at lower elevations and summering at higher elevations and that movement from one drainage to the next is happening. Several moose on the Wasatch are moving from Cascades Springs in the winter over to Little Cottonwood Canyon to summer. These movements can help future researchers recognize critical moose habitat. There are many more things we are looking at and will continue to look at with the help of this data that has been collected over the seven years of this study. This data has only begun to be analyzed; many more observations and discoveries will come from this data that was collected.

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