DETERMINING CAUSE-SPECIFIC MORTALITY OF ADULT MOOSE IN NORTHEAST MINNESOTA, FEBRUARY 2013 – JULY 2017

Michelle Carstensen, Erik C. Hildebrand, Dawn Plattner, Margaret Dexter, Véronique St-Louis, Christopher Jennelle, and Robert G. Wright (Minnesota IT Services)

SUMMARY OF FINDINGS

The primary goal of this study is to improve our understanding of the causes of non-hunting mortality in northeastern Minnesota's declining moose (*Alces alces*) population. Our goal is to respond to potential mortalities within 24 hours of death, prior to decomposition of tissues, and determine proximate cause of death and contributing factors. From 2013–2015, we captured and radio collared a total of 173 adult moose (123 females, 50 males). Mean age at capture was 6.1 (±0.3) years of age; range was 1 to 16 years. A total of 57 collared moose (40 females, 17 males) have died, excluding 12 capture-related mortalities that will be censored from subsequent survival analyses. Annual mortality rates were 19%, 12%, 15%, and 14% in 2013, 2014, 2015, and 2016, respectively. The mortality rate from January–July 2017 was 9%. Overall proximate causes of death included: wolf predation (n=18, 32%), parasitic infections (n=17, 30%), bacterial infections (n=12, 21%), accidents (n=2, 3%), hunter-harvest (n=1, 2%), calving complication (dystocia) (n=1, 2%), and undetermined health issues (n=6, 10%). At least 40% of the moose killed by wolves had other serious health issues that may have predisposed them to predation. *Parelaphostrongylus tenuis* was confirmed in 23% of all moose mortalities as either the direct cause (n=7, 12%) or a contributing factor (n=6, 11%) in their deaths. Whole carcasses were retrieved for 22 (39%) of mortalities, with field necropsies performed on the remaining 35 (61%) moose. Response times from initial mortality notification (e.g., text message or email) to a team in the field at the death site were ≤24 hours in 38 cases (67%), between 24 and 48 hours in 11 cases (19%), and >48 hours in 8 cases (14%). There are currently 27 moose remaining in the study with active collars that are still being monitored for survival. Unfortunately, collar failure rates have been high (causes unknown, assumed to be battery or transmission failures), with 21 collars recovered from live moose via remote blow-off mechanisms and another 53 collars unaccounted for; thus, we are not certain of their status (live or dead).

INTRODUCTION

Until recently, 2 geographically distinct moose (*Alces alces*) populations occurred in Minnesota (MN), one in the northwestern (NW) and the other in the northeastern (NE) part of the state. Since the mid-1980s the NW population has decreased from an estimated 4,000 to less than 100 moose, and since 2006 the NE population has declined 58% from an estimated 8,840 to 3,710 moose (DelGiudice 2017). However, there is some evidence that the moose population in the NE may be stabilizing over the last 5 years (2012-2017) at approximately 4,000 animals. Mean annual mortality rates of adults have been similarly high (21%) in both regions (Murray et al. 2006, Lenarz et al. 2009). Parasites, including liver flukes (*Fascioloides magna*) and brainworm (*Parelaphostrongylus tenius*) and other non-specific health-related issues have been documented in the majority of moose deaths through these past research efforts (Wünschmann et al. 2015). Climate change has also been implicated as an underlying factor in both population declines.

There were inverse relationships between warming ambient temperatures and decreasing survival of adult moose (Murray et al. 2006; Lenarz et al. 2010). Trends in temperature and precipitation patterns are likely to increase in intensity over the next century. If moose are unable to sufficiently thermoregulate above certain ambient temperature thresholds, we might expect to see increased body temperatures and energy expenditures required to stay cool, which over time could have negative consequences for body condition, reproduction, and survival. Currently, no data exist to support the direct adverse effects of ambient temperature on the physiology, survival, or reproduction of free-ranging moose.

This study will determine cause-specific mortality by deploying satellite-linked Global Positioning System (GPS) collars on moose in NE MN and by preparing an extensive network of responders highly trained in conducting field necropsies. Moose mortalities will be thoroughly investigated within 24 hours of death to identify the proximate cause of mortality and to examine the influence of potential contributing factors. Once causes of death and major influential factors are identified, appropriate management actions may be taken to address the population decline. Our main objectives are to 1) determine causes of non-hunting mortality (i.e., identify specific disease and parasite agents) and assess the role nutrition plays as a contributing factor; and 2) investigate how ambient temperatures relate to moose survival in NE MN by applying an unprecedented field approach and comprehensive data collection methods.

Recently, a minimally invasive telemetry system for ruminants, called a mortality implant transmitter (MIT), has been developed to allow nearly continuous monitoring of body temperature with a battery lifetime of approximately 2 years. Using these MITs and GPS collars on adult moose in this study will allow us to correlate ambient temperature with their physiology, behavior (habitat use and activity), and fitness (survival and reproduction). This study will be the first to examine these relationships in a way that includes monitoring body temperature. The results of this study will be critical to an improved understanding of if, when, and how moose are able to successfully modulate their internal body temperature. Such an understanding should prove valuable in the formulation of future population and habitat management strategies and activities.

METHODS

Moose (n=173; 123 females, 50 males) were captured within the 3,732.8 km^2 study area located between 47°12’N and 47°95’N latitude and 90°33’W and 91°72’W in NE MN (Figure 1) from 2013 to 2015, as described previously (Butler et al. 2013; Carstensen et al. 2014, 2015, 2016). All moose were fitted with GPS-Iridium satellite collars (Vectronic Aerospace GmbH; Berlin, Germany). Mortality implant transmitters (Vectronic Aerospace GmbH) were placed orally into a subset of the captured moose and provided immediate notification of mortality and recorded internal body temperature. External temperature loggers (Hobo TidbitV2; Onset Corporation, Bourne, MA) were attached to the GPS collars and were programmed to collect ambient temperature every 60 minutes. Additional ambient temperature loggers (black globes and white funnels) were placed in 7 open habitat sites throughout the study area. Data from the temperature loggers will be used along with data from 12 National Oceanic and Atmospheric Association and Remote Automatic Weather Stations in NE MN to determine the best ambient temperature predictor for moose with MITs in this study.

Moose mortality response teams have 8 primary team leaders that have undergone extensive necropsy training, and they are supported by about 20 secondary and tertiary team members (including MNDNR, tribal, academic, US Forest Service, and other personnel) available upon request. Every effort is made to respond to a moose mortality event with 24 hours of notification and to remove carcasses intact from the field and deliver them to the University of Minnesota Veterinary Diagnostic Laboratory (UMN VDL) for a complete necropsy by a board-certified pathologist. If a moose was found to be alive, but obviously ill, it was euthanized (via gunshot to the neck). If carcass extraction was not possible, a thorough and complete field necropsy was performed, guided by an established protocol. Samples were submitted to the UMN VDL for diagnostic evaluation (Carstensen et al. 2014, 2015, 2016).

Moose age was determined by cementum annuli at time of capture and we used one-way analysis of variance to compare age among years. A two-sample T-test was used to compare the mean age of moose killed by predators to those that died of health-related causes. Dead moose were categorized by age as young (≤3 years), prime (4–8 years), and old (≥9 years) and chi-square analyses was used to compare age cohorts by predator and health-related causes of death. Annual (January-December) survival rates were estimated using Kaplan-Meier to allow for staggered entry design.

RESULTS AND DISCUSSION

Annual Survival and Cause-Specific Mortality

From 2013–2015 a total of 173 adult moose (123 females, 50 males) were captured and radio collared. Mean age at capture was 6.1 (±0.3, *n*=163) years for all moose; range was 1 to 16 years. Age of moose at capture was similar [*F-stat*=1.65, *p*=0.19] among years (6.0 years in 2013, n=101; 5.8 years in 2014, n=32; and 7.2 years in 2015, n=30). Annual (January–December) survival rate was 81%, 88%, 85% and 86% in 2013 through 2016, respectively; 91% of moose have survived from January–July 2016 (Figure 2). A total of 57 collared moose (40 females, 17 males) have died since this study began; which excludes 12 capture-related mortalities that are censored from subsequent survival analyses. Overall proximate causes of death included: wolf predation (n=18, 32%), parasitic infections (n=17, 30%), bacterial infections (n=12, 21%), accidents (n=2, 3%), hunter-harvest (n=1, 2%), calving complication (dystocia) (n=1, 2%), and undetermined health issues (n=6, 10%; Figure 3). Health-related causes were attributed to 68% of total deaths, with the remaining 32% being predator-related.

Eight (44%) of the wolf-killed moose had significant health conditions that likely predisposed them to predation, including encephalitis and meningitis in the brain*, P. tenuis* infections, winter tick (*Dermacentor albipictus*) infestations, calving, and pneumonia in the lungs (Figure 4a). Unfortunately, diagnostics were limited in 10 of the wolf-killed moose due to the degree of carcass consumption prior to the mortality team's arrival to the scene. It is possible that health issues may have compromised some of these moose as well.

Parasitic infections were the second leading cause of moose deaths (Figure 4b). *P. tenuis* directly led to the death of 7 moose in this study; however, this parasite was also implicated in 5 wolf-caused deaths and 1 bacterial infection. Overall 23% of the moose that died during this study have been impacted by *P. tenuis* and this is likely an underestimate, as not all dead moose could be evaluated for this parasite. Winter tick infestations were primarily seen in spring 2013 (attributed to 3 moose deaths), as the severe and prolonged winters in 2012-13 and 2013-14 likely reduced tick survival. However, the past 3 winters have been extremely mild and it's likely that winter tick loads have recently increased on moose. In spring 2016, one moose in the study died from winter ticks; however, significant tick infestations were observed in other moose as well. We had expected that moose surviving into spring 2017 would experience a significant winter tick burden and this would result in an increase in tick-related mortalities; however, none of the collared moose died from winter tick burdens in 2017 but the sample size has markedly declined to only 41 animals left to monitor at the beginning of this year. Most moose in this study had livers that were damaged by liver flukes (*F. magna*), the severity of which varied from mild cases to severe infections that directly caused the death of 3 moose. Similarly, the majority of moose in this study had hydatid cysts in the lungs or liver, caused by *Echinococcosis granulosis*, but only 2 moose had severe enough infections with this parasite to cause mortality. We also observed one moose with an extensive cysticercus (*Taenia krabbei*) infection throughout the body, including the heart, which resulted in death due to reduced cardiac function.

Bacterial infections were the third leading cause of moose deaths (Figure 4c). Four moose were attacked by a wolf or wolves and survived the initial encounter, but the wounds became infected and led to their death days to several weeks later. Prior to this study, scant evidence in the literature points to secondary bacterial infections caused by a predator attack as a major cause of moose mortality. Other trauma, including one case of conspecific fighting of antlered males, resulted in puncture wounds that provided a route for bacteria to enter the body and cause systemic infection and septicemia. The exact circumstances that led to some of these trauma-induced injuries were unknown.

The remainder of moose deaths were caused by accidents (1 vehicle collision and 1 fall through the ice), hunting (1 moose was legally harvested by a tribal member), calving complications or dystocia (1 moose had twin calves stuck in the birth canal while being expelled simultaneously), and undetermined health-related deaths (6 moose).

There are currently 27 moose remaining in the study with active collars. Unfortunately, collar failure rates have been high (causes unknown, assumed to be battery or transmission failures), with 21 collars recovered from live moose via remote blow-off mechanisms and another 53 collars unaccounted for; thus, we are not certain of their status (live or dead). Three moose had their collars slip off their necks, presumably due to an excessively loose fit, and were recovered in the field.

Timing of Mortalities

Timing of these mortalities suggest that most deaths occur in spring (44%, March–May); however, moose died in all seasons (winter 17%, summer 23%, and fall 16%; Figure 5). Health-related mortalities occurred during all months of the study; however, there were no wolf-related deaths in October through January (Figure 6).

Mean age of moose (n=55, excludes 2 moose with age results pending) at death was 8.4 years (±0.5 year); range was 1 to 15 years old. Mean age of moose that died from health-related causes (n=35; excluding 2 moose with accidental deaths and 1 moose harvested by hunters) was 8.1 years (±0.6 year), similar [*T-stat*=2.0, p=0.7] to those (n=18) that died of wolf-related causes (8.6 ±1.0 years). Interestingly, both health and predator-related causes of death impacted nearly every age cohort in this study (Figure 7), yet there was some evidence (X^2 *stat*= 45.0, p=0.08) to support that wolves were more selective for the young (≤3 years of age) or old (≥9 years of age) cohorts and more prime-aged moose were dying of health-related issues.

Mortality Response Times

Whole carcasses were retrieved for 22 (39%) mortalities, with field necropsies performed on the remaining 35 (61%) moose. Response times from initial mortality notification (e.g., text message or email) to a team in the field at the death site were ≤24 hours in 38 cases (67%), between 24 and 48 hours in 11 cases (19%), and >48 hours in 8 cases (14%). Delays in mortality responses >24 hours have been due to collar failures and wolves actively feeding on the moose carcass and preventing the collar from sending a mortality alert.

Mortality Implant Transmitters

We successfully deployed 63 MITs in moose during this study. Deployment failures occurred in 20 moose, where the MIT was not fully swallowed and regurgitated (*n*=19) or the bolus failed to reach the rumen (*n*=1). A revised and improved MIT deployment technique was implemented during the final year of capture of this project, and improved success rates from 73% (43 of 59 attempts, 2013-2014) to 85% (20 of 23 attempts, 2015) (Minicucci et al. 2017). To date, 20 moose with working MITs have died in the study and their body temperature data was collected; however, 4 of these moose were capture-related mortalities and their data will be censored from further analyses. Another 11 MIT datasets have been recovered from remotely blown collars (n=9) and slipped collars (n=2); however, 17 moose with MITs have collars that have malfunctioned and their survival status is unknown; it's unlikely these data will be ever be recovered. Currently, 15 of the 27 moose remaining in the study with functioning collars have MITs.

MNDNR collaborated with the Alaska Department of Game and Fish to conduct a MIT calibration project at the Moose Research Center in Kenai, Alaska from 2014–2015. The MIT was shown to be a highly accurate measurement of internal body temperature in moose (Herberg et. al 2016). After removing water intake-induced low temperatures, MITs recorded internal body temperatures only 0.03 °C (95% CI -0.57-0.55) lower than vaginal implant transmitters (VITs) and were therefore considered highly accurate. We have begun some preliminary analyses using MIT data recovered to date. MIT data from 25 wild moose (15 females, 10 males) in this study were recovered either at death (*n*=16), from collars that slipped or were remotely released (*n*=6), or from recollaring events (*n*=3). MIT values were obtained for an average of 400 days for these moose (range 57 to 941 days). Out of these 25 animals, 23 had between 0.19% and 11.25% of internal temperatures considered above normal (i.e. ≥ 39.2°C). The percent MIT temperatures that were above normal varied seasonally, ranging from 0.63-25.07% (μ=8.18%), 0.04-13.46% (μ=1.92%), 0-2.41% (μ=0.64%), and 0-2.39% (μ=0.15%) in summer, fall, spring, and winter, respectively. There may be behavioral tradeoffs moose have to make to seek dense cover to "cool-off", especially in the summer, to the detriment of time spent in high quality forage habitat. Further analyses, focusing on the summer months, will incorporate the environmental conditions (habitat & ambient temperatures) moose experienced, as well as movement patterns and activity levels they exhibited, in the time periods before and after periods of abnormally high internal body temperatures, in an effort to unveil some of these tradeoffs.

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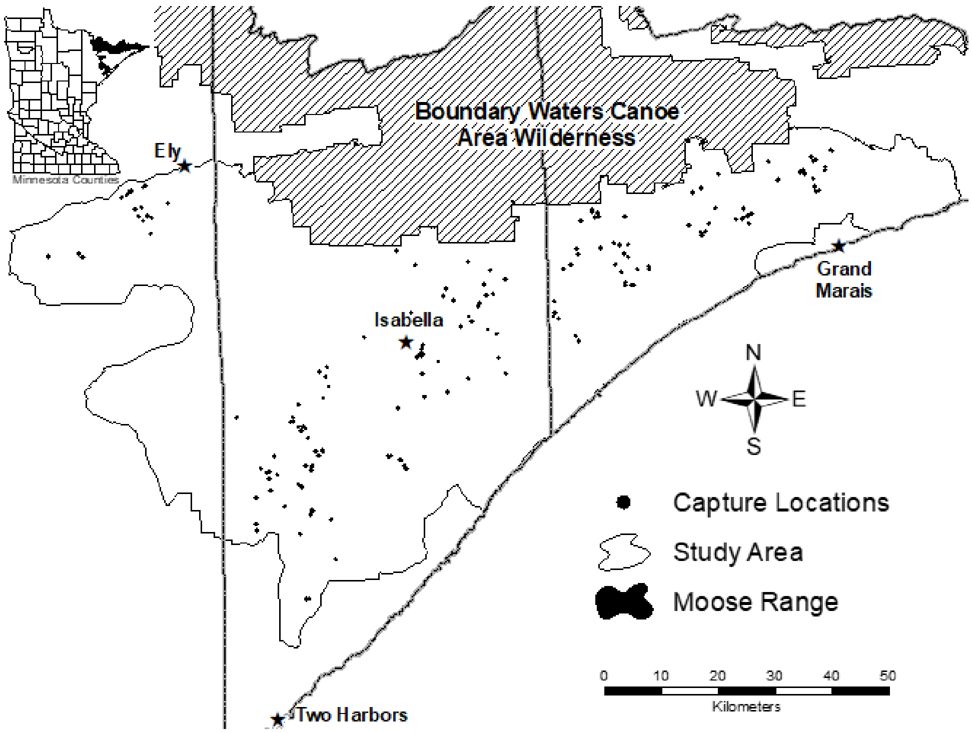

Figure 1. Study area in northeast Minnesota where 179 moose (included 6 recaptures) have been captured and radio-collared (2013–2015) to study cause-specific mortality.

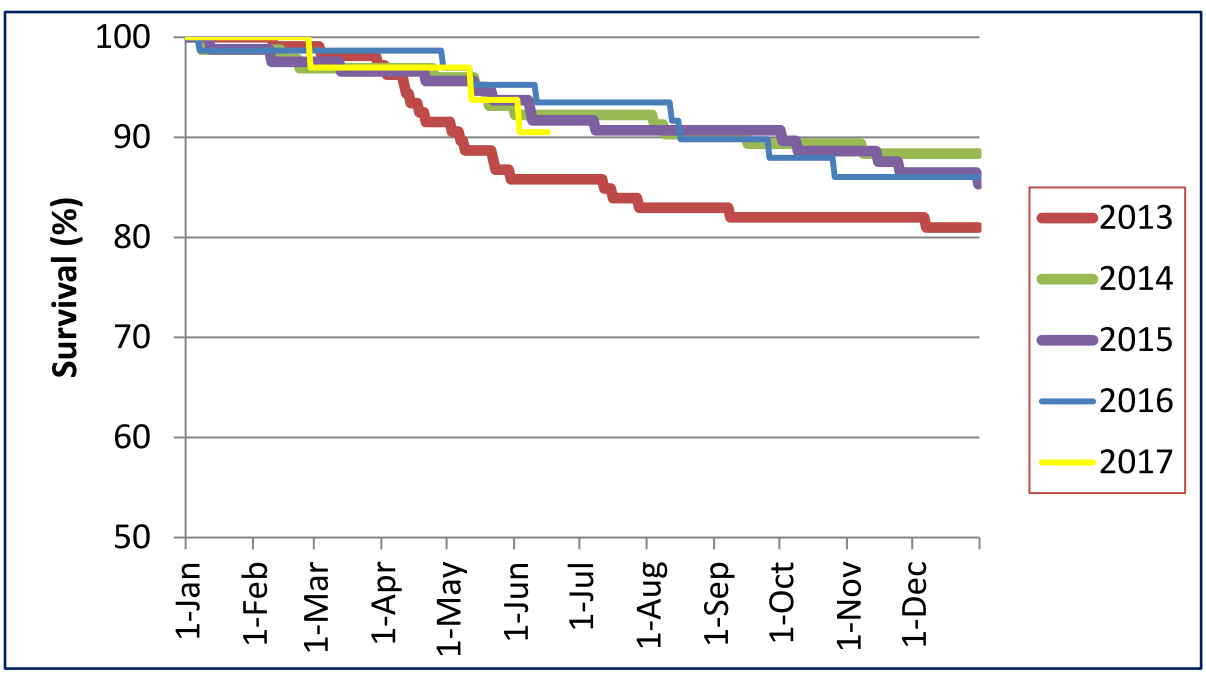

Figure 2. Annual survival of radio-collared, adult moose (*n*=173) captured from 2013-2017, northeast Minnesota.

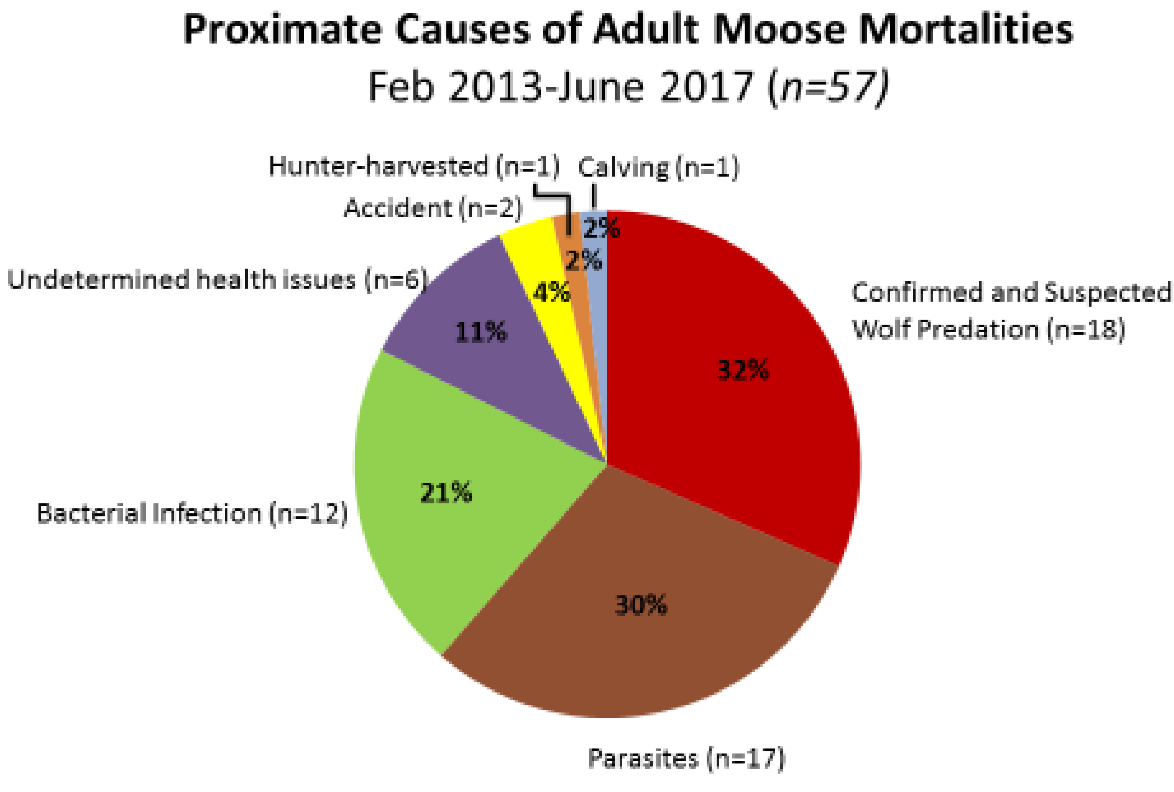

Figure 3. Cause-specific mortality of radio-collared, adult moose (*n*=57) from February 2013-July 2017, northeast Minnesota.

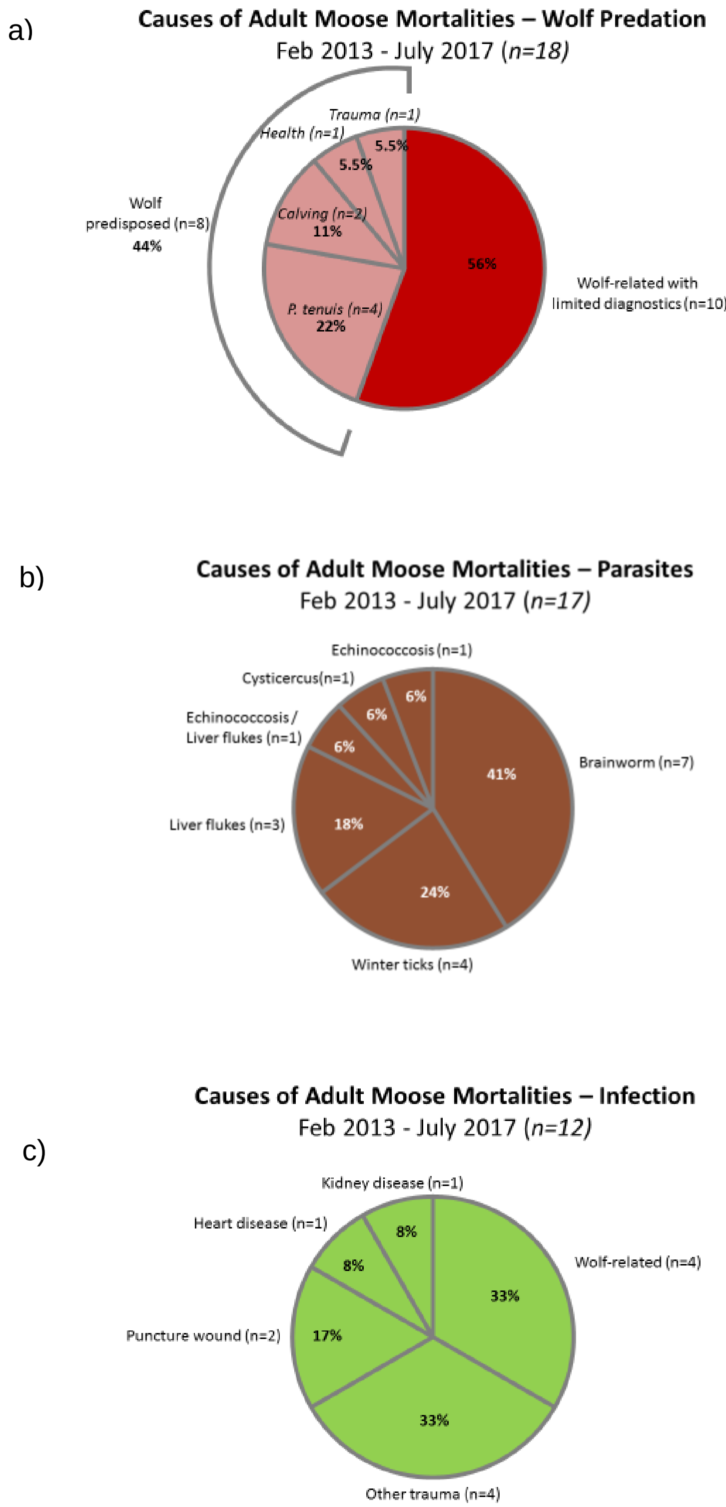

Figure 4. Breakdown of adult moose mortalities caused by wolf predation (a), parasites (b), and bacterial infections (c), Feb 2013-July 2017, northeast Minnesota.

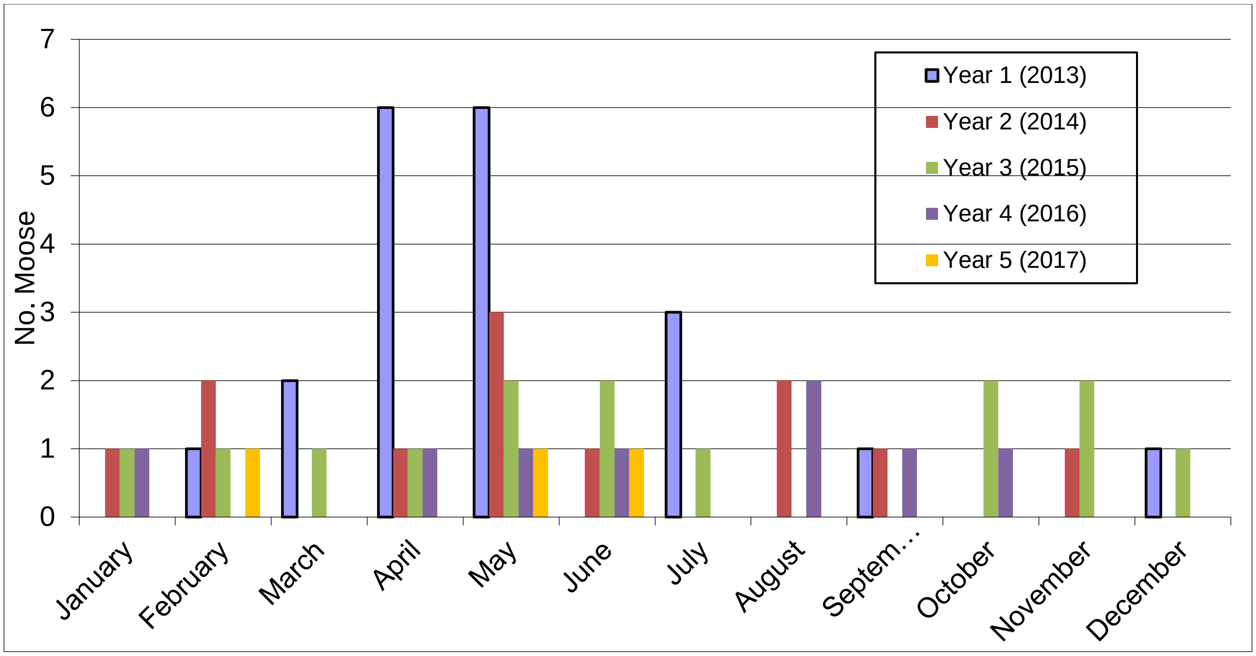

Figure 5. Timing of mortalities for radio-collared, adult moose (*n*=57) from January 2013-July 2017, northeast Minnesota.

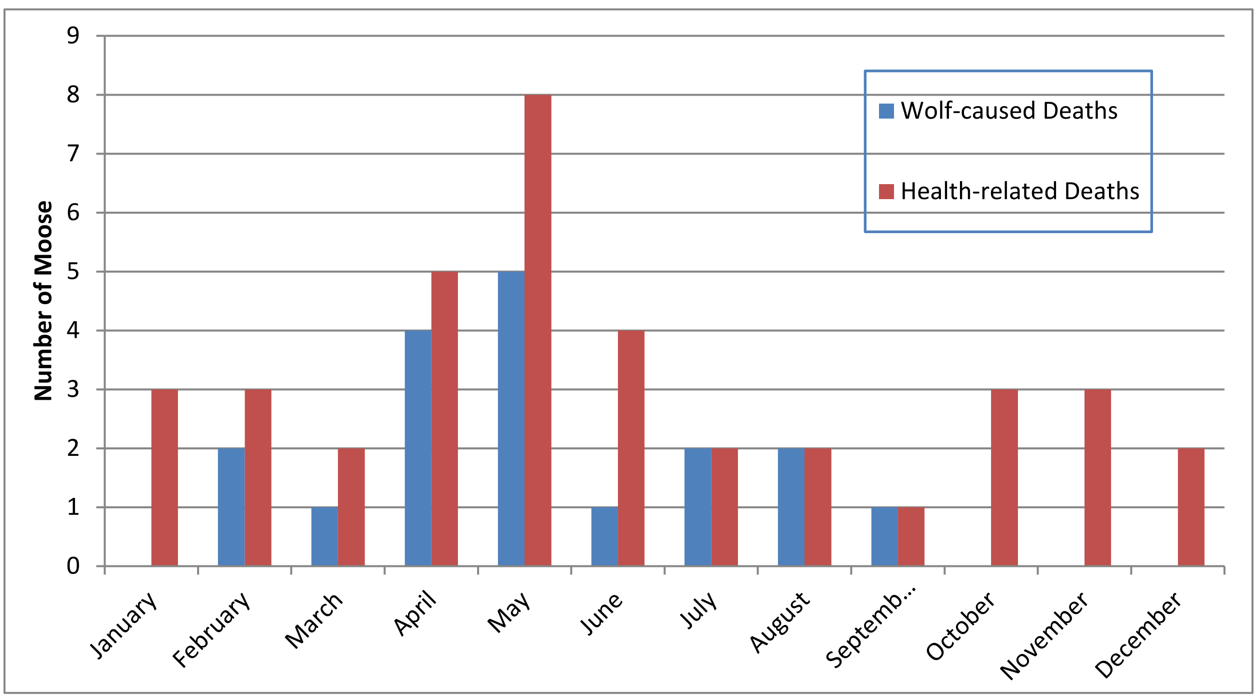

Figure 6. Timing of wolf-caused (*n*=18) and health-related (*n*=38) moose mortalities, 2013-2017, northeast Minnesota.

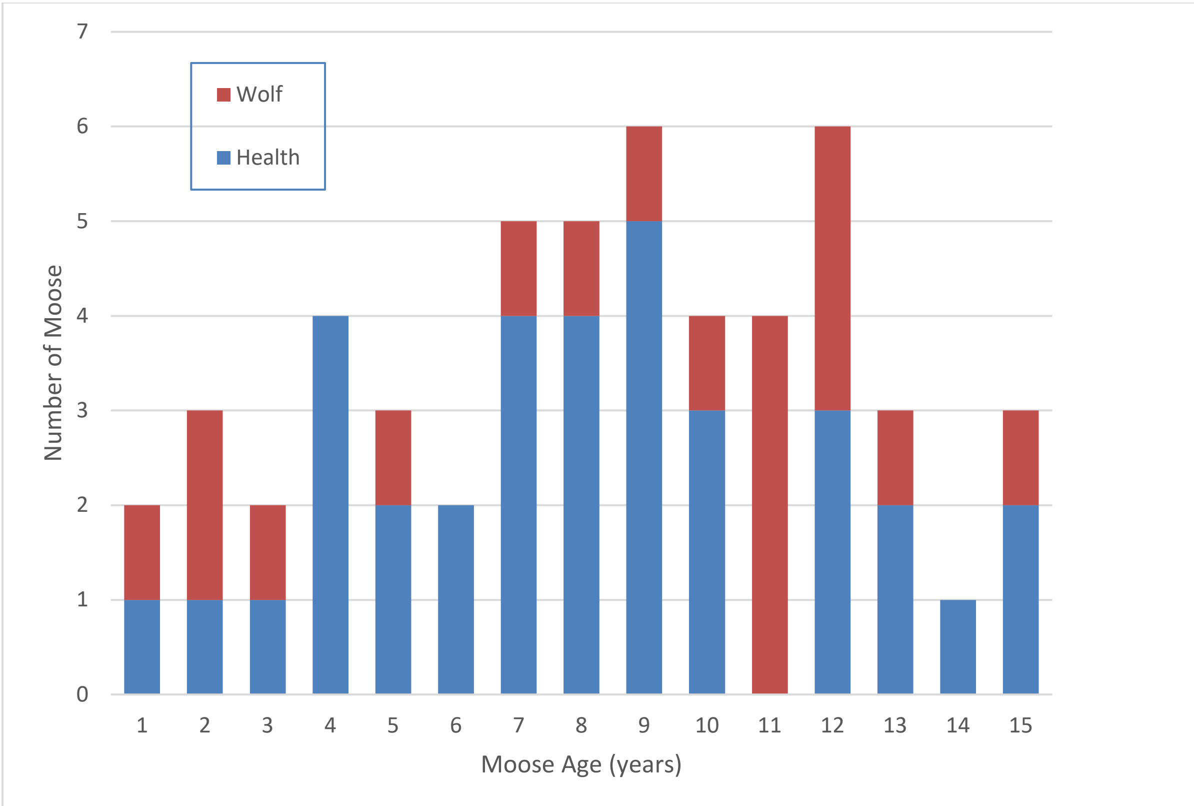

Figure 7. Known ages of radio-collared, adult moose (*n*=53) that died from health-related (blue) or wolf-related (red) causes (2013-2017), northeast Minnesota, 2013-2017.