CAUSES OF NON-HUNTING MORTALITY OF ADULT MOOSE IN MINNESOTA, 2013 – 2017

Michelle Carstensen, Erik C. Hildebrand, Dawn Plattner, Margaret Dexter, Arno Wünschmann[1], and Anibal Armien[1]

SUMMARY OF FINDINGS

Minnesota's moose (*Alces alces*) are dying at rates much higher than elsewhere in North America. Moose have been nearly extirpated from the northwestern part of the state and aerial surveys indicate the northeastern population has declined 55% over the past decade. In 2013, a new study began to determine cause-specific mortality of adult moose in northeastern Minnesota by using GPS-satellite collars to get rapid notification of mortality events and recover carcasses within 24 hours of death. A total of 173 moose were collared over 3 years with annual non-hunting mortality rates of 19%, 12%, 15%, 13% and 14% in 2013-2017, respectively, and an overall mean of 14.4%. In total, 57 moose have died from non-hunting sources of mortality and 3 moose were legally harvested. Response times from mortality notification to arrival at the carcass were within 24 hours for 65% of death events. Most causes of mortality were health-related (65%), which included parasites (30%), bacterial infections (20%), accidents (3%), calving (2%) and other undetermined health issues (10%).The remainder was wolf-related (30%), with predisposing health conditions identified in nearly half of these moose. Legal harvest accounted for 5% of moose deaths. During the same time period, we also necropsied anecdotal moose deaths (n=91) across northern Minnesota, which included vehicle or train collisions, sick, and found dead animals. *Parelaphostrongylus tenuis* was confirmed in 42% of these cases, which is nearly twice the rate of detection of this parasite as in the collared moose studied during the same time period.

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 66% from an estimated 8,840 to 3,030 moose (DelGiudice 2018). However, there is some evidence that the moose population in the NE may be stabilizing over the last 7 years (2012-2018) 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 (Murray et al. 2006, Lenarz et al. 2010, Wünschmann et al. 2015). Climate change has also been implicated as an underlying factor in both population declines. Recent study of moose calf survival documented survival rates between 29-40% from 2013-2016, with predation by wolves accounting for over two-thirds of mortalities (Severud 2017).

[1] University of Minnesota, Veterinary Diagnostic Lab, St. Paul, MN

This 5-year study was designed to document causes of non-hunting mortality of adult moose in NE MN by deploying satellite-linked collars and by preparing an extensive network of responders trained in conducting field necropsies. Moose mortalities were thoroughly investigated within 24 hours of death to identify the proximate cause of mortality and to examine the influence of potential contributing factors. Further, efforts to investigate reports of non-collared sick and dead moose were intensified to provide additional anecdotal information on moose population health during the same time period. Once causes of death and major influential factors are identified, appropriate management actions may be taken to address the population decline.

METHODS

Moose (>1 year of age) 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 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 (Minicucci et al. 2018, Herberg et al. 2018).

Moose mortality response teams have 8 primary team leaders that have undergone 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 within 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 field necropsy was performed. Samples were submitted to the UMN VDL for diagnostic evaluation (Carstensen et al. 2014, 2015, 2016).

From 2013 to 2017, efforts were enhanced to respond to reports of sick or dead non-collared moose from anywhere in MN, from hereafter referred to as "anecdotal moose." This included sick moose that were still alive at the time of the initial report, recently found dead animals, and vehicle or train collisions. MNDNR biologists and conservation officers responded immediately to these reports and samples or whole carcasses were collected in a similar manner to the collared moose study, with the exception of salvage permits provided for the meat of vehicle-killed moose.

Moose age was determined by cementum annuli analysis of incisor teeth removed at time of capture and we used one-way analysis of variance to compare age among years. Annual (Jan-Dec) survival rates were estimated using Kaplan-Meier to allow for staggered entry design. Moose were censored from the analysis on the date their collar stopped transmitting data, regardless of their survival state beyond that time, if known. Censored animals included those that died <2 weeks post-capture (presumed to be capture-related mortalities), slipped collars, remotely-release collars through a built-in blow off mechanism, hunter-harvested moose, and collars that stopped transmitting location data due to collar malfunction.

RESULTS AND DISCUSSION

Annual Survival and Cause-Specific Mortality of Collared Moose

From 2013–2015 a total of 173 adult moose (123 females, 50 males) were captured and 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 rates were 81%, 88%, 85%, 87% and 86% in 2013 through 2017, respectively (Figure 1); the overall 5-year mean for non-hunting mortality was 14.4%. This is lower than the average non-hunting mortality rate of 21%, reported previously in MN, but higher than the 8-12% rates of North American moose populations (Mytton and Keith 1981, Larsen et al. 1989, Ballard et al. 1991, Stenhouse et al. 1995, Modafferi and Becker 1997). A total of 60 collared moose (41 females, 19 males) have died since this study began; which excludes 12 capture-related mortalities that are censored from subsequent survival analyses. Most collared moose mortalities (96%) occurred within the current moose range in northeast MN (Figure 2). Overall proximate causes of death included: wolf predation (*n*=18, 30%), parasitic infections (*n*=18, 30%), bacterial infections (*n*=12, 20%), accidents (*n*=2, 3%), hunter-harvest (*n*=3, 5%), 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, *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 a leading cause of moose deaths (Figure 4b). *P. tenuis* directly led to the death of 8 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 4 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 37 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 in various skeletal muscles and heart, which likely 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 predator, most likely 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 consistent with 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 (3 moose was legally harvested during tribal hunts), 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 were 18 moose remaining in the study with active collars at the start of 2018. Unfortunately, collar failure rates have been high (causes unknown, assumed to be battery or transmission failures), with 79 collars that failed at varying times throughout the study (Table 1). Luckily, we were able to recover 40 of these failed collars (51%) from live moose via remote release mechanisms and obtain the data stored on the collar (e.g. MIT, activity, GPS location). Three moose had their collars slip off their necks, presumably due to an excessively loose fit, and were recovered in the field. Of the 18 collared moose that remained active into 2018, we attempted to remotely blow off all of these collars over 3 separate flights in January and February, and successfully recovered 16 of those collars. The satellite service for the 2 remaining collars was turned off at the end of March.

Anecdotal Moose Mortality

From 2013–2015 a total of 91 anecdotal sick/dead moose (46 females, 43 males, and 2 unknown sex) reports were investigated throughout Minnesota (Figure 2). This included 62 adults (mean age was 4.5 ±0.5 years, *n*=48), 11 yearlings (>1 and <2 years of age), and 18 calves (<1 year of age). The majority (52%) of reports involved vehicle-killed moose, followed by found dead (24%), sick and euthanized (17%), and train-killed (7%) animals (Figure 5). The majority of these cases reported during the fall season (35%), where moose are moving more due to the breeding season and as a result, are more vulnerable to both vehicle and train collisions (Figure 6). Further, we had the most reports of found dead moose in the fall season, likely due to hunters afield pursing other big game and upland birds. Nearly half of all vehicle-killed moose cases occurred in the summer when tourist season peaks in the northeast and moose may be moving more in response to insect harassment.

Trauma was the cause of death for moose hit by either vehicles (*n*=47) or trains (*n*=6); however, examination of their internal organs confirmed *P. tenuis* infection in 8 moose, brain lesions of unknown cause in 2 moose, and marked liver fluke-induced hepatitis in one moose. Decomposition was a confounding factor in determining the cause of death for half of the 22 moose found dead by members of the public; however, *P. tenuis* infection (*n*=9), winter tick-associated anemia (*n*=1), marked liver fluke-induced hepatitis (*n*=1), and bacterial infection (*n*=1) were confirmed in the remainder. Interestingly, *P. tenuis* infection was determined to be the cause of 15 of the 16 sick moose reports where the animals had to be euthanized. One of these moose was suffering from grain overload and brainworm simultaneously; both condition likely contributed to its death. The only sick moose that didn't have *P. tenuis* infection was an old bull that was injured by conspecific fighting and was dying from a bacterial infection from its wounds.

Our findings of parasitic loads of anecdotal moose from 2013-2017 were very similar to those reported by Wünschmann et al. (2015) for 62 anecdotal moose cases investigated between 2003 and 2013 in Minnesota. Those authors reported 45% of moose had *P. tenuis* infections, 60% had evidence of liver flukes, and 23% had noticeable winter tick loads. Similarly, we found 42% of moose had *P. tenuis* infections, 76% had evidence of liver flukes (18 marked, 13 moderate, and 20 mild infections of 76 cases evaluated), and 21% had noticeable winter tick loads (4 marked, 5 moderate, and 2 mild infestations of 52 cases evaluated).

Parelaphostrongylus tenuis infections occurred in anecdotal moose at nearly twice the rate of collared moose during the same 5-year time period in this study. This is likely due to a sightability bias for *P. tenuis*-exposed moose, as the infection causes animals to seek open areas (roads, train tracks, fields, pastures, logging openings) for prolonged periods of time, which greatly enhances opportunities for humans to see them and report sick moose. In some cases, these brainworm-infected moose appeared to be stuck in the mud or stranded on ice-covered lakes and local wildlife staff would “save” these moose from their dire predicaments. Celebrations were often short-lived as these animals soon returned to compromising situations again and would be euthanized due to public safety concerns. In the collared moose study, it’s likely *P. tenuis* infections were underestimated due to limited diagnostics in cases were carcasses were heavily scavenged or decomposition was too advanced. Thus, the true impact of *P. tenuis* on Minnesota’s moose likely lies between 23-42%, and is clearly playing a key role in the population decline.

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Table 1. Sample size of active, added, dead, and censored moose annually, throughout the 5-year study, 2013-2017.

	2013	**2014**	**2015**	**2016**	**2017**
Active collars at start of year (n)	0	79	81	72	37
New collars added (n)	111	31	31	0	0
Non-hunting related deaths (n)	20	12	13	6	3
Censored moose (n):					
• Capture-related deaths	4	3	5	0	0
• Hunting-related deaths	0	0	1	1	1
• Slipped collars	1	1	1	0	0
• Transmission failures/missing animals	7	13	16	28	15
Active collars at end of year (n)	79	81	72	37	18

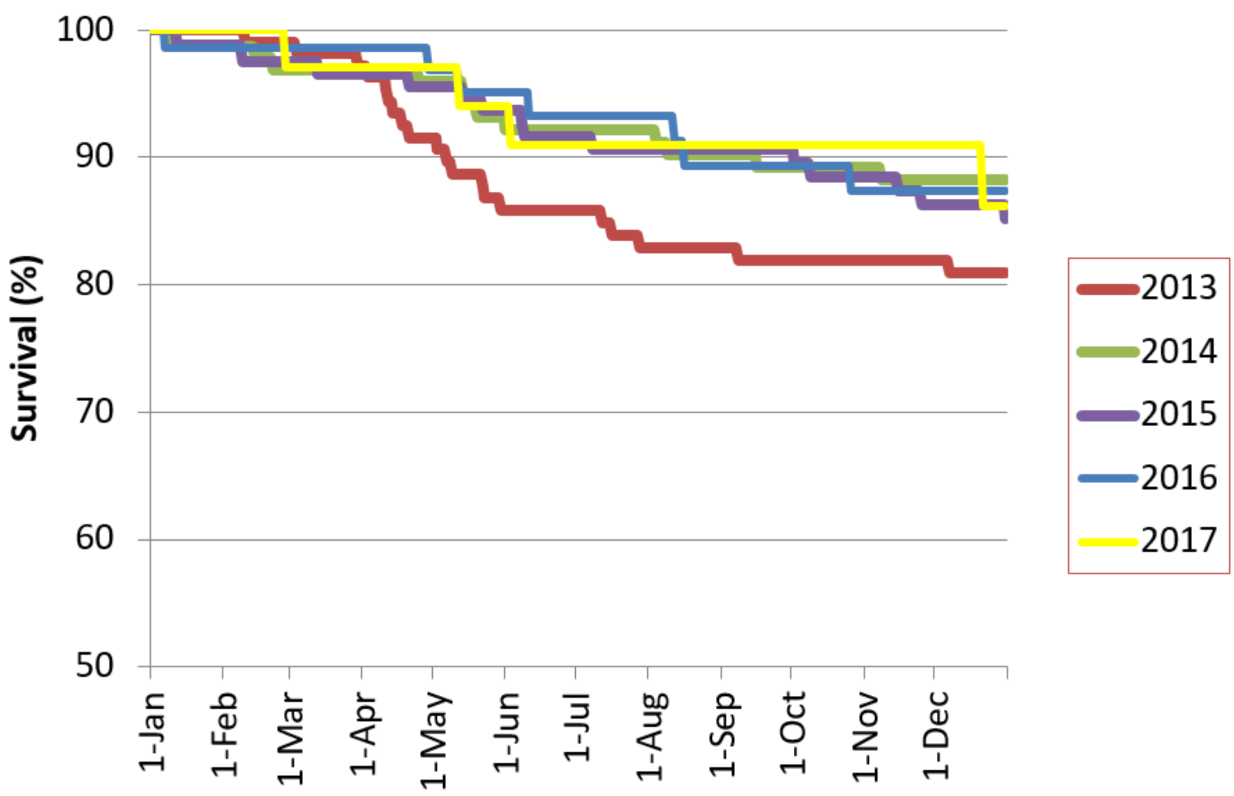

Figure 1. Annual survival of collared, adult moose (*n*=173) captured from 2013-2017, northeast Minnesota.

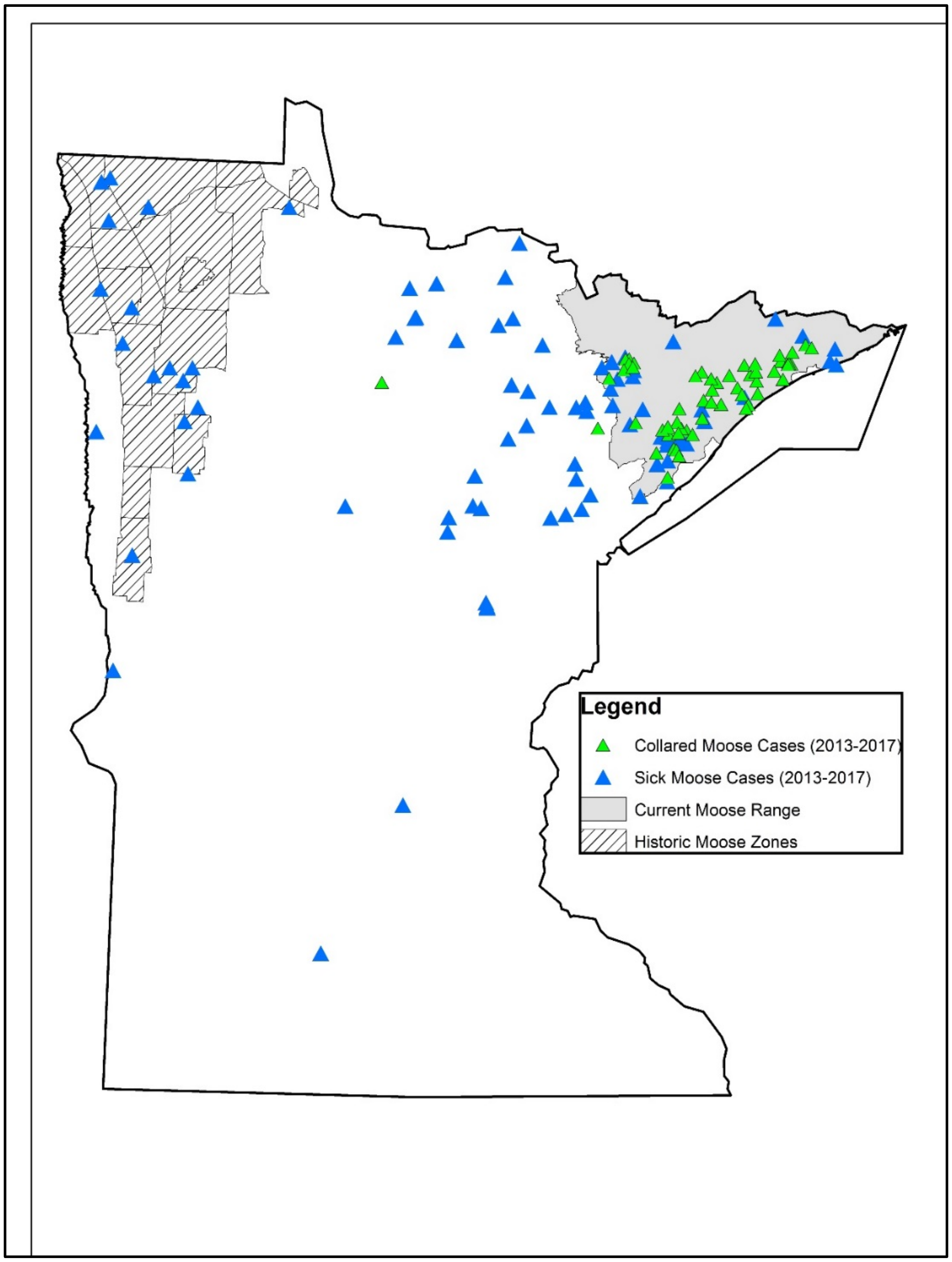

Figure 2. Location where mortalities were investigated for collared (*n*=60) and anecdotal moose (*n*=91) in Minnesota, 2013-2017.

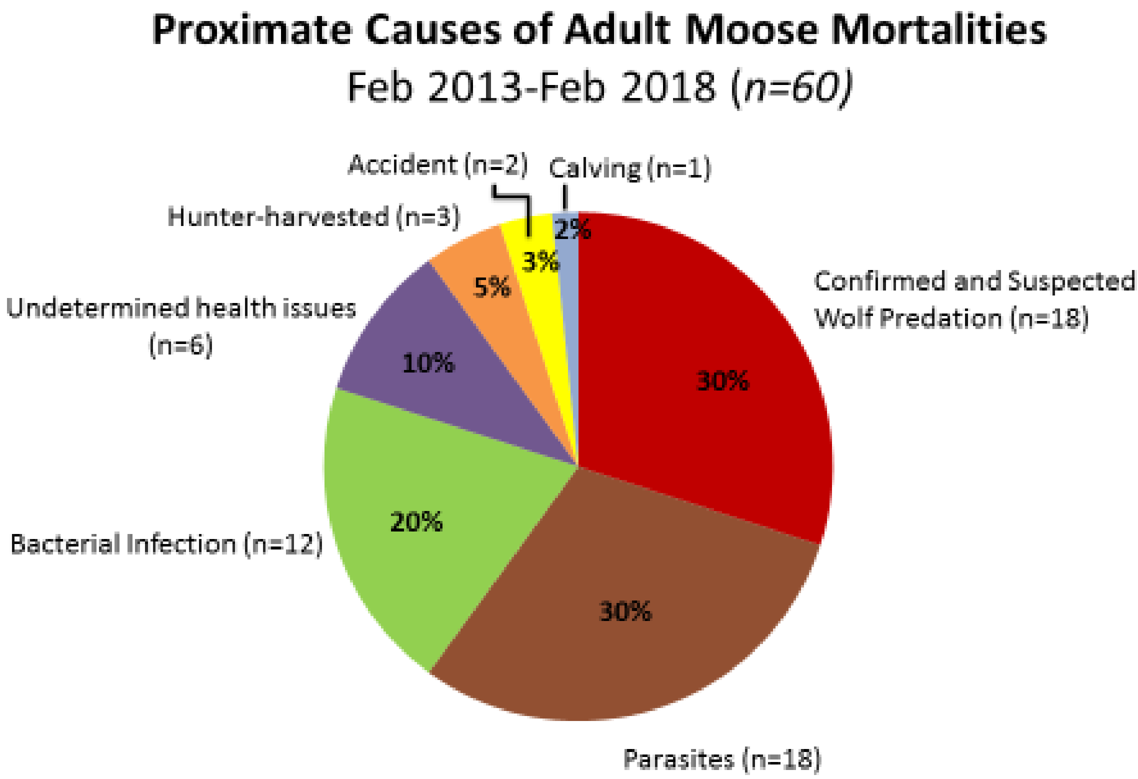

Figure 3. Cause-specific mortality of collared, adult moose (*n*=60) from 2013–2017, northeast Minnesota.

a)

b)

c)

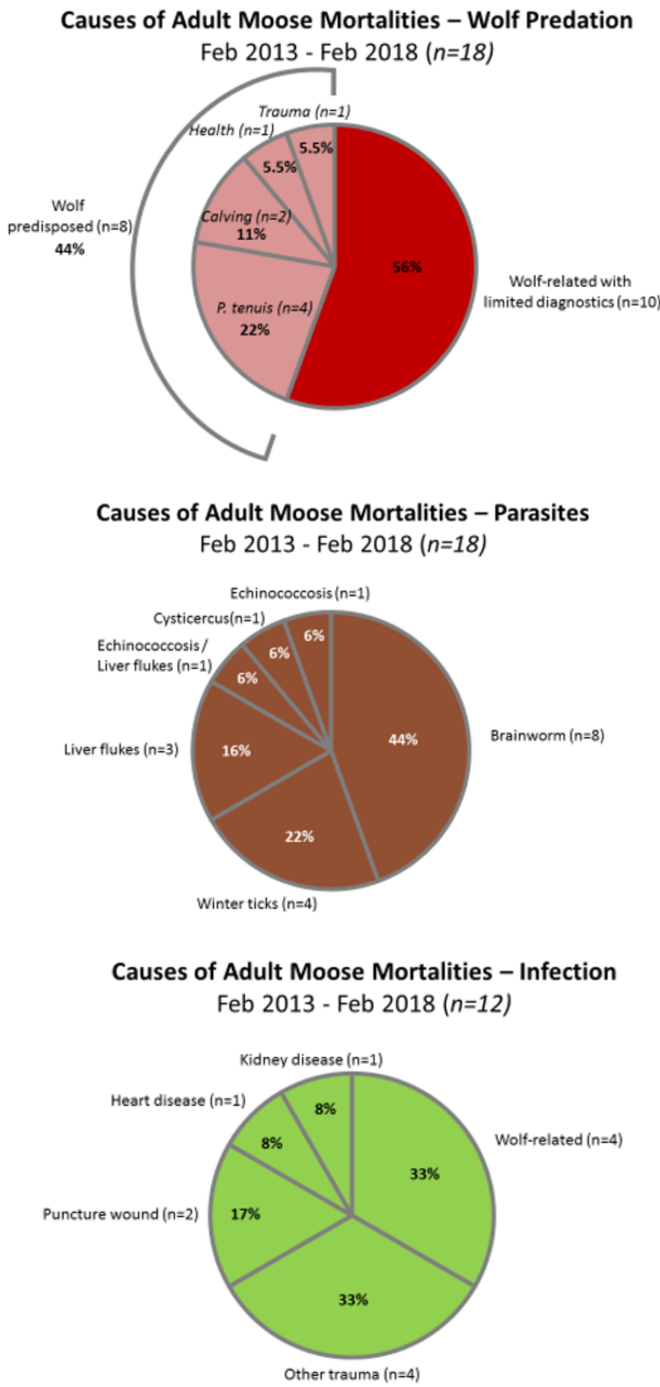

Figure 4. Breakdown of adult moose mortalities caused by wolf predation (a), parasites (b), and bacterial infections (c), 2013–2017, northeast Minnesota.

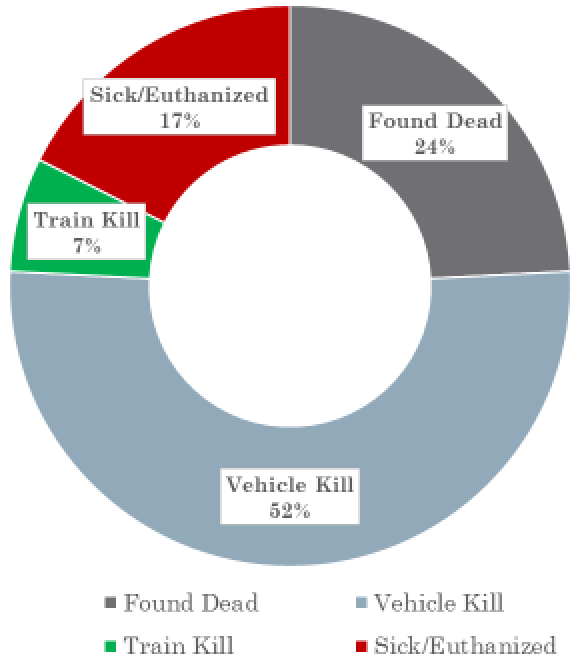

Figure 5. Causes of anecdotal moose (*n*=91) from 2013–2017 in Minnesota.

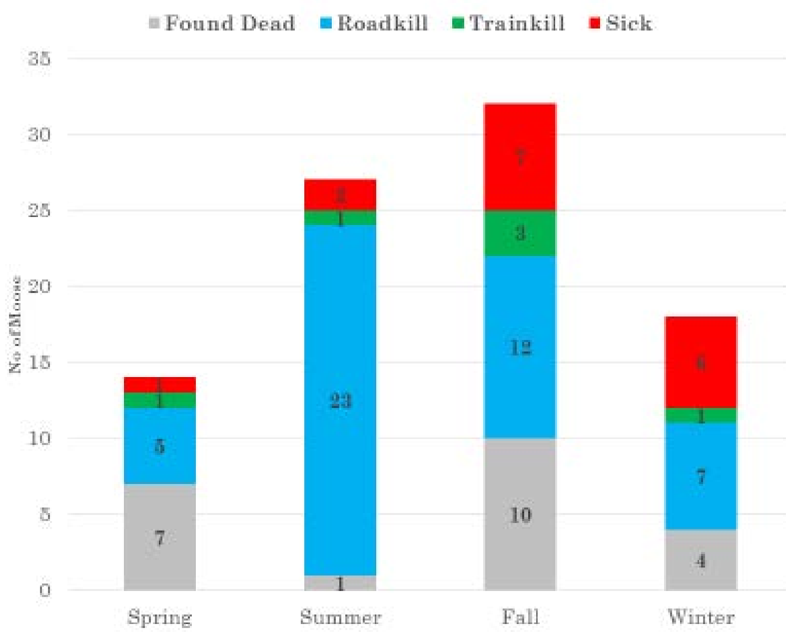

Figure 6. Seasonal variation in the causes of anecdotal moose deaths (*n*=91) in Minnesota from 2013–2017.