M.L. 2014 Project Abstract
For the Period Ending June 30, 2017

PROJECT TITLE: Moose Decline and Air Temperatures in Northeastern Minnesota
PROJECT MANAGER: Michael A. Larson
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 05m

APPROPRIATION AMOUNT: **$600,000**
AMOUNT SPENT: **$589,480**
AMOUNT REMAINING: **$ 10,520**

Overall Project Outcomes and Results

We used GPS collars, mortality implant transmitters (MITs), which continuously record internal body temperatures, and samples of moose urine voided in snow to study moose in northeastern Minnesota, a population that recently experienced significant declines.

Annual mortality rates of adult moose were 12–19% during 2013–2016, higher than the 8–12% rates reported in stable moose populations elsewhere in North America. The main causes of death for 57 moose were wolf predation (32%), parasites (30%), bacterial infections (21%), and other health issues (17%). MIT temperatures were 37.55–42.10°C in 25 moose; more MITs will be recovered later. Average daily MIT temperature increased 0.0009°C for every 1 degree increase in average daily air temperature. Twenty-three moose had 0.2–11% of internal temperatures considered above normal (i.e. ≥39.2°C). Habitat types used when an animal was hot compared to what was available was significantly different in some moose during summer.

The average pregnancy rate was similar to the North American average (83%). For GPS-collared calves born in 2013–2014 and unmarked calves (with collared mothers) born in 2015–2016 survival to 30 days of age was 58.4% and ~65%, respectively. By early spring survival declined to <34.1% and 33–40%, respectively. For 57 calf mortalities wolf predation consistently was the primary cause of death (66.7%), and bear predation was next (15.8%). Hiding cover was a dominant attribute at calving sites compared to pre-calving sites, whereas canopy closure and forage availability were greater at peak-lactation sites, indicating that balancing security and nutritional requirements influenced habitat selection over time.

Ratios of urinary urea nitrogen to creatinine ≥3.5 indicated more severe nutritional restriction during winters 2013, 2016, and 2017 compared to 2014 and 2015. Annual incidences of severe nutritional restriction were correlated with estimates of population size (r = -0.863), calf production (r = -0.922), and winter survival of adult moose (r = -0.860), indicating that winter undernutrition is playing a role in the poor population performance.

Our results will improve understanding of if, when, and how moose are able to successfully modulate their internal body temperature, which can inform strategies for conserving the population, especially through habitat management.

Project Results Use and Dissemination

For the moose research projects supported by this funding we have produced 8 peer-reviewed publications, 4 manuscripts currently in review, and several more to come with final analyses of the

data. There have been 15 DNR agency reports written, and they are available from our wildlife publications website (http://www.dnr.state.mn.us/publications/wildlife/index.html). Agency staff and graduate students have given 117 presentations at professional conferences of all levels—state to international—other meetings with professional biologists, and to all manner of public audiences, from school groups to sporting and nature groups to a veterans group.

During these 3 years the lead investigators, Drs. DelGiudice and Carstensen, have participated in 38 interviews with journalists from television, radio, and print outlets, and there have been more than 175 additional instances of media coverage about our research. Media outlets included all major newspapers in Minnesota and 2 adjacent states, many smaller newspapers, the Washington Times, National Geographic, public and commercial radio stations in Minnesota, and public, network, and cable television stations in Minnesota.

Furthermore, we have posted information on our DNR moose research website (http://www.dnr.state.mn.us/moose/index.html) throughout the project, and our results will be used to inform public stakeholder groups and DNR decisions about moose conservation.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2014 Work Plan Final Report

Date of Report: August 11, 2017

Final Report

Date of Work Plan Approval: June 4, 2014

Project Completion Date: June 30, 2017

PROJECT TITLE: Moose Decline and Air Temperatures in Northeastern Minnesota

Project Manager: Michael A. Larson

Organization: Minnesota Department of Natural Resources

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Location: Work will take place in St. Louis, Lake, and Cook Counties.

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$600,000**
	Amount Spent:	**$589,480**
	Balance:	**$ 10,520**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 5m

Appropriation Language:
$600,000 the second year is from the trust fund to the commissioner of natural resources in cooperation with the University of Minnesota to study the physiology and behavior of adult moose and effects of female condition on calf production and survival to determine the impact of air temperature on moose population performance and decline. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Moose Decline and Air Temperatures in Northeastern Minnesota

II. PROJECT STATEMENT:

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 69% from an estimated 8,840 to 2,760 moose. Mean annual mortality rates of adults have been similarly high (21%) in both regions. Climate change has been implicated as an underlying factor in both population declines. There were inverse relationships between warming ambient temperatures and decreasing survival of adult moose. Unlike in the NW region, however, in the NE little is known about other potentially important factors contributing to the natural mortality of moose (e.g., predation, disease, parasites, undernutrition). Two aggressive companion studies are presently investigating specific causes of mortality and survival rates of adults and calves, and their quantitative impacts on performance (survival and reproduction) of the NE population.

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.

The primary goal of our 3-year study is to thoroughly investigate how ambient temperatures relate to moose productivity, reproductive success, and 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 ≥2 years. Using these MITs and global positioning system (GPS) collars on adult moose in this study will allow us to correlate ambient temperature with adult female physiology, behavior (habitat use and activity), and fitness (survival and reproduction). We will estimate the seasonal survival of 30 implanted moose, determine specific causes of mortality, and assess calf production. We also will estimate survival and determine the causes of mortality of calves of GPS-collared mothers. Presently, less is known about calf productivity, survival, and mortality factors than for adult moose in northern Minnesota.

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. In particular, we aim to determine if moose modify their activity and use available habitat in response to ambient temperatures, and to evaluate population performance. Such an understanding should prove valuable in the formulation of future population and habitat management strategies and activities.

III. PROJECT STATUS UPDATES:

Project Status as of December 2014:
On July 1, 2014, we had 94 collared adult moose remaining from the previous study that was funded by LCCMR "Determining causes of mortality in moose populations." Since then we have investigated mortalities of 4 collared adult moose, and 14 collars have stopped transmitting location information. We plan to capture 24–26 new adult moose during January–February 2015 to return the sample size to >100 collared adults. Each captured adult moose will receive an MIT.

We placed ambient temperature loggers (black globes and white funnels) in 7 open habitat sites throughout the study area. Data from the temperature loggers will be used with data from 12 official weather stations in

northeastern Minnesota to determine the best ambient temperature predictor for moose with MITs in this study. Further, an MIT calibration study was initiated in December 2014 using captive moose at the Moose Research Center in Alaska. This calibration study, which is being funded by MN DNR, will determine the best methods for interpretation of MIT data generated in wild moose in Minnesota.

We monitored the movements and survival of moose calves that had been GPS-collared during spring 2014. We investigated the mortalities of collared moose calves that died. We measured habitat characteristics at 88 pre-calving, calving, and mortality sites of calves GPS-collared during spring 2013 and 2014. We also conducted a controlled study of new GPS calf collars to determine the effects of physical disturbance and weather conditions on the durability and proper functioning of the collars.

Amendment Request (12/21/2014): This amendment will extend the completion date for capturing adult moose—Outcome 1 of Activity 1—from 6/30/2015 to 6/30/16, allowing us to capture 24–30 moose each of the next 2 winters. Increased survival of collared adult moose during 2014, free replacement collars for January–February 2015, and reduced capture costs have made it possible to utilize funding from this grant to add new individuals (24–30 each winter) into the study over 2 years. This greatly enhances our ability to capture environmental variation among years and extends the life of the study. Further, along with matching funds from DNR, more MITs can be placed in captured moose in January–February 2016, which will provide a larger sample of physiological data for this study. Extending this timeline and maintaining a viable sample size of collared adult moose (>100) through 2016 will not otherwise impact our work plan and will enable us to spend funds in the high priority areas of the project. **Amendment approved by the LCCMR (12/30/2014).**

Project Status as of June 2015:
From February 16 until February 22, 2015, we captured 32 adult moose (20 females, 12 males). Unfortunately, 5 of those moose died shortly after capture and were censored from the study. Given the elevated rate of capture-related mortality, we decided to discontinue captures and not deploy additional collars for Dr. Ron Moen (not using ENRTF funding) as we had intended. We deployed 27 new collars and 23 MITs, which returned our study sample to 101 moose. Moose at capture were generally in good condition (44% normal, 53% thin, and 3% very thin). There was minimal hair loss noted from winter ticks. Pregnancy rate, determined by progesterone values in blood samples, was 89%; higher than 2013 (83%) and 2014 (77%).

During January–June 2015 6 collared moose died and were investigated. Three moose died from health-related causes (1 undetermined and 2 with diagnostic results still pending), and 3 moose died from predator-related causes (1 wolf kill, 1 likely wolf kill, and 1 injury caused by wolves that led to a secondary infection that was lethal).

Our MIT calibration project with Alaska Game & Fish, which began in December 2014 and is funded by DNR, has shown the MIT to be a highly accurate measurement of internal body temperature in moose. On average, the MIT was only 0.25°C higher than body temperature determined by vaginal implant transmitters. Further, preliminary analyses of data from MITs recovered from moose that have died in Minnesota (n = 8) indicated prolonged elevated temperatures (>102°F) for 10-30% of readings during the summer months.

We are monitoring the current calving activity of 60 adult female moose with functioning GPS collars. So far they have produced 46–61 calves, depending upon the assumed rate of having twins (0–32%). We have investigated 17 possible calf mortality sites and found direct evidence of a calf mortality at 8 of them. Whether or not the mother returns to the site after fleeing has been a reliable indicator of actual calf mortality. We are collecting habitat data at the calving and mortality sites.

Amendment Request (06/04/2015): This amendment, prompted by Executive Order 15-10 issued on April 28, 2015, directing the Minnesota Department of Natural Resources to discontinue placing radio collars on moose, will eliminate Outcome 1 of Activity 2 (Capture & collar 40 moose calves), alter the methods for Outcomes 2 and 3 of Activity 2, and reallocate some of the funds related to capturing and collaring moose so we will be able to

achieve the main Outcomes for Activity 2 using alternative methods and to track and investigate the mortalities of already-collared adult moose for a longer period of time than was initially proposed.

Budget requests:

- Increase Personnel for Activity 1 from $74,000 to $111,000 to add a 3rd year of partial support for a Wildlife Health Specialist to investigate the mortalities of adult moose
- Reduce Wildlife helicopter capture costs from $48,000 to the actual amount spent of $31,770
- Reduce Univ. of Minnesota Veterinary Diagnostic Lab for Activity 2 from $5,000 to $4,000 because we will be submitting fewer whole calf carcasses and tissue samples for analysis
- Increase Satellite data acquisition for Activity 1 from $35,000 to $60,000 to add a 2nd and 3rd year of data acquisition for adult moose and increase the duration of time we collect hourly locations of adult female moose to enable us to identify possible sites of calf mortality events
- Reduce Satellite data acquisition for Activity 2 from $15,000 to $3,000 because we are not deploying collars on moose calves during 2015
- Reduce GPS collar costs for Activity 1 from $75,000 to $0 because the adult moose collars we deployed during 2015 were left over from previous years of the study and no new collars were purchased
- Reduce GPS collar costs for Activity 2 from $55,000 to $0 because we were able to cancel the order for calf moose collars that were no longer needed
- Reduce Mortality implant transmitters from $27,000 to the actual amount spent of $25,856
- Reduce Air temperature loggers from $4,500 to $0 because we used other funds to purchase them
- Reduce Pharmaceuticals from $6,000 to the actual amount spent of $5,821
- Increase Travel expenses for Activity 1 from $29,030 to $59,029 because fleet expenses are greater than we projected
- Reduce Fleet and other travel expenses for paid staff for Activity 2 from $27,909 to $22,909 because lodging and fleet expenses are less than we projected
- Reduce Lodging & meals for volunteers from $7,500 to $3,100 because lodging costs are less than we projected
- Increase Airplane flights for Activity 1 from $10,500 to $23,554 because in addition to the spotter plane used during capture operations we will need to track down missing moose and eventually remotely trigger the release (i.e., removal) of the adult moose collars
- Add $50,400 for Aerial surveys for Activity 2 because we will need to observe adult female moose and their remaining calves during late-fall and winter to estimate calf survival without collared calves
- Add $19,000 for Activity 2 as Unallocated.

Amendment approved by the LCCMR (6/11/2015).

Project Status as of December 2015:

Adult moose mortality rate in our 3rd year of the study (January 1 to December 15, 2015) was 13%, which was similar to 2014 (12%) and lower than 2013 (19%). Causes of the 13 mortalities during this past year included 2 predator-related causes (1 confirmed wolf kill and 1 likely wolf kill) and 11 health-related causes (1 brainworm, 5 bacterial infections, 1 multiple health issues, and 4 undetermined cases). Three cases are still pending.

Our MIT calibration project with the Alaska Department of Fish and Game is concluding in December 2015. Our graduate student (not funded by ENTF) has completed 4 two-week observation sessions (1 per season) to record moose behaviors (feeding, drinking, grooming, walking, ruminating, etc.) relative to MIT readings in our efforts to successfully calibrate these devices. Data analysis is underway, and we hope to apply this calibration to wild moose that have MITs in Minnesota.

Fifty (83.3%) of the 60 monitored females calved during 2015, reflecting a “normal” pregnancy rate for this population compared to moose across North America. Mean calving date in 2015 was 11 May (range = 29 April–14 June), 3 days earlier than in 2013 and 8 days earlier than in 2014. Seventy-six percent of births occurred during 3–15 May. The 50 monitored females gave birth to an estimate of 65 calves. Importantly, the 2015

calving season (3rd in our study, 1st using ENRTF funding) improved our understanding of the annual variability of calf production, the timing, location, and habitat associated with calving activity in northeastern Minnesota. Nine confirmed calf mortalities occurred during 3 May–2 June; causes included 6 wolf (*Canis lupus*) kills, 1 bear (*Ursus americanus*) kill, and 2 unknown predator kills. Presently, our examination of movement behavior of dams shows that it is most reliable for signaling mortalities of calves from birth to 30 days of age.

During late-October through early-December 2015 we completed our fall helicopter survey. We observed 40 of the cows that had calved this spring and 23 calves (15 singletons and 4 sets of twins) accompanying them. Assuming a twinning rate of 30% for the 40 cows, this sample cohort began with 52 calves being born. Further assuming that we observed all surviving calves during the aerial survey the estimated survival rate of calves to late-fall was 44%.

We calculated the Heat Stress Index for moose in northeastern Minnesota from daily maximum temperatures during January and the entire winter season for 1960 to 2015 to examine potential relationships between this index and the production and survival of calves. Preliminarily, there is a strong correlation between the January and winter index values and the frequency of severe winter nutritional restriction in the moose population determined from a companion study.

Amendment Request (12/17/2015): This amendment request moves money that is unallocated to provide additional funding for more temporary personnel time and travel expenses related to extra data collection in the field. Budget requests:

- Increase Personnel for Activity 2 from $47,000 to $57,000 to employ 1 field technician during spring/summer 2016 to help collect data on moose calving and calf mortality for another field season.
- Increase Lodging & meals for volunteers for Activity 2 from $3,100 to $12,100 to add a winter field season of data collection for assessing the nutritional status of the moose population.
- Reduce Unallocated from $19,000 to $0 to provide the increases listed above.

Amendment approved by LCCMR (12-22-2015).

Project Status as of June 2016:

The adult moose mortality study began its 4th year in January 2016. Annual mortality rates in the first 3 years were 19%, 12% and 15%, for 2013, 2014, and 2015, respectively. Thus far in 2016 (Jan-June), only 3 moose have died and the mortality rate is 5%. While moose survival appears to be higher in 2016, we also have far less moose to monitor compared to previous years. In each of the first 3 years of this study, the year began with >100 collared moose on the air for daily monitoring. However, the inability to collar additional moose this past winter has resulted in a much lower sample size in Year 4. In January 2016, we had 75 moose to monitor and by June 2016, only 53 moose were still transmitting data on a daily basis.

Since this study began in 2013, we have investigated 49 adult moose mortalities. Health-related issues have been the leading proximate cause of moose mortalities (65%); whereas wolf predation accounted for the remaining one third (35%) of deaths. Overall proximate causes of death included 17 confirmed and likely wolf kills (35%), 15 parasitic infections (31%), 11 bacterial infections (22%), 5 undetermined health issues (10%), and 1 accidental death (2%). Whole carcasses were retrieved for 18 (37%) of the mortalities, with field necropsies performed on the remaining 31 moose (63%). 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 32 cases (65%), 24–48 hours in 11 cases (22%), and >48 hours in 6 cases (12%).

Our spring 2016 helicopter survey indicated that calf mortality during winter was minimal; the one-year calf survival rate was 40%, down from 44% as estimated from the fall helicopter survey. Monitoring of the calving movements of 34 GPS-collared adult females and confirming with field investigations have indicated at least a 79.4% pregnancy rate entering the 2016 calving season, which is near normal for North American moose. Based

on findings of the MN DNR's annual winter survey of the moose population in northeastern Minnesota and this calf study, we expect about 1,739 calves to be produced in spring 2016.

We are augmenting the 2016 field investigations of calf mortalities with hair identification and DNA analyses of various other samples (e.g., scat) collected at suspected mortality sites to confirm predator species and individual relationships of moose (e.g., calf to mother). Since the 2016 calving season began in late-April we have investigated the mortalities of 6 calves of GPS-collared adult females: 3 wolf-kills, 2 probable wolf-kills, and 1 by unknown cause (awaiting results of these further laboratory analyses). As of early-June, the calf mortality rate was at least 22.2%.

Winter 2015–2016 was the fourth season of physiologically assessing nutritional restriction of moose in northeastern Minnesota. Relevant to the potential influence of climate change on the declining moose population, preliminary statistical analyses of data from winters 2013 to 2015 have yielded strong relationships, showing that as the winter heat stress index (HSI) for moose increased, the severity of winter nutritional restriction also increased at the population level. Additionally, as the severity of winter nutritional restriction increased, winter and winter-to-summer survival rates of the GPS-collared adult moose decreased, as did our annual moose population estimates.

Project Status as of December 2016:
The adult moose mortality study has now completed its 4th year. Annual mortality rates were 19%, 12%, 15%, and 15% during 2013, 2014, 2015, and 2016, respectively. Since the June 2016 project status report, 5 additional adult moose have died from July through December, bringing the total number of deaths investigated in 2016 to 8 moose and the annual mortality rate to 15%. We started the 4th year with 75 collared moose alive and transmitting data, and as of December 26, 2016, there were 40 working collars remaining on moose. Collar failures (e.g., dead batteries or other technology malfunctions) continue to be a problem. Accordingly, we have spent more time searching for missing moose with fixed-wing and helicopter flights to check statuses and attempt to remotely blow-off collars.

Since the adult moose study began in 2013 we have investigated 54 adult moose mortalities. Health-related issues have been the leading proximate cause of moose mortalities (67%), whereas wolf predation accounted for the remaining deaths (33%). Overall proximate causes of death included 18 confirmed and likely wolf kills (33%), 16 parasitic infections (30%), 12 bacterial infections (22%), 5 undetermined health issues (9%), 2 accidental deaths (4%), and one hunter-harvested moose (2%). Whole carcasses were retrieved for 21 (39%) of the mortalities, with field necropsies performed on the remaining 33 moose (61%). Response times from initial mortality notification (e.g., text message or email) to having a team in the field at the death site were ≤24 hours in 36 cases (67%), 24–48 hours in 11 cases (20%), and >48 hours in 7 cases (13%).

Updating preliminary analyses of the 2016 reproductive season, we observed 28 (80.0%) of 35 GPS-collared adult female moose make a calving movement, and along with additional field observations of calves with GPS-collared adult females, we determined 31 (88.6%) of the 35 cows were pregnant. This is a robust pregnancy rate compared to the average for moose in North American. At the population level we estimated that 1,893 calves were produced with an estimated average birth-date of 12 May 2016 (median = 11 May 2016, range = 24 Apr–10 June). We observed evidence of 14 calf mortalities during spring/summer 2016, with an average age at death of only 13.8 days (SE = ±3.2, range = 2.7–33.7 days). During 2013 to 2016 approximately 40% of the calves died by 30 days of age. Causes of calf mortality in 2016 included 10 wolf-kills, 2 bear-kills, 1 unknown predator-kill, and 1 death following a possible vehicle collision.

Our fall/early-winter helicopter survey to assess calf survival since late-summer will be conducted in the upcoming 2 weeks. We are currently conducting analyses of calving activity, mortality, and habitat survey data to identify forest habitat characteristics that best allow calving female moose to fulfill their requirements for forage quality and predator avoidance.

After 4 winters (2013–2016) of physiologically assessing the nutritional status of moose at the population level in northeastern Minnesota, preliminary data analyses are yielding strong relationships between the increasing incidence of severe nutritional restriction and decreasing winter survival of GPS-collared adult moose, decreasing population estimates, and declining calf production. We had also observed an increasing incidence of severe nutritional restriction of moose with increasing winter temperatures (i.e., moose heat stress index), but this was ephemeral.

Amendment Request (12/31/2016): This amendment request moves money that remains unspent in budget items that are completed and allocates those funds to budget items that either relate to data collection in the field that is an ongoing expense or required more funding to complete than we had originally budgeted, as detailed below.

Budget requests:

- Reduce Personnel for Activity 2 from $57,000 to the actual amount spent of $56,758, shifting the remaining balance of $242 to P/T contract for Univ. of Minnesota for graduate student for Activity 2.
- Retroactively increase P/T contract for Univ. of Minnesota for graduate student for Activity 2 from $80,000 to $80,326 because actual expenses were $326 greater than we projected.
- Reduce P/T contract for Univ. of Minnesota Veterinary Diagnostic Lab for Activity 2 from $4,000 to the actual amount spent of $3,997, shifting the remaining balance of $3 to Fleet for Activity 2.
- Reduce Satellite data acquisition for calf moose collars for Activity 2 from $3,000 to the actual amount spent of $2,755, shifting $84 to P/T contract for Univ. of Minnesota for graduate student for Activity 2 and $161 to fleet for Activity 2.
- Reduce cost of Mortality implant transmitters for Activity 1 from $25,856 to the actual amount spent of $25,698, shifting the remaining balance of $158 to Fleet for Activity 1.
- Increase Fleet in Activity 1 by $158 from $59,029 to $59,187 to help cover ongoing needs for travel to recover and investigate moose mortalities in the field.
- Retroactively increase Fleet for Activity 2 from $22,909 to $23,233 because actual expenses were $324 greater than we projected.
- Reduce Aerial surveys for Activity 2 from $50,400 to $50,240, shifting the difference of $160 to Fleet for Activity 2.

Amendment approved by the LCCMR (1/4/2017).

Amendment Request (05/02/2017): This amendment request increases the FTE for the Wildlife Health Specialist for Activity 1 from an average of 0.43 FTE for 3 years (1.29 FTEs total) to an average of 0.5 FTE for 3 years (1.5 FTEs total) because overall salary expenses for that position have been less than originally estimated due to different pay rates for the 2 people who have been in that position during the project. Also, within the Other budget category, this amendment request moves money that will remain unspent in two budget items to provide funding for additional data collection, as detailed below.

Budget requests:

- Reduce Aerial surveys for calves for Activity 2 by $8,000 because scheduled calf surveys were less expensive than planned.
- Reduce Direct & necessary services for Activity 1 by $1,356 and Activity 2 by $1,257 ($2,613 total) because the Division of Fish & Wildlife cannot charge its portion anymore.
- Increase Airplane flights for moose captures & tracking for Activity 1 by $10,613 because that will allow us more flight time to remotely trigger more collars to release from live moose, many of which need to be located by VHF radio telemetry because of collar failures (see December 2016 Project Status above), and we need to physically recover the collars to download MIT data.

Amendment approved by the LCCMR (5/4/2017).

Project Status as of June 2017:
The adult moose mortality project began its 5th year in January 2017. The mortality rate of adult moose during January–July 2017 was 9%. Since the December 2016 project status report, 3 additional moose have died from January through July 2017. Causes of these 3 mortalities were health-related, including brainworm infection, calving complications (i.e., dystocia, twin calves stuck in the birth canal while being expelled simultaneously), and an undetermined health issue (heavy parasite loads and eye infection, but no clear cause of death determined at necropsy).

We completed helicopter surveys of GPS-collared adult females with calves during winter and early spring to estimate the survival of calves, which was 32.6% through 350 days of age for 2016–2017.

Overall Project Outcomes and Results:

We used GPS collars, mortality implant transmitters (MITs), which continuously record internal body temperatures, and samples of moose urine voided in snow to study moose in northeastern Minnesota, a population that recently experienced significant declines.

Annual mortality rates of adult moose were 12–19% during 2013–2016, higher than the 8–12% rates reported in stable moose populations elsewhere in North America. The main causes of death for 57 moose were wolf predation (32%), parasites (30%), bacterial infections (21%), and other health issues (17%). MIT temperatures were 37.55–42.10°C in 25 moose; more MITs will be recovered later. Average daily MIT temperature increased 0.0009°C for every 1 degree increase in average daily air temperature. Twenty-three moose had 0.2–11% of internal temperatures considered above normal (i.e. ≥39.2°C). Habitat types used when an animal was hot compared to what was available was significantly different in some moose during summer.

The average pregnancy rate was similar to the North American average (83%). For GPS-collared calves born in 2013–2014 and unmarked calves (with collared mothers) born in 2015–2016 survival to 30 days of age was 58.4% and ~65%, respectively. By early spring survival declined to <34.1% and 33–40%, respectively. For 57 calf mortalities wolf predation consistently was the primary cause of death (66.7%), and bear predation was next (15.8%). Hiding cover was a dominant attribute at calving sites compared to pre-calving sites, whereas canopy closure and forage availability were greater at peak-lactation sites, indicating that balancing security and nutritional requirements influenced habitat selection over time.

Ratios of urinary urea nitrogen to creatinine ≥3.5 indicated more severe nutritional restriction during winters 2013, 2016, and 2017 compared to 2014 and 2015. Annual incidences of severe nutritional restriction were correlated with estimates of population size (r = -0.863), calf production (r = -0.922), and winter survival of adult moose (r = -0.860), indicating that winter undernutrition is playing a role in the poor population performance.

Our results will improve understanding of if, when, and how moose are able to successfully modulate their internal body temperature, which can inform strategies for conserving the population, especially through habitat management.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Determine the physiological and behavioral impacts that ambient temperatures have on adult moose and determine specific causes of mortality.

Description: Global Positioning System (GPS) collars and mortality implant transmitters (MITs) will be deployed on 30 adult moose (approximately 22 females and 8 males) in January–February of 2015. Additionally, external ambient temperature loggers will be placed on each collar. The collars will notify the research team when a moose has died by way of a motion-sensitive switch in the collar and a subsequent text message. A network of

strategically stationed response teams will reach moose within the critical 24 hours after death, ensuring the carcass and tissue samples are suitable for diagnostics. When possible, carcasses will be transported intact to a nationally-certified laboratory in Minnesota for a full diagnostic workup. Otherwise, trained field biologists will perform a thorough field examination (necropsy). Diagnostic screening for more than 30 diseases, toxicities and deficiencies will occur by Board-certified veterinary pathologists. Further, internal body temperature data will be compared to ambient temperatures to determine if moose alter their use of specific habitat types depending on ambient temperatures or their current physiological state.

Summary Budget Information for Activity 1:

ENRTF Budget: $ 355,978
Amount Spent: $ 347,155
Balance: $ 8,823

Activity Completion Date: 6/30/2017

Outcome	Completion Date	Budget
1. Capture, collar, and implant 30 adult moose in the study area	6/30/2016	$ 89,772*
2. Determine behavioral impacts of ambient temperature on moose	6/30/2017	$ 173,004*
3. Continue to determine specific causes of mortality of moose that die during the study period	6/30/2017	$ 93,202*
4. Quantifying rate of exposure to diseases and toxicity and nutritional deficiencies	6/30/2017	$ 0**
5. Preliminary data analyses and final LCCMR report	6/30/2017	$ 0**
6. Descriptive reports/articles in peer-reviewed publications addressing findings	6/30/2017	$ 0**

* Of the $355,978 for Activity 1, $9,935 is for Direct & Necessary services to support the appropriation.
** Analyses and reports for Outcomes 4–6 will be completed through in-kind contributions of the lead investigators and others.

Activity Status as of December 2014:
Plans are underway to capture 24–26 moose during January–February 2015 to rebuild the sample size to >100 collared adult moose. Fortunately, warranty collar replacements have arrived and no additional new collars need to be purchased at this time; 30 MITs and external temperature loggers have been ordered. Seven ambient temperature loggers were placed in open habitat types in the study area and are downloaded monthly. In addition, ambient temperature data from NOAA and RAWS stations within the study area have been downloaded each month. An MIT calibration study (not funded by LCCMR) was initiated with captive moose in Alaska to improve our understanding of the MIT data and to develop methods for data analyses for moose with MITs for this LCCMR-funded study. Four collared adult moose have died since this project began in July 2014. Through investigations of those mortalities we determined that the causes of mortality included wolf predation (1 confirmed wolf kill, 1 likely wolf kill) and health conditions (1 likely brainworm, 1 multiple health issues).

Activity Status as of June 2015:
From February 16 until February 22, 2015, we captured 32 adult moose (20 females, 12 males). Unfortunately, 5 of those moose died shortly after capture and were censored from the study. Capture myopathy was the cause of death in 4 moose; the fifth moose had a seizure during handling that may have been attributable to a tumor on its adrenal gland. Given the elevated rate of capture-related mortality, we decided to discontinue captures and not deploy additional collars for Dr. Ron Moen (not using ENRTF funding) as we had intended. We deployed 27 new collars and 23 MITs, which returned our study sample to 101 moose. Since this project began in 2013, we have collared 168 unique moose and successfully deployed 61 MITs.

Moose at capture were generally in good condition, as body condition scores at capture were 44% normal, 53% thin, and 3% very thin. There was minimal hair loss noted from winter ticks. Pregnancy rate, determined by progesterone values in blood samples, was 89%; higher than 2013 (83%) and 2014 (77%). Biological samples collected at capture are being evaluated for a variety of disease agents, and results are pending.

During January–June 2015 6 collared moose died and were investigated. Three moose died from health-related causes (1 undetermined and 2 with diagnostic results still pending). Three moose died from predator-related causes (1 wolf kill, 1 likely wolf kill, and 1 injury caused by wolves that led to a secondary infection that was lethal). Thus far in the 3rd year of this study, 6% of the collared moose have died. For the same period during Years 1 and 2 mortality rates were 19% and 12%, respectively.

Our MIT calibration project with Alaska Game & Fish, which began in December 2014 and is funded by DNR, has shown the MIT to be a highly accurate measurement of internal body temperature in moose. On average, the MIT was only 0.25°C higher than body temperature determined by vaginal implant transmitters. Further, preliminary analyses of data from MITs recovered from moose that have died in Minnesota (*n* = 8) indicated prolonged elevated temperatures (>102°F) for 10-30% of readings during the summer months. Continued work on this calibration study will shed new light on the proper interpretation of MIT data from moose in this ENRTF-funded study and assist with our understanding of potential effects of ambient temperature on moose survival, habitat use, and production of calves.

Activity Status as of December 2015:
Adult moose mortality rate in our 3rd year of the study (January 1 to December 15, 2015) was 13%, which was similar to 2014 (12%) and lower than 2013 (19%). Causes of the 13 mortalities during this past year included 2 predator-related causes (1 confirmed wolf kill and 1 likely wolf kill) and 11 health-related causes (1 brainworm, 5 bacterial infections, 1 multiple health issues, and 4 undetermined cases). Three cases are still pending.

Since this study began in 2013, we have investigated 45 adult moose mortalities (20, 12, and 13 in 2013, 2014, and 2015, respectively). Health-related issues have been the leading proximate cause of moose mortalities (64%); whereas wolf predation accounted for the remaining one third (36%) of deaths. Overall proximate causes of death included 16 confirmed and likely wolf kills (36%), 10 bacterial infections (22%), 5 confirmed and likely brainworm infections (11%), 5 multiple chronic health issues (11%), 3 winter tick infestations (7%), 1 accident (2%), and 5 undetermined health issues (11%). Whole carcasses were retrieved for 16 (36%) of the mortalities, with field necropsies performed on the remaining 29 moose (64%). 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 28 cases (63%), 24–48 hours in 11 cases (24%), and >48 hours in 6 cases (13%).

Mean age of moose at death was 8.3 years (±0.6 years, *n* = 44, and 1 moose has a pending age) and there was no difference in the mean age of health-related (8.6 years ±0.8, *n* = 24, missing 1 age) and wolf-related (7.8 years ±1.0, *n* = 20) deaths. Interestingly, both health- and predator-related causes of death impacted nearly every age cohort in this study, which suggests that wolves are not selecting for just young (<3 years of age) or old (>8 years of age) moose and are able to prey upon prime aged individuals (4–8 years old) as well.

Our MIT calibration project with the Alaska Department of Fish and Game is concluding in December 2015. Our graduate student (not funded by ENTF) has completed 4 two-week observation sessions (1 per season) to record moose behaviors (feeding, drinking, grooming, walking, ruminating, etc.) relative to MIT readings in our efforts to successfully calibrate these devices. Data analysis is underway, and we hope to apply this calibration to wild moose that have MITs in Minnesota.

Activity Status as of June 2016:
The adult moose mortality study began its 4th year in January 2016. Annual mortality rates in the first 3 years were 19%, 12% and 15%, for 2013, 2014, and 2015, respectively. Thus far in 2016 (Jan-June), only 3 moose have died and the mortality rate is 5%. While moose survival appears to be higher in 2016, we also have far less moose to monitor compared to previous years. In each of the first 3 years of this study, the year began with >100 collared moose on the air for daily monitoring. However, the inability to collar additional moose this past winter has resulted in a much lower sample size in Year 4. In January 2016, we had 75 moose to monitor and by

June 2016, only 53 moose were still transmitting data on a daily basis. Collar failures remain a problem and are likely due to loss of battery power or other malfunctions. Several fixed-wing aircraft flights occurred in the last few months to search for moose with failed collars to confirm status (alive or dead) and remotely blow-off collars if possible. To that end, we have successfully blown off a total of 8 collars (2 on 12-Feb 2015, 2 on 10-Nov 2015, and 4 on 21-April 2016) from moose that were still alive but with an inactive collar. Recovering these failed collars is very important as movement, activity, and MIT data were stored on the collar successfully retrieved.

Causes of the 3 mortalities in 2016 included 2 health related cases (1 liver fluke infection and 1 winter ticks) and 1 predator-related case (1 wolf kill with pre-existing health issues). Winter tick infestations appeared higher this spring, likely related to the two previous mild winters and high tick survival. The last time we documented moose mortalities related to winter ticks was in 2013. The moose that was killed by wolves was in the process of calving while the attack occurs, as the fetus was found in the birth canal during necropsy. This moose also had 3 serious health issues include a heavy winter tick infestation, a severe liver fluke infection, and *P. Tenuis* tracts in her brain.

Since this study began in 2013, we have investigated 49 adult moose mortalities. Health-related issues have been the leading proximate cause of moose mortalities (65%); whereas wolf predation accounted for the remaining one third (35%) of deaths. Overall proximate causes of death included 17 confirmed and likely wolf kills (35%), 15 parasitic infections (31%), 11 bacterial infections (22%), 5 undetermined health issues (10%), and 1 accidental death (2%). Whole carcasses were retrieved for 18 (37%) of the mortalities, with field necropsies performed on the remaining 31 moose (63%). 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 32 cases (65%), 24–48 hours in 11 cases (22%), and >48 hours in 6 cases (12%).

Our MIT calibration project with the Alaska Department of Fish and Game concluded in December 2015. Our graduate student (not funded by ENTF) had completed 4 two-week observation sessions (1 per season) to record moose behaviors (feeding, drinking, grooming, walking, ruminating, etc.) relative to MIT readings in our efforts to successfully calibrate these devices. Preliminary data analysis is showing the MITs to be highly accurate, only varying within 0.2°C from the vaginal implant readings. We have successfully determined the effect of drinking water (or eating snow) behaviors on temporarily lowering rumen temperatures and these calibration can now be applied to MIT data-sets from wild moose in MN. Further data analyses is underway to determine the effect (if any) of rumination on rumen temperatures and also to correlated moose behaviors with changes to internal body temperature.

Activity Status as of December 2016:
The adult moose mortality has now completed its 4th year at the end of December 2016. Annual mortality rates over this first 4 years were 19%, 12%, 15%, and 15% during 2013, 2014, 2015, and 2016, respectively. Since the June 2016 project status report, 5 additional moose have died from July through December, bringing the total number of deaths investigated in 2016 to 8 moose and the annual mortality rate to 15%. We started the 4th year with 75 collared moose alive and transmitting data, and as of December 26, 2016, there were 40 working collars remaining on moose. Collar failures (e.g., dead batteries or other technology malfunctions) continue to be a problem. Accordingly, we have spent more time searching for missing moose with fixed-wing and helicopter flights to check statuses and attempt to remotely blow-off collars. To that end, we have successfully blown off a total of 11 collars from moose that were still alive but with an inactive collar (2 on 12-Feb 2015, 2 on 10-Nov 2015, 4 on 21-April 2016, and 2 on 10-Nov 2016). Recovering these failed collars is very important because movement, activity, and MIT data were stored on the collar and successfully retrieved.

Causes of the 5 mortalities since June 2016 included 2 health-related cases (1 liver fluke infection and 1 bacterial infection from a puncture wound), 1 predator-related case (wolf-kill), 1 accident (vehicle-collision), and 1 moose legally harvested by a tribal hunter during Fond du Lac's moose hunting season. It was unexpected that it took

nearly to the end of the 4th year of this study to document our first collared moose to be killed by a vehicle collision because we document over a dozen non-collared moose deaths annually. This collared moose also have a severely damaged liver at the time of the accident, but it's unknown if this health issue contributed to her death.

Since this study began in 2013 we have investigated 54 adult moose mortalities. Health-related issues have been the leading proximate cause of moose mortalities (67%), whereas wolf predation accounted for the remaining deaths (33%). Overall proximate causes of death included 18 confirmed and likely wolf kills (33%), 16 parasitic infections (30%), 12 bacterial infections (22%), 5 undetermined health issues (9%), 2 accidental deaths (4%), and one hunter-harvested moose (2%). Whole carcasses were retrieved for 21 (39%) of the mortalities, with field necropsies performed on the remaining 33 moose (61%). Response times from initial mortality notification (e.g., text message or email) to having a team in the field at the death site were ≤24 hours in 36 cases (67%), 24–48 hours in 11 cases (20%), and >48 hours in 7 cases (13%).

With the completion of our MIT calibration project with the Alaska Department of Fish and Game (not funded by ENRTF), our graduate student (also not funded by ENRTF) completed a draft of his Master's Thesis that is currently in review by his graduate committee. The first chapter in his thesis evaluates the accuracy of the MITs compared to vaginal implant readings, documenting how highly accurate the MITs are. The second chapter evaluates how the activity sensor of the collars corresponds to moose behaviors (e.g., resting, foraging, walking, ruminating, running). Further data analysis is underway to determine habitat use of moose in this study. The MIT calibration, activity sensor and behavior correlation, and habitat use analyses are all essential components to lay the groundwork for our upcoming analyses of the MITs deployed during this study in wild moose in Minnesota. Since the study began in 2013 we have recovered 24 MIT datasets from moose (including deaths and slipped/blown collars) that will be utilized over the next 6 months to determine effects of ambient temperate on the physiological and behavioral response in our MN moose.

Activity Status as of June 2017:

The adult moose mortality project began its 5th year in January 2017. The mortality rate of adult moose during January–July 2017 was 9%. Since the December 2016 project status report, 3 additional moose have died from January through July 2017. Causes of these 3 mortalities were health-related, including brainworm infection, calving complications (i.e., dystocia, twin calves stuck in the birth canal while being expelled simultaneously), and an undetermined health issue (heavy parasite loads and eye infection, but no clear cause of death determined at necropsy).

Final Report Summary:

Annual survival and cause-specific mortality
Annual mortality rates of adult moose were 19%, 12%, 15%, and 14% in 2013, 2014, 2015 and 2016, respectively. In all but 1 year they were higher than the 8–12% non-hunting mortality rates observed in stable or slightly increasing moose populations in North America.

We started the 5th year of this project in January 2017 with 41 collared moose alive and transmitting data, and as of July 31, 2017, there were 27 working collars remaining on moose. Collar failures (e.g., dead batteries or other technology malfunctions) continue to be a problem. Accordingly, we have spent more time searching for missing moose with fixed-wing and helicopter flights to check statuses and attempt to remotely blow-off collars. To that end, we have successfully blown off a total of 21 collars from moose that were still alive but with an inactive collar. However, another 53 moose have collars that are unaccounted for due to transmission failures, so we cannot confirm their status as alive or dead. Recovering these failed collars is critical because of the amount of data stored on-board, including activity and MIT data. The collars need to be successfully retrieved for us to have access to the data.

A total of 57 collared moose (40 females, 17 males) have died since this study began; excluding 12 capture-related mortalities that were censored from survival analyses. 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 (i.e., dystocia; n=1, 2%), and undetermined health issues (n=6, 10%; Figure 1). 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 infestations, calving, and pneumonia in the lungs (Figure 2a). 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. Health issues may possibly have compromised some of these moose as well.

Parasitic infections were the second leading cause of moose deaths (Figure 2b). *P. tenuis* directly led to the death of 7 moose in this study. This parasite was also implicated in 5 wolf-induced 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 because not all dead moose could be evaluated for this parasite. Winter tick (*Dermacentor albipictus*) infestations were primarily seen in spring 2013 (attributed to 3 moose deaths). The severe and prolonged winters in 2012-13 and 2013-14 likely reduced tick survival and therefore tick loads during the subsequent seasons. The most recent 3 winters, however, have been extremely mild, and it is likely that winter tick loads have recently increased on moose. In spring 2016, one moose in the study died from winter ticks, and significant tick infestations were observed in other moose as well. We 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, but none of the collared moose have died from winter tick burdens so far in 2017. The sample size, however, 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 of 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 1 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 2c). Four moose were attacked by a wolf or wolves and survived the initial encounter, but the wounds became infected and led to their deaths days to several weeks later. Prior to this study, scant evidence existed in the literature suggesting that secondary bacterial infections caused by a predator attack was 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 legal 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 issues (6 moose).

Timing of mortalities

Most deaths occurred during spring (44%, March–May); however, moose died in all seasons (winter 17%, summer 23%, and fall 16%; Figure 3). Health-related mortalities occurred during all months of the study; however, there were no wolf-related deaths during October through January (Figure 4).

Average age of moose at death was 8.4 years (±0.5 years, range = 1–15 years old, *n*=55, which excludes 2 moose with age results still pending). Average age of moose that died from health-related causes was 8.1 years (±0.6 years, *n*=35, excluding 2 moose with accidental deaths and 1 moose harvested by hunters), similar to those that died of wolf-related causes (8.6 ±1.0 years, *n*=18, *T-stat*=2.0, *p*=0.7). Interestingly, both health- and predator-related causes of death impacted nearly every age cohort in this study (Figure 5), yet there was some evidence to support that wolves were more selective for the young (≤3 years of age) or old (≥9 years of age) cohorts (X^2= 45.0, *p*=0.08), and more prime-aged moose were dying of health-related issues.

Mortality Response Times

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

Mortality Implant Transmitters

We successfully deployed 63 MITs in moose over 3 years of captures (2013-2015). 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 MIT deployment technique was implemented during the final year of capture, and it improved success rates from 73% (43 of 59 attempts during 2013-2014) to 85% (20 of 23 attempts during 2015, Minicucci et al. 2017). To date, 20 moose with working MITs have died in the study, and their body temperature data was collected, but 4 of these moose were capture-related mortalities and their data were censored from analyses. Another 11 MIT datasets have been recovered from remotely blown collars (n=9) and slipped collars (n=2), but 17 moose with MITs have collars that have malfunctioned, and it is unlikely the data from them will be ever be recovered. Currently, 15 of the 27 moose remaining in the study with functioning collars have MITs, which we plan to recover, if possible.

We collaborated with the Alaska Department of Game and Fish to conduct an MIT calibration project at the Moose Research Center in Kenai, Alaska during 2014–2015. The MIT was shown to provide highly accurate measurements of internal body temperature in moose (Herberg 2017, UMN thesis). After removing low temperatures induced by water intake, MIT-recorded internal body temperatures were only 0.03°C (95% CI = -0.57– 0.55) lower than the VIT (vaginal implant transmitter)-recorded temperatures. Applying some of that work to the wild moose dataset, we have begun some preliminary analyses using the MIT data from the collars that were recovered up to this point. We will continue updating these results as new collars are retrieved and downloaded.

Determining physiological and behavioral impact of ambient temperature on moose: A preliminary analysis

A goal of this study was to quantify moose physiological (body temperature) and behavioral (movement rates, habitat use) responses to changing air temperatures. Effects of temperature may be direct (e.g., death due to "heat stress") or indirect (e.g., reduced foraging to seek thermal cover, leading to poor body condition). Due to the limited availability of MIT datasets recovered thus far (27 of 63 deployed; 43%), attempting to link internal body temperature to moose reproductive success or survival is not yet possible. However, we are able to take a first look at patterns in body temperature of wild moose in Minnesota to better understand if "heat stress" events actually occur, and if so, what circumstances lead to periods of excess heat. Further analyses will be possible as additional datasets are added in the future.

Summary statistics of MIT-measured body temperature in wild moose

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); data from the other 2 of

the 27 MITs recovered so far were not available in time for the analyses presented here. MIT temperature values were obtained between January 23, 2013 and March 16, 2017 for an average of 400 days for these moose (range = 56–951 days). Among these 25 individuals, the MIT-measured body temperatures ranged from 37.55°C to 42.10°C, with an overall average of 38.28°C and average maximum temperatures of 40.56°C. Abnormally-low observations, due to intake of water or snow, were removed prior to further analyses (based on lower thresholds detailed in Herberg (2017) of 37.54°C in the warm season (spring, summer, fall) and 37.66°C in the winter).

We observed notable seasonal and day vs. night differences in average MIT values across all individuals (Figure 6). MIT-recorded internal temperatures were on average highest in the summer and lowest in winter, and they were also lower during the day than during the night.

Over the course of 24 hours, MIT-recorded temperatures were, on average, at their lowest around mid-day, and increased until approximately 8-9 pm before leveling off and decreasing again during the course of the night (Figure 7). This daily pattern appears to hold across all seasons but is more pronounced during the summer.

Ambient temperature effects on moose internal body temperatures

We calculated daily averages in ambient temperature using values from the 3 NOAA weather stations located in the moose range in Minnesota (i.e., Ely, Eveleth, and Grand Marais). We also calculated daily averages in MIT-recorded body temperatures for all 25 moose and over the duration of the study. Here we focused on daily averages because we wanted to investigate the broad-scale effect of ambient temperature over several months on body temperature by smoothing out the finer-scale effect of time-of-day on temperatures. Daily averages in MIT showed a clear temporal pattern of warmer body temperatures in summer and cooler in fall, winter, and spring (Figure 8).

We fit statistical models to evaluate how daily averages in MIT-temperatures varied both seasonally and as a function of daily averages in ambient temperatures. Our seasonal model showed that MIT temperatures are on average 0.27°C higher in the summer than in the spring, and on average 0.16°C lower in the winter compared to spring (the reference level in the model). There was no difference in MIT-recorded temperature between spring and fall.

All seasons combined, there is a slight overall increase in average daily MIT temperature (0.0009°C) for every degree Celsius increase in average daily temperature. The magnitude of increase in MIT temperature as a function of ambient temperature varies across seasons (Figure 9).

Are moose "over-heating"?

Out of the 25 animals we analyzed, 23 had between 0.19% and 11.25% of internal temperatures considered above normal (i.e. ≥ 39.2°C). The proportion of MIT temperatures that were above normal varied seasonally [i.e., 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]. As with MIT values overall, there is a noticeable day/night pattern in the proportion of MIT values that are above normal for all seasons except winter, with a higher proportion of values above normal during the night than during the day (Figure 10).

We interpolated MIT values at times of GPS locations (i.e., hourly during the calving season and every 4 hours the rest of the year) to investigate if the habitat types used when an animal was hot (i.e. ≥ 39.2°C) differed from the ones used when an animal was not hot. In the summer months, we found that the proportion of habitat types used when an animal was hot compared to what would be expected based on what is available was significantly different in 6 of 18 animals (the set of data for which we had abnormally warm MIT temperatures

during summer at the temporal resolution of the GPS-collar data). Of these 6 animals, 2 showed greater use of deciduous cover and lower use of woody wetlands when the body temperature exceeded 39.17 C in the summer than what would be expected based on the "non-hot" locations. This pattern will be investigated further once we recover data from all collars with MITs.

Now that we have identified times and locations when individuals had abnormally high body temperatures, we plan to investigate further if moose select habitat differently when they experience physiological changes in internal body temperature (e.g., if animals select different landcover types to cool-down). In a companion study, Street et al. (2016) showed that ambient temperature, particularly in summer, affects habitat selection in moose in Minnesota. A comparison of used vs. available locations for moose in Minnesota revealed patterns of habitat use that vary across time of day and ambient temperature, with increasing use of coniferous and treed wetlands and decreased use of deciduous and mixedwoods (optimal foraging habitat) at mid-day and as temperature increases (Street et al. 2016). Ultimately, and as suggested by these results, 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 foraging habitat. This has important implications for forest management because good foraging habitat and adequate thermal refugia for moose occur in different forest conditions. The MIT data we have provides additional information we can use to better understand the behavioral responses of moose to changes in physiology following an increase in body temperature, and will complement the study of Street et al. (2016).

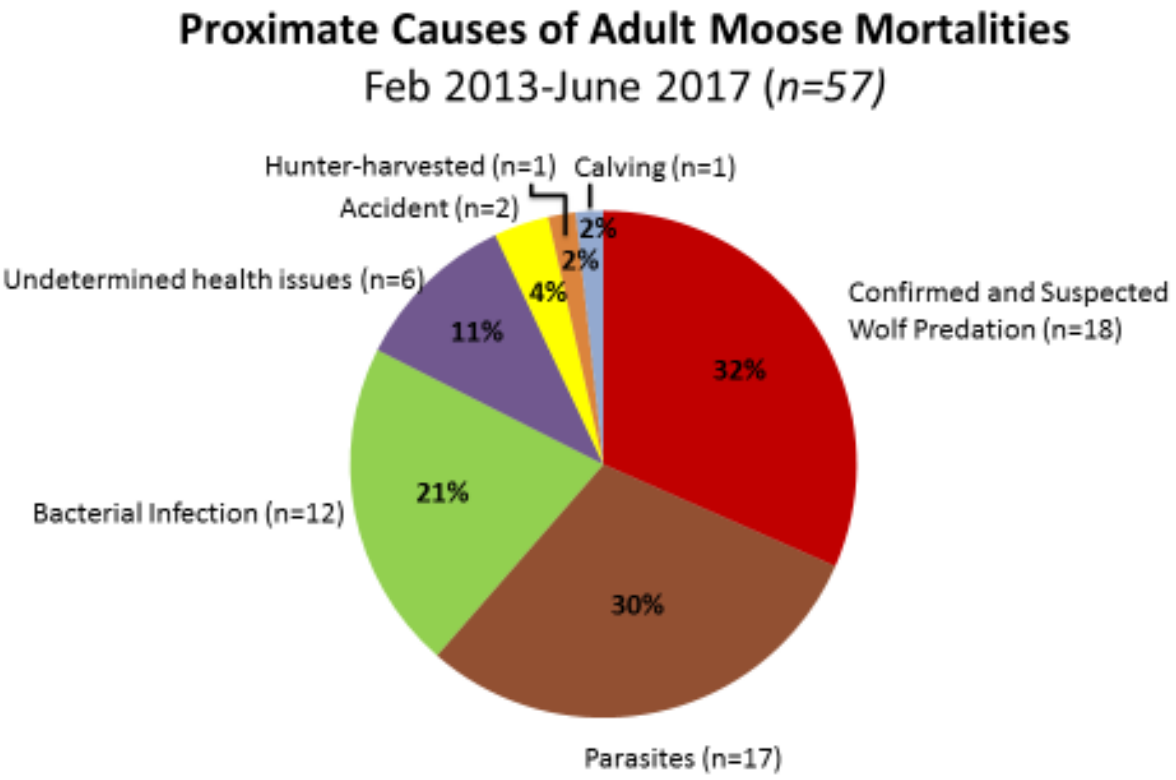
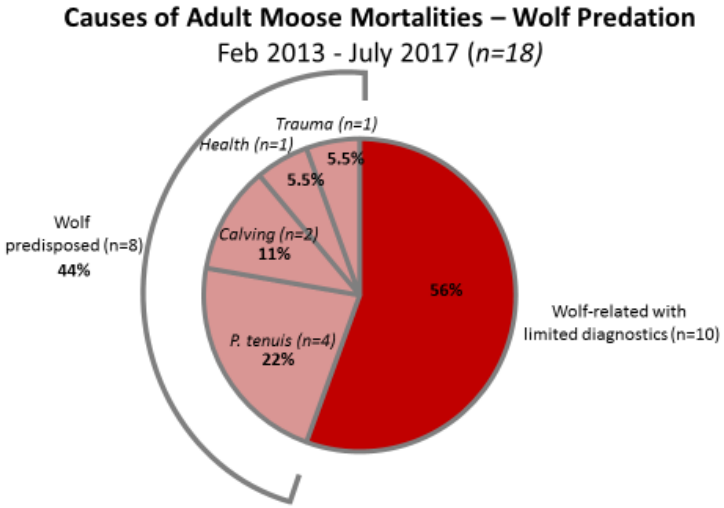
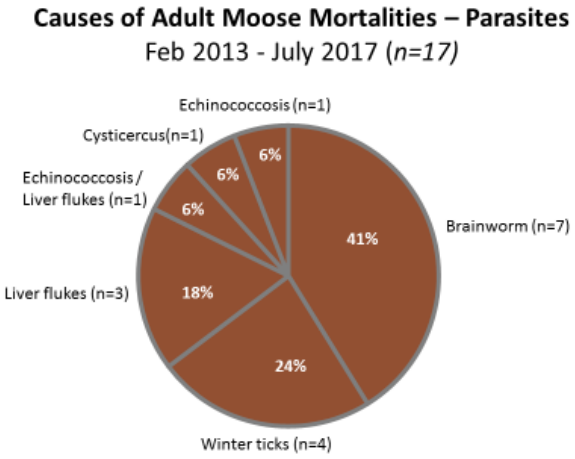


Figure 1. Cause-specific mortality of radiocollared, adult moose (*n*=57) from February 2013 to July 2017, northeast Minnesota.

a)



b)



c)

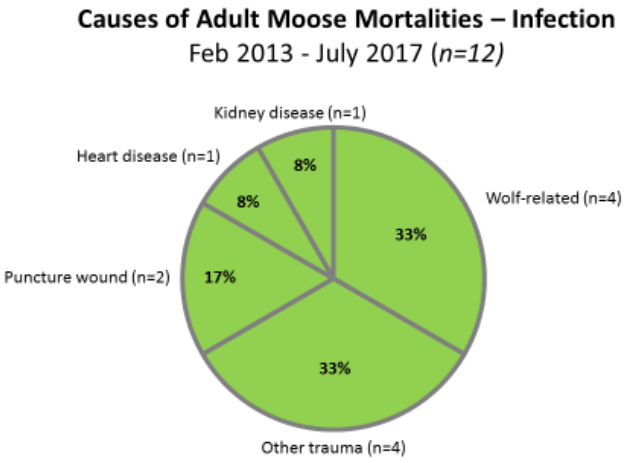


Figure 2. Breakdown of adult moose mortalities caused by wolf predation (a), parasites (b), and bacterial infections (c), Feb 2013-July 2017, northeast Minnesota

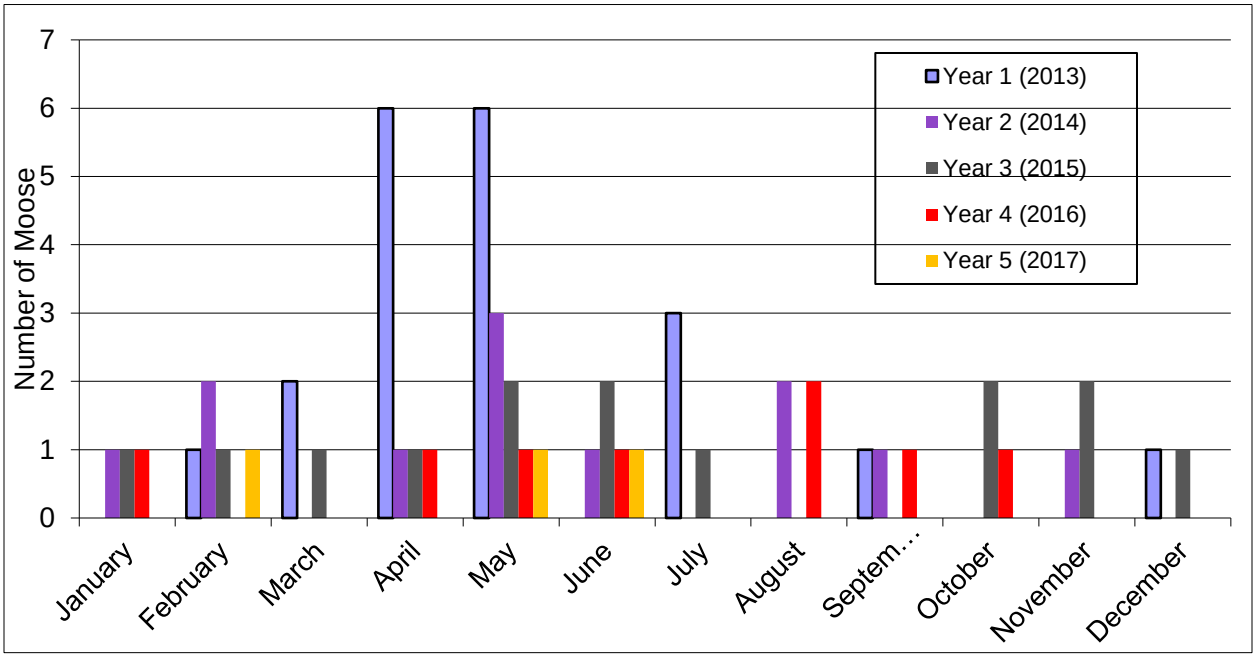


Figure 3. Timing of mortalities for radio-collared adult moose (*n*=57) from January 2013 through July 2017, northeast Minnesota.

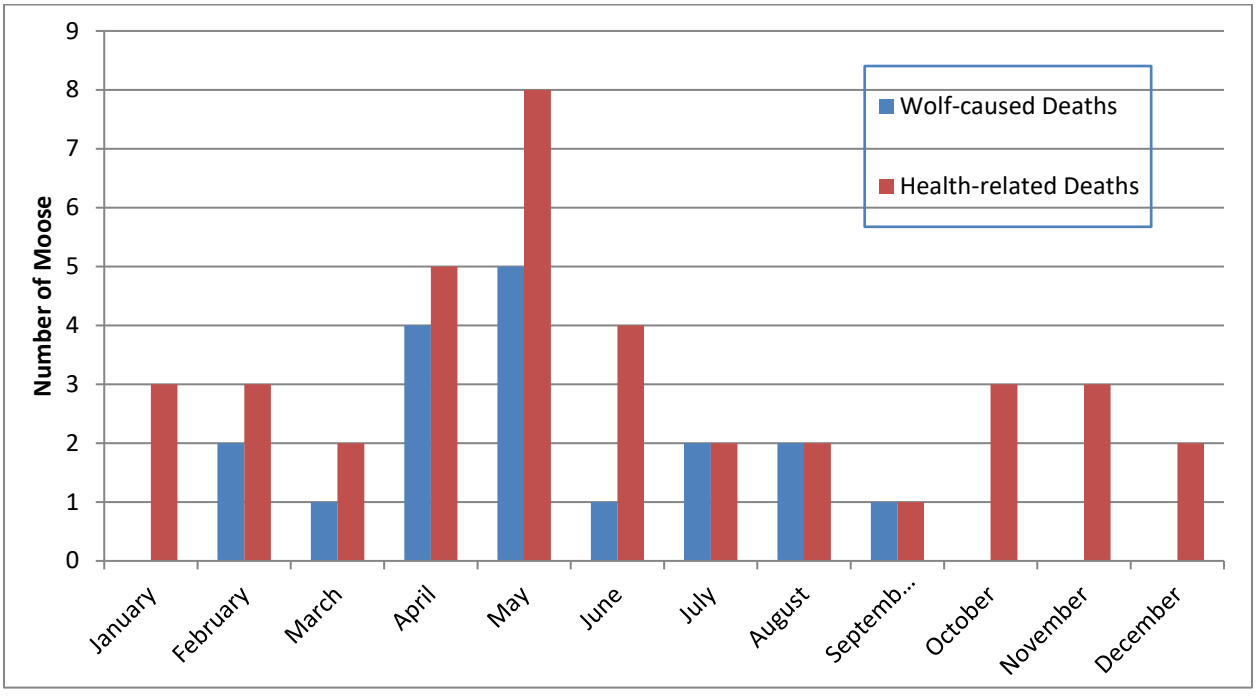


Figure 4. Timing of wolf-caused (*n*=18) and health-caused (*n*=38) moose mortalities, 2013-2017, in northeast Minnesota.

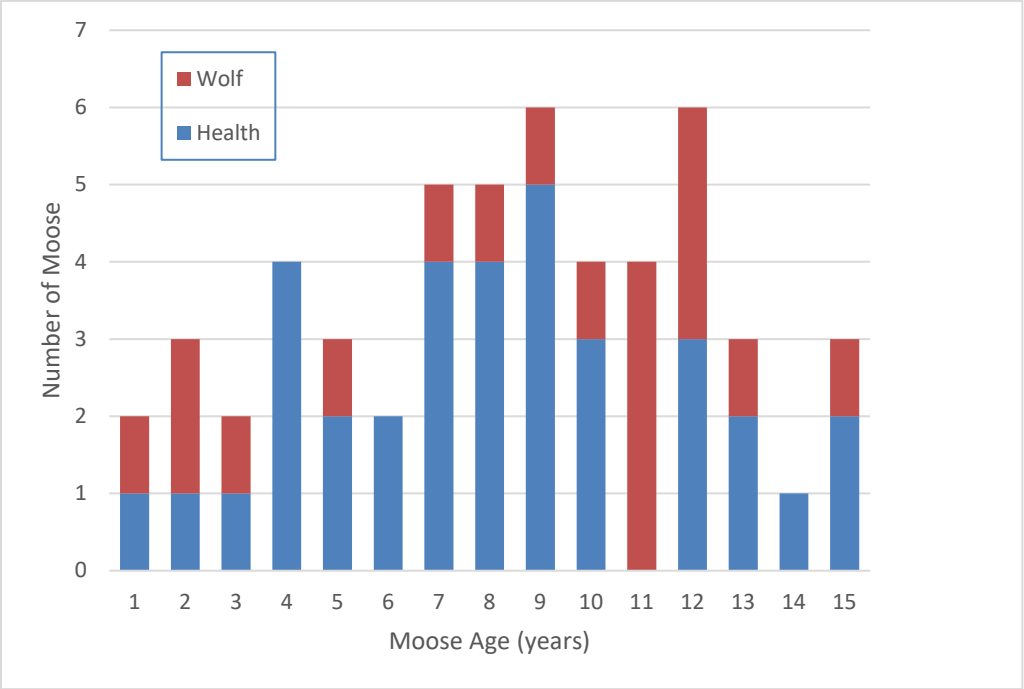


Figure 5. Known ages of radio-collared, adult moose (*n*=53) that died from health-related (green) or wolf-related (red) causes (2013-2017), in northeast Minnesota.

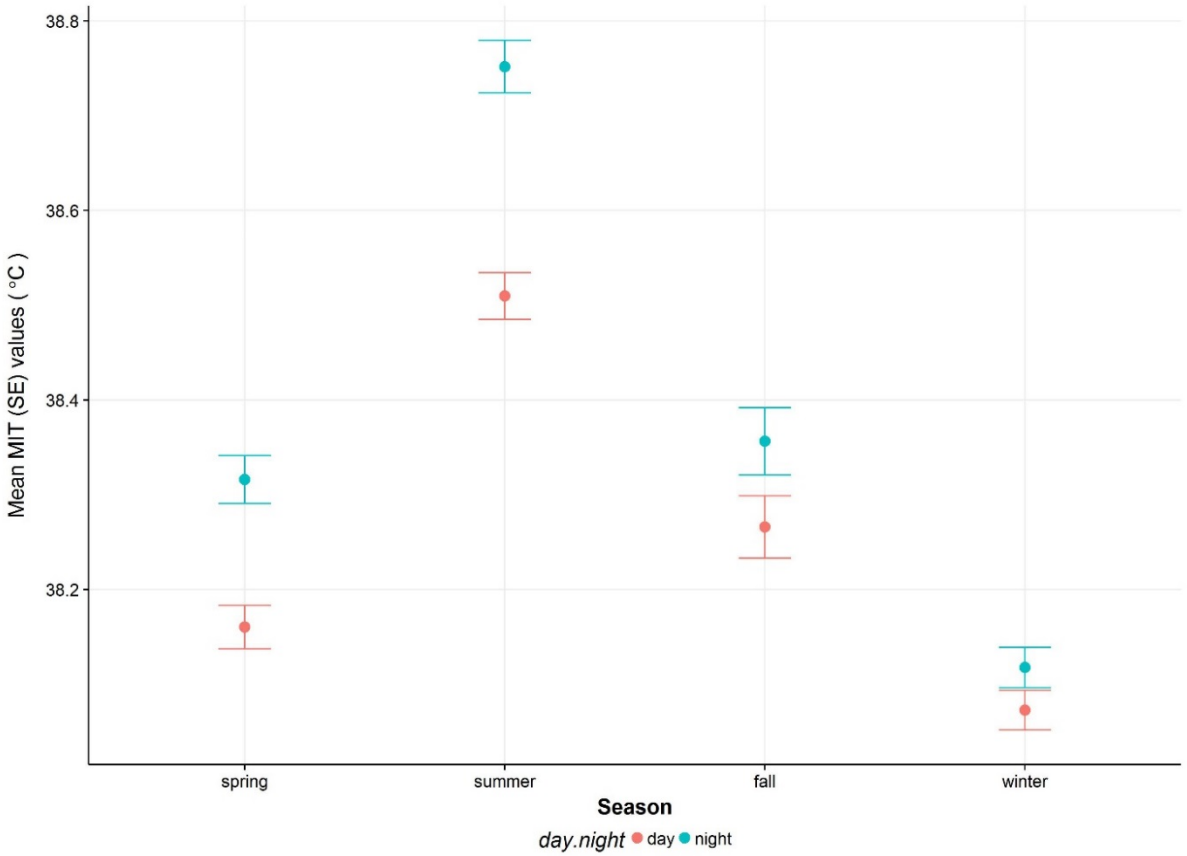


Figure 6. Mean (±SE) in MIT-recorded body temperature data in 25 moose across seasons, comparing daytime (pink) and nighttime (blue).

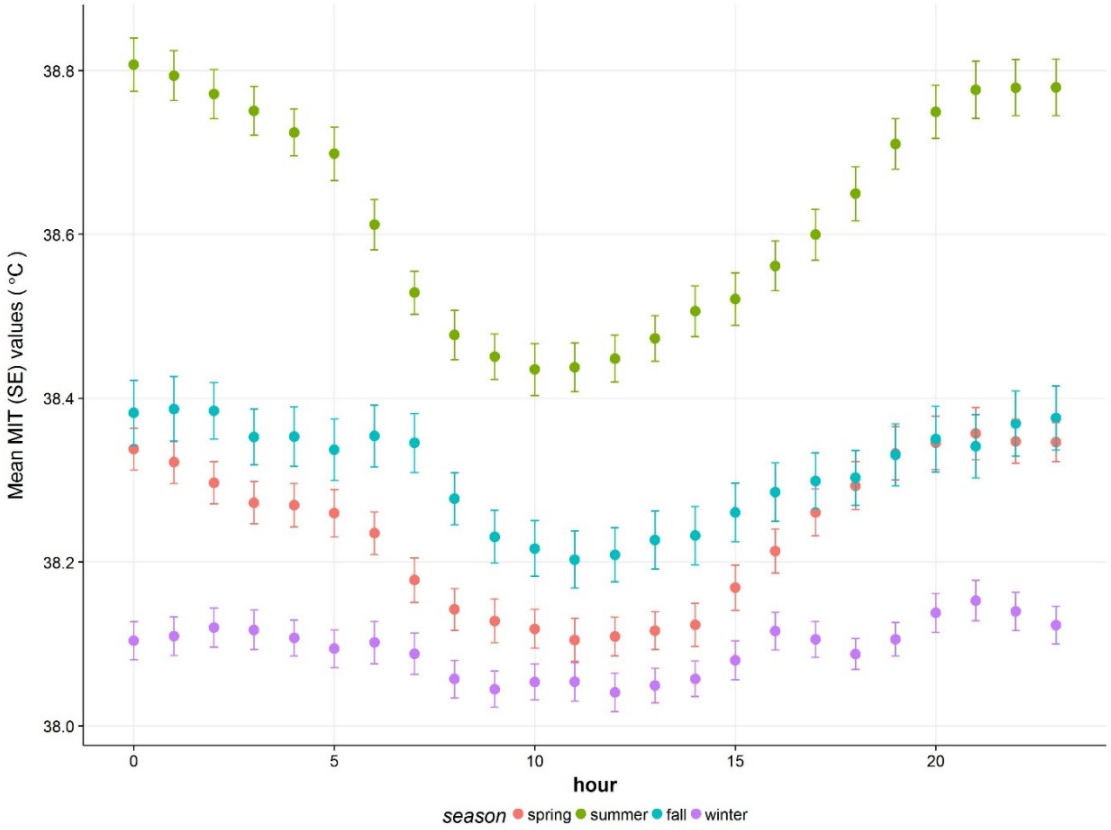


Figure 7. Mean (±SE) MIT-recorded body temperatures over 24-hr periods across all moose, years, and seasons.

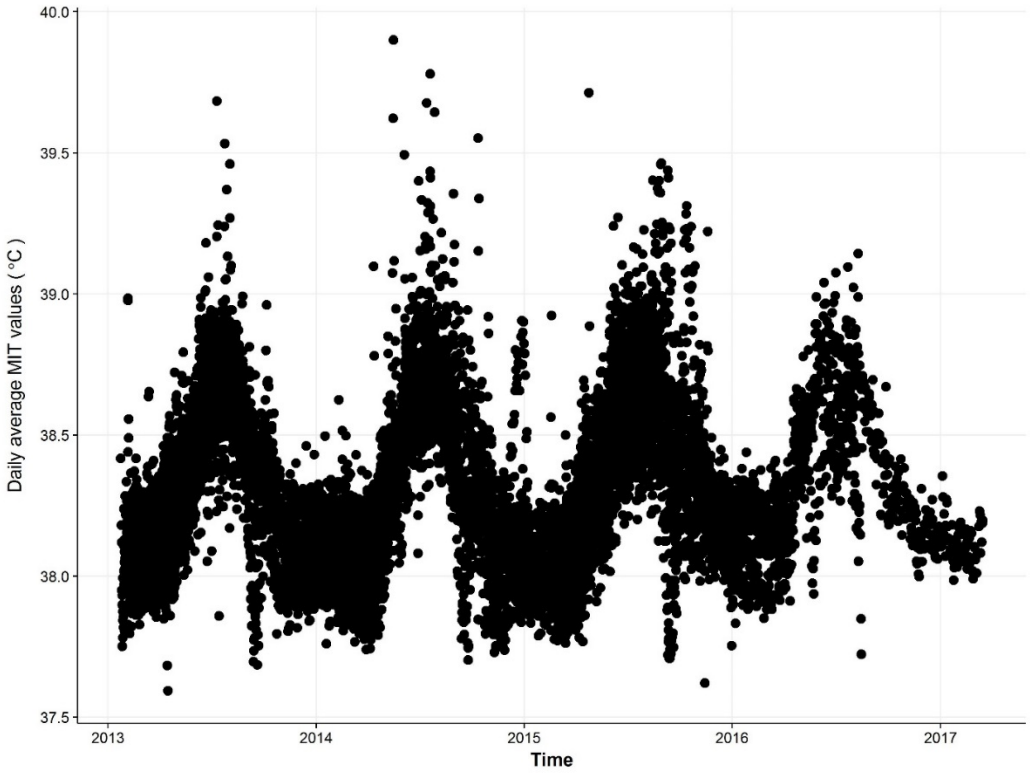


Figure 8. Daily average MIT-recorded body temperature data, all 25 moose combined.

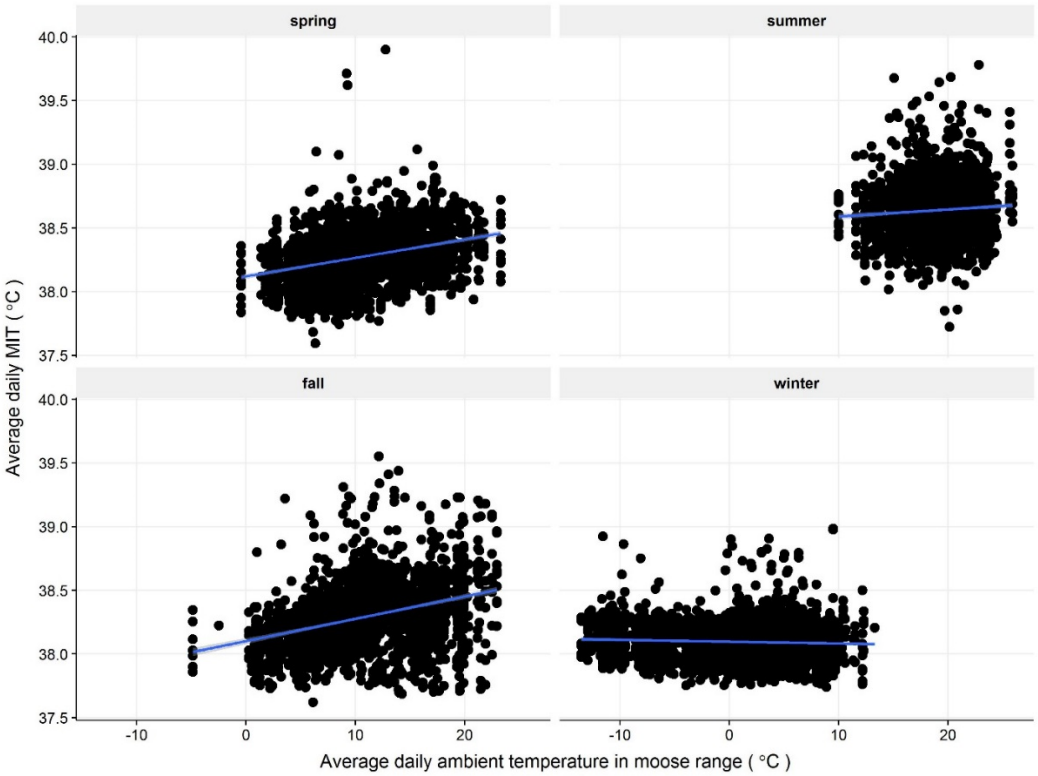


Figure 9. Relationship between daily averages in MIT-recorded temperatures and daily averages in ambient temperatures in the moose range. The ambient temperature was averaged over three weather stations located in Ely, Eveleth, and Grand Marais. The blue lines approximate the slopes of linear models of average daily MIT as a function of average daily temperature.

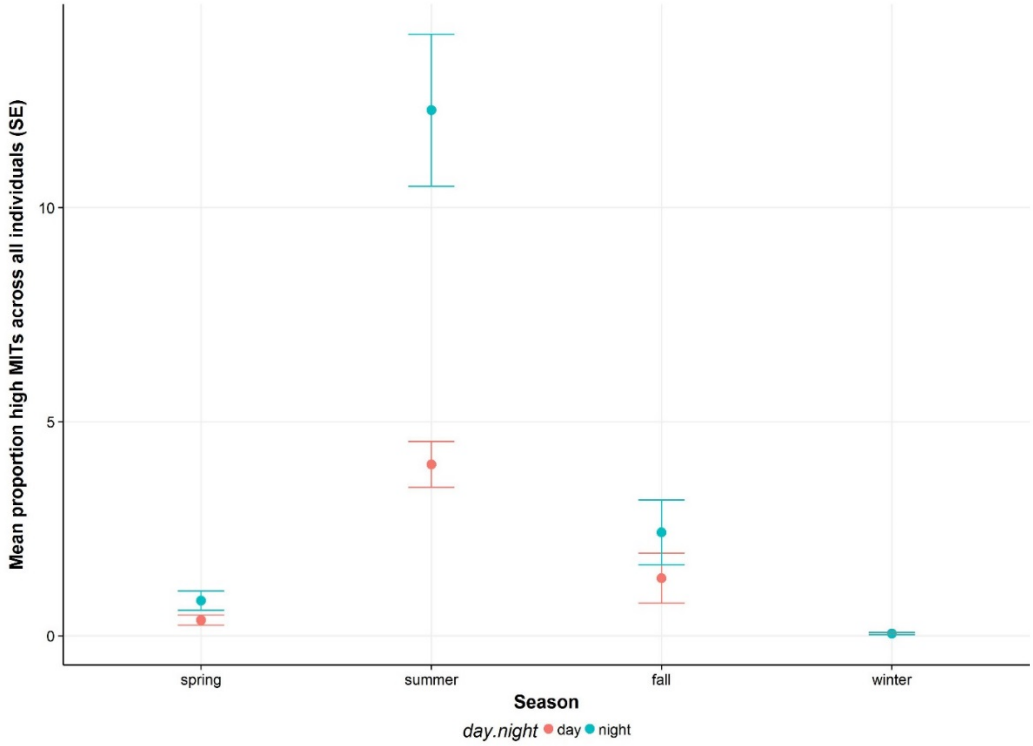


Figure 10. Mean (±SE) proportion of MITs considered abnormally high (i.e., above 39.17 C) across season during daytime (pink) and nighttime (blue).

ACTIVITY 2: Determine the potential effects of the condition and behavior of adult female moose on calf productivity and survival.

Description: Calving behavior and activity (i.e., movements) of all adult GPS-collared female moose will be intensely monitored in near real-time by several proven computer methods during May to early-June 2015 to determine pregnancy and, using twinning rates determined during previous years of this study, overall calf production. We will continue to monitor hourly locations of females with calves throughout the summer, using rapid movements of more than 400m to identify possible calf mortality sites. As with the adults, intact fresh carcasses of calves or remaining tissue samples will be transported to the Veterinary Diagnostic Laboratory at the University of Minnesota for diagnostic workup, or detailed necropsies will be conducted in the field. We will use aerial surveys of collared mothers during late-fall, mid-winter, and late-winter to observe remaining calves and estimate seasonal and annual survival rates of calves. Prolonged physiological stress and behavioral responses to increased temperatures can have debilitating effects on the nutritional condition and overall health of adult moose, which can compromise their ability to become pregnant, fetal development, and survival of calves throughout their first year. Seasonal and annual survival and specific causes of mortality of the calves of collared adults will be determined during their first year and relationships with ambient temperature, physiological status (e.g., body temperatures) and behavior (e.g., habitat use) of the dams will be examined. We will also examine the potential relationship between calf survival and the population-level nutritional condition of moose determined by collecting and analyzing urine voided in the snow during winter.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 244,022
Amount Spent: $ 242,325
Balance: $ 1,697

Activity Completion Date: 6/30/2017

Outcome	Completion Date	Budget
1. Determine the relationship between physiological & behavioral responses of females and the production and survival of calves	6/30/2017	$ 153,409*
2. Continue to determine specific causes of mortality of calves during their first year	6/30/2017	$ 90,613*

* Of the $244,022 for Activity 2, $9,218 is for Direct & Necessary services to support the appropriation.

Activity Status as of December 2014:
We monitored the movements and survival of moose calves that had been GPS-collared during spring 2014. We investigated the mortalities of collared moose calves that died. We measured habitat characteristics at 88 pre-calving, calving, and mortality sites of calves GPS-collared during spring 2013 and 2014. We also conducted a controlled study of new GPS calf collars to determine the effects of physical disturbance and weather conditions on the durability and proper functioning of the collars.

Activity Status as of June 2015:
We are monitoring the current calving activity of 60 adult female moose with functioning GPS collars. As of May 25th 46 of 60 adult females (76.7%) had calved, as determined from remotely tracking female movements. This means that minimum calf production of the study cohort is at least 46 calves (assuming all singletons) and may be as high as 61 calves (assuming a 32% twinning rate as in 2014). Based on cumulative data and winter pregnancy-testing by serum progesterone concentrations at adult capture, we expect a minimum of 53 females (88.9%) to calve and a study cohort of 53–70 calves. We have investigated 17 possible calf mortality sites and found direct evidence of a calf mortality at 8 of them. Whether or not the mother returns to the site after fleeing has been a reliable indicator of actual calf mortality. During investigative visits to the calving sites (approached only after the mother and calves have moved away) and mortality sites we are conducting extensive habitat analyses to assess each site for escape or hiding cover and forage availability and quality. Estimated calf mortality through May was 11–28%.

Activity Status as of December 2015:
Fifty (83.3%) of the 60 monitored females calved, reflecting a "normal" pregnancy rate for this population compared to moose across North America. Mean calving date in 2015 was 11 May (range = 29 April–14 June), 3 days earlier than in 2013 and 8 days earlier than in 2014. Seventy-six percent of births occurred during 3–15 May. The 50 monitored females gave birth to an estimate of 65 calves, and we estimated calf production for the entire population to be 1,728 calves, which represents a decrease of 56.9% from 2006 when an estimated 4,008 calves were produced. Importantly, the 2015 calving season (3rd in our study, 1st using ENRTF funding) improved our understanding of the annual variability of calf production, the timing, location, and habitat associated with calving activity in northeastern Minnesota.

We used the movement patterns of collared cows (i.e., rapid, long distance moves and repeated returns to where the cow fled from) to investigate potential calf mortalities. Nine confirmed calf mortalities occurred during 3 May–2 June; causes included 6 wolf (*Canis lupus*) kills, 1 bear (*Ursus americanus*) kill, and 2 unknown predator kills. Average age at death was 13.2 days old (range = 2–23 days old). Presently, our examination of movement behavior of dams shows that it is most reliable for signaling mortalities of calves from birth to 30 days of age. Mortality data from 2013 to 2015 show consistently that the population is losing 40% of its calves by 30 days of age.

During late-October through early-December 2015 we completed our fall helicopter survey. We observed 40 of the cows that had calved this spring and 23 calves (15 singletons and 4 sets of twins) accompanying them. Assuming a twinning rate of 30% for the 40 cows, this sample cohort began with 52 calves being born. Further assuming that we observed all surviving calves during the aerial survey the estimated survival rate of calves to late-fall was 44%.

We calculated the Heat Stress Index for moose in northeastern Minnesota from daily maximum temperatures during January and the entire winter season for 1960 to 2015 to examine potential relationships between this index and the production and survival of calves. Preliminarily, there is a strong correlation between the annual index values and the frequency of severe winter nutritional restriction in the moose population determined from a companion study.

We have conducted detailed habitat surveys at 65 cow locations prior to their calving movement (pre-calving sites), 91 calving sites, 22 peak lactation sites, and 34 calf mortality sites. We will focus our analyses on assessments of hiding and thermal cover and forage availability at these sites to better understand habitat selection by adult females to balance their need to protect their calves from predators, to regulate their body temperature, and to obtain quality forage to fulfill their nutritional requirements and those of their calves.

Activity Status as of June 2016:
Our spring 2016 helicopter survey indicated that calf mortality during winter was minimal; the one-year calf survival rate was 40%.

Monitoring of the calving movements of 34 GPS-collared adult females and confirming with field investigations have indicated at least a 79.4% pregnancy rate entering the 2016 calving season. This is near normal for North American moose, and as of early-June the calving season is not yet complete. Based on findings of the MN DNR's annual winter survey of the moose population in northeastern Minnesota and this calf study, we expect about 1,739 calves to be produced in spring 2016.

In an attempt to better understand variation of maternal movement patterns (e.g., flees and return-visits) in response to mortality of their calves by different causes (e.g., wolf and black bear predation) we analyzed movement patterns and other evidence associated with calf deaths by "known causes" during 2013 to 2015. We are augmenting the 2016 field investigations with hair identification and DNA analyses of various other samples (e.g., scat) collected at suspected mortality sites to confirm predator species and individual

relationships of moose (e.g., calf to mother). Since the 2016 calving season began in late-April we have investigated the mortalities of 6 calves of GPS-collared adult females: 3 wolf-kills, 2 probable wolf-kills, and 1 by unknown cause (awaiting results of these further laboratory analyses). As of early-June, the calf mortality rate was at least 22.2%.

We also are engaged in detailed statistical analyses of several data sets. First, we are examining how variations in maternal movement behavior and habitat composition may be related to survival probability of calves over time and space. Second, ongoing data analyses are providing us with a deeper, valuable understanding of maternal abandonment behavior induced by calf capture and how to minimize its occurrence. And finally, winter 2015–2016 was our fourth season of physiologically assessing nutritional restriction of moose in northeastern Minnesota. Relevant to the potential influence of climate change on the declining moose population, preliminary statistical analyses of data from winters 2013 to 2015 have yielded strong relationships, showing that as the winter heat stress index (HSI) for moose increased, the severity of winter nutritional restriction also increased at the population level. Additionally, as the severity of winter nutritional restriction increased, winter and winter-to-summer survival rates of the GPS-collared adult moose decreased, as did our annual moose population estimates.

Activity Status as of December 2016:
Thirty-five GPS-collared adult female moose were monitored beginning in late-April 2016 for calving movements, or a long distance movement followed by intense localization. We observed 28 of 35 (80.0%) make a calving movement, and along with additional field observations of calves with GPS-collared adult females, we determined 31 (88.6%) of the 35 cows were pregnant. This is a robust pregnancy rate compared to the average for moose in North American. At the population level we estimated that 1,893 calves were produced with an estimated average birth-date of 12 May 2016 (median = 11 May 2016, range = 24 Apr–10 June). Following confirmation of calf presence (e.g., calf pellets, tracks, afterbirth), we investigated predator attacks on calves, indicated by a rapid, long distance movement ("flee") by the GPS-collared mother, followed by a return to the origin of her flee. We observed evidence of 14 calf mortalities with an average age at death of only 13.8 days (SE = ±3.2, range = 2.7–33.7 days). During 2013 to 2016 approximately 40% of the calves died by 30 days of age. The dominant cause of death in 2016 has been wolf predation, as it was during 2013–2015. Specifically, causes of calf mortality in 2016 included 10 wolf-kills, 2 bear-kills, 1 unknown predator-kill, and 1 death following a possible vehicle collision. The average distance cows initially fled from the calf mortality site was 1,634 m (± 444, 126–5,805 m, *n* = 12), but 8 of 12 cows returned to the mortality site an average 2.6 ± 0.5 times. Average ground-search time by field staff when a calf mortality occurred was 67.6 min (± 9.9, 25–134 min, *n* = 14), covering 2.7 hectares (± 0.5, 0.9–7.4 ha, *n* = 13). Understanding movement behaviors of cows can yield important insight into mechanisms driving the decline of the population in northeastern Minnesota and aid in future management decisions. Our fall/early-winter helicopter survey to assess calf survival since late-summer will be conducted in the upcoming 2 weeks. We are currently conducting analyses of calving activity, mortality, and habitat survey data to identify forest habitat characteristics that best allow calving female moose to fulfill their requirements for forage quality and predator avoidance.

After 4 winters (2013–2016) of physiologically assessing the nutritional status of moose at the population level in northeastern Minnesota, *preliminary data analyses* are yielding strong relationships between the increasing incidence of severe nutritional restriction and decreasing winter survival of GPS-collared adult moose, decreasing population estimates, and declining calf production. We had also observed an increasing incidence of severe nutritional restriction of moose with increasing winter temperatures (i.e., moose heat stress index), but this was ephemeral. Additional data from more winters will be required before any firm conclusions about the potential influence of climate change on the nutritional status of moose can be drawn.

Activity Status as of June 2017:

We completed helicopter surveys of GPS-collared adult females with calves during winter and early spring to estimate the survival of calves, which was 32.6% through 350 days of age for 2016–2017.

Final Report Summary:

The multi-year (2013−2016) study of the production, survival, and cause-specific mortality of moose calves (*Alces alces*) provides insight into the annual variation of these demographic parameters and how that variability impacts the performance, dynamics, and trend of the moose population in northeastern Minnesota. The average pregnancy rate of this population was robust (83.2%, 95% Confidence Interval = 76.5−89.8%), very comparable to the North American average for moose (83%). During 2013, however, coincident with a heavy winter tick (*Dermacentor albipictus*) infestation of moose in this region and a high annual adult mortality rate of 19%, we recorded the lowest pregnancy rate (74.3%). Estimated average calf production at the population level was 1,628 (± 167 [standard error]) calves, but ranged from 1,040 (2013) to 1,893 (2016) calves during the study (Figure 11). The winter tick infestation and the low pregnancy rate were not directly linked but together would have a uniquely strong negative impact on the population's performance and abundance. Furthermore, the pregnancy rate was highest during the past 2 years (88 and 89%, respectively), coincident with the highest calf production and recent stability of the estimated population.

During the first 2 years of the study, prior to funding from the ENRTF, we had the technical advantage of examining natural survival and cause-specific mortality of 40 calves from birth using GPS collars on both the newborns (neonates) and their mothers (dams). During the following 2 years, using the knowledge gained from carefully monitoring the movements of GPS-collared dams the first 2 years and helicopter surveys of GPS-collared dams and their calves during fall and late-winter to early-spring, we were able to continue informative assessments of the life history of calves in this population. The median calving dates during 2013–2016 did not vary markedly among years (May 14, 18, 10, and 12, respectively; half of the births occurred before and half after the median date; Table 1). Furthermore, during a given spring, calving activity tended to be clustered (e.g., 75% occurred during 4−14 May 2016), but overall, calving occurred for well over a month (e.g., 24 April−10 June 2016). The average age of all dams of collared calves was 6.4 years old (± 0.5, n = 43) but ranged from 1 to 14 years old. We also noted no difference between average body mass (15.8 kg ± 0.3, 12.0−20.5 kg, n = 38) or hind foot length (45.9 cm ± 0.3, 42−49 cm, n = 42) for twins versus singleton calves or between male and female calves.

The greatest risk of mortality for moose calves consistently occurred within the earliest weeks of life when they were most vulnerable to predation (Figure 12). For all GPS-collared calves in 2013 and 2014 survival to 30 days of age was 58.4% (95% CI = 46.1−74.0%, Figure 12), meaning the mortality rate was 41.6%. By 206 days of age (i.e., early February), survival declined to <34.1% (95% CI = 22.6−51.6%) and possibly as low as 28.5% (95% CI = 17.8−45.7%). Indeed, the "hazard" (i.e., instantaneously probability of death) peaked at 15 days old, then declined until a second peak at 90 days of age. Average age of death for calves that died before 1 year of age was 31 days old (± 7, n = 31); the median age of mortality was 18.3 days old, coincident with the initial peak in the hazard function.

Similarly, in 2015 and 2016, 30-day survival (of uncollared calves) was 63.2% (95% CI = 51.8−77.0%) and 66.7% (95% CI = 50.7−68.3%), respectively. By the late-winter/early-spring helicopter surveys of 2015 and 2016, survival to nearly 1 year of age (i.e., recruitment) was down to 40.5% and 32.6%, respectively. Figure 13 depicts 350-day survival for moose calves during the final year of the study (2016). During all 4 years most of the calf mortality occurred between 30 and 50 days of age.

Causes of calf mortality were consistent over the 4 years. We documented 31 mortalities of GPS-collared calves during 2013 and 2014, with predation accounting for 25 (84%) of those deaths. Specifically, there were 20 wolf

(*Canis lupus*)-kills (64.5%), 5 black bear (*Ursus americanus*)-kills (16.1%), 2 natural abandonments (6.5%), 1 drowning (3.2%), 1 abandonment of unknown cause (3.2%), 1 unknown predation event (3.2%), and 1 death from infection caused by wolf bites (3.2%). During the first 9 months of age the cumulative probability of being preyed upon by wolves was 50.2%; it was 11.7% for bear predation and 9.6% for "other causes." In 2015, 11 mortalities of uncollared calves included 9 wolf-kills (81.8%), 1 bear-kill (9.1%), and 1 unknown predator-kill (9.1%). In 2016 we documented 15 mortalities of uncollared calves from 28 mortality investigations—9 (60.0%), 3 (20.0%), and 1 (6.7%) were attributed to wolf, bear, and unknown predation, respectively. Two deaths (13.3%) were caused by a possible vehicle collision.

Collective findings addressing reproductive success (production of calves and calf survival) have shown that fertility (i.e., pregnancy rate) of the adult female moose in this population is quite "normal," a reflection of reasonably adequate nutrition leading up to and during the fall rut. However, any elevation of mortality of adult (reproductive) females will continue to negatively impact annual calf production. That, and relatively low survival of calves to 1 year of age, primarily due to wolf predation during their first 30 to 50 days of life, will make it very difficult for the population's performance (growth rate) to support increasing numbers of moose into the future.

Movement behavior and a number of extraneous or environmental factors, such as habitat availability and use for calving and calf-rearing, may influence annual survival of calves, specific causes of mortality, and recruitment. Most GPS-collared dams and their calves were an average of 101 m (± 1.5) apart throughout the year (Figure 14), but the dam-to-calf distance was often highly variable, and on rare occasions the distance between them was far greater (up to 29 km).

Our study assessed habitat composition at a fine spatial scale at 34 pre-calving, 37 calving, 25 peak-lactation (about 21 days following birth), and 5 mortality sites in 2015. For this analysis, models of all possible combinations of ground slope, average visibility of a calf silhouette at 15 m (i.e., an indicator of cover for concealment, or predator avoidance), average canopy closure, and total forage availability were developed to assess characteristics of habitat used by dams and their calves. The variable for predator avoidance cover occurred in 5 of the 6 best-fitting models. Interestingly, median percentage of the calf model visible from 15 m was 40% less at calving sites than at pre-calving sites, indicating that predator avoidance cover may have been of heightened importance to dams as they "decided" where to calve. In contrast, canopy closure and total amount of forage were greater at peak-lactation sites than at calving sites (Figure 15), indicating that the balance between security and nutritional requirements may influence changes in use of habitat. In-depth data analyses at a broad scale for 2013–2015 and synthesis of information to improve our understanding of these requirements and their relationship to habitat use and population performance will continue.

Because nutrition is central to our understanding of all other aspects of an animal's ecology (e.g., movements, habitat use, reproduction, survival), we have been physiologically assessing the nutritional status of moose at the population level during winter, the natural seasonal nutritional bottle-neck for northern ungulates (i.e., hoofed animals). Specifically, we have been determining the incidence of severe nutritional restriction via the collection and chemical analysis of fresh urine specimens voided in snow (snow-urine) throughout most of moose range in northeastern Minnesota. Currently, years of research and examination of numerous chemistries in urine from northern ungulates under controlled or known nutritional conditions have shown that milligrams of urinary urea nitrogen (UN) excreted per milligram of creatinine (expressed as a ratio, UN:C) has the greatest value and sensitivity for assessing the severity of nutritional restriction during winter. This technique permits non-invasive, cost-effective sampling of moose across vast areas at the landscape scale and the collection of relatively large sample sizes.

During 1 January to 31 March 2013−2017, we collected 944 snow-urine samples during 6 2-week sampling intervals. The initial 5 years of nutritional assessments have produced a number of notable findings. For example, average winter UN:C ratios indicated more severe nutritional restriction for moose during winters

2013, 2016, and 2017 (3.7, 3.5, and 3.7 mg:mg, respectively) than during 2014 and 2015 (2.9 and 2.9 mg:mg, respectively). Urinary UN:C ratios of 3.5 and higher indicate a "starvation diet" (i.e., severe nutritional restriction). Even more informative, sampling yielded the greatest incidence of urine specimens with UN:C ratios indicative of severe nutritional restriction during winter 2013 (31.7%), coincident with the most severe winter tick infestation during the 4-year study and the highest annual mortality rate of adult GPS-collared moose (19%). Most importantly, from 2013 to 2017, the incidence of severe nutritional restriction of moose has been inextricably and inversely correlated with annual estimates of population size (r = -0.863, y = -80.943x + 5,406; Figure 16), calf production (r = -0.922, y = -42.521x + 2,578; Figure 17), and winter survival of GPS-collared adult moose (r = -0.860, y = -0.0043x + 1.009; Figure 18). These strong relationships indicate that undernutrition during winter is playing a key role in the poor population performance influencing the decline of moose in northeastern Minnesota since 2006. The source(s) of the varying incidence of severe nutritional restriction and exactly how severe nutritional restriction relates to the health-related causes of mortality and predation of moose are the subject of ongoing analyses but also require additional study.

Table 1. Calving date summary for GPS-collared cow moose during 2013–2016, northeastern Minnesota. Calving activity was concluded based on observation of a "calving movement" made by pregnant adult females.

Year	Mean	Median	Earliest	Latest	"Peak" calving	% of calves during peak
2013	14 May	14 May	2 May	2 June	6–17 May	73%
2014	19 May	18 May	5 May	16 June	11–22 May	75%
2015	11 May	10 May	29 Apr	14 June	3–15 May	76%
2016	12 May	12 May	24 Apr	10 June	4–14 May	75%

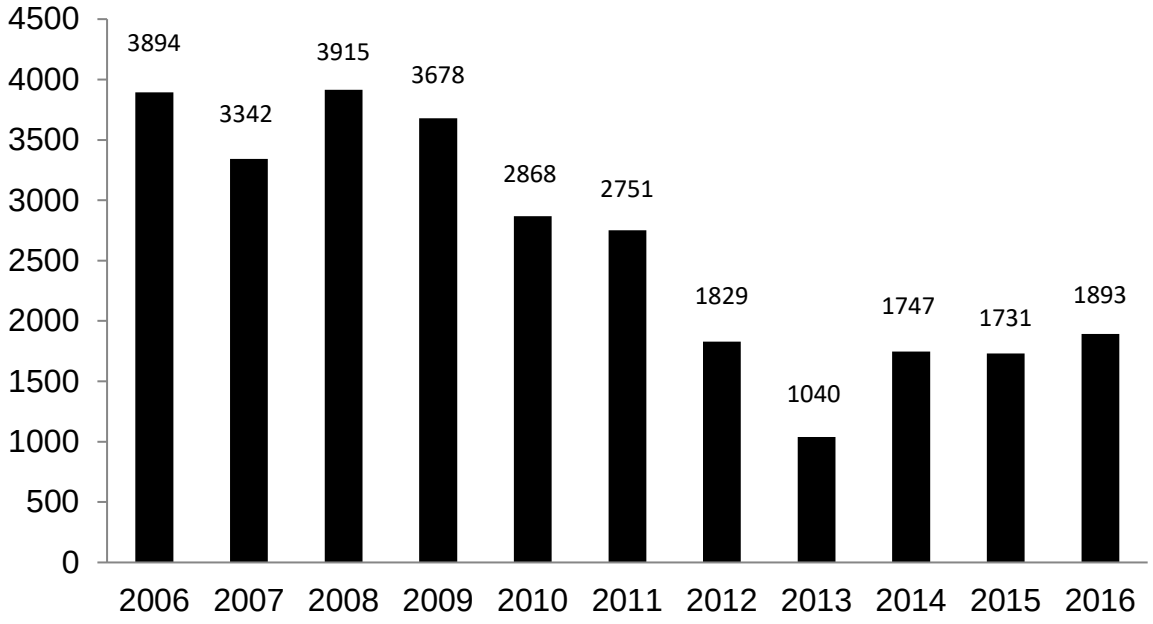


Figure 11. Estimated moose calf production from 2006 to 2016, based on pregnancy rates generated from the reproductive study (2013−2016) and population composition data derived from annual moose surveys, northeastern Minnesota.

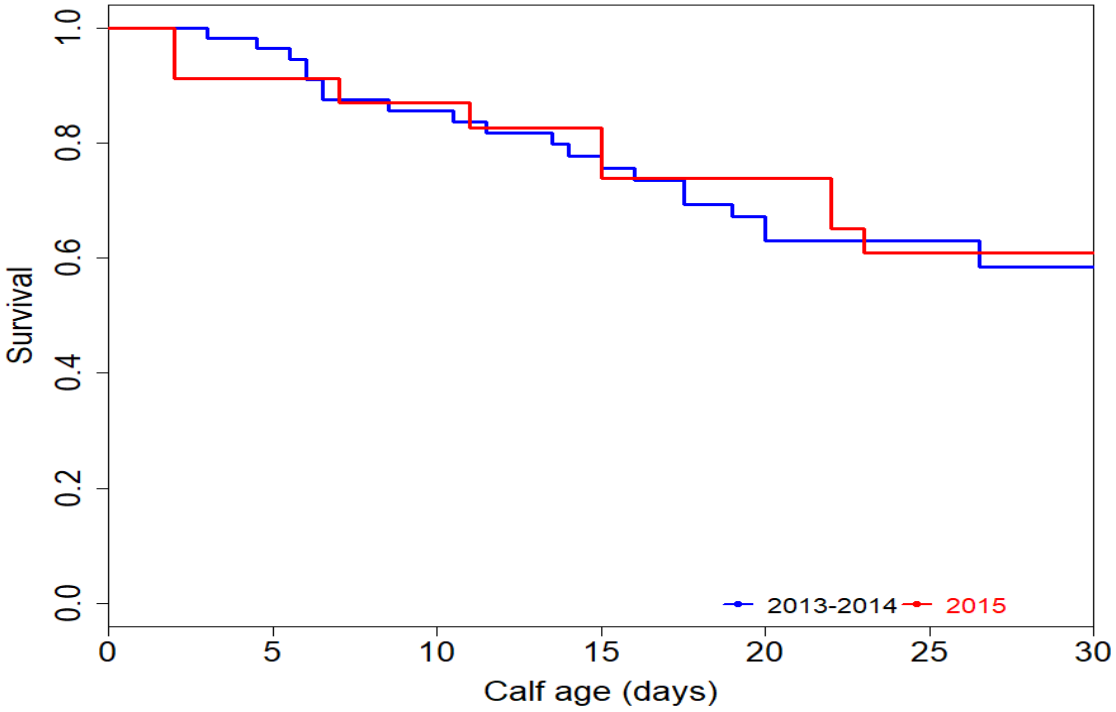


Figure 12. Kaplan-Meier 30-day survival for known moose calf mortalities, May–June 2013–2015, northeastern Minnesota. Mortality was confirmed by GPS collars (pooled 2013 and 2014, blue line, *n* = 54 calves) or through investigations triggered by dam movement patterns and observation of calf remains (2015, red line, *n* = 65 calves).

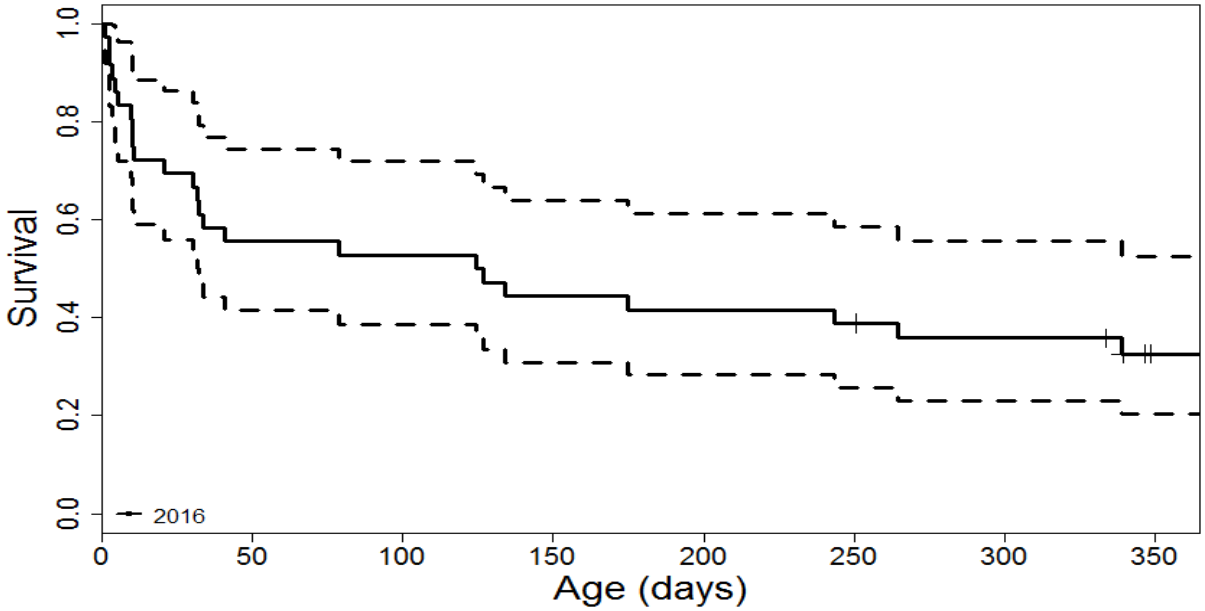


Figure 13. Kaplan-Meier 350-day survival for known moose calf mortalities, 2016−2017, northeastern Minnesota. Tick marks indicate individuals censored due to unknown fate. Dashed lines represent 95% confidence intervals.

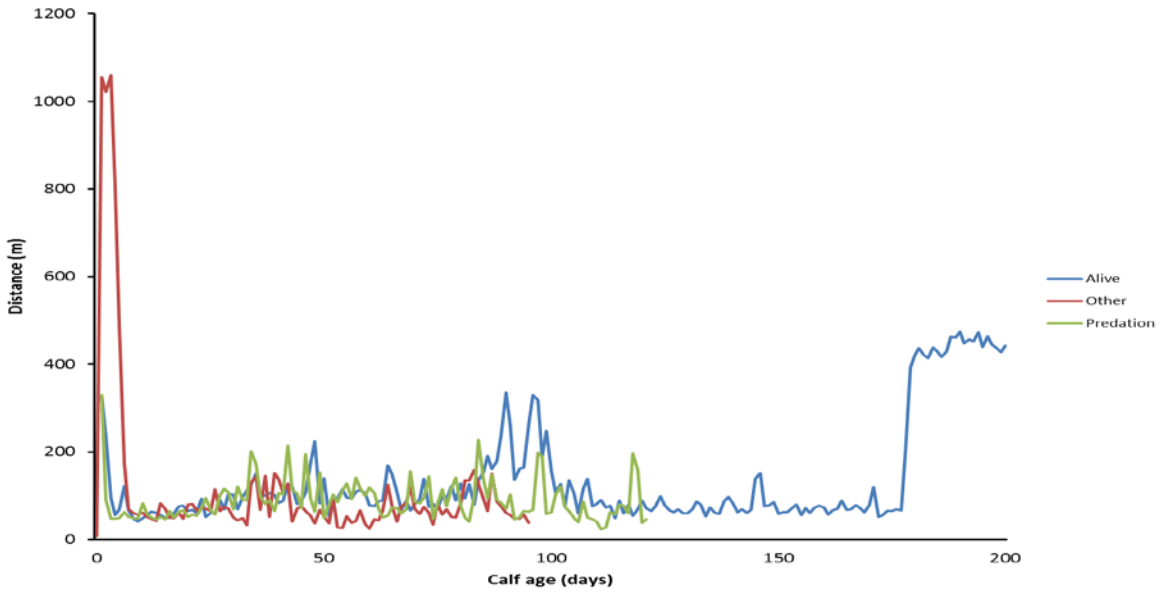


Figure 14. Mean daily distance between moose dams and their calves, by calf age (up to 200 days old) and fate type (Alive, Other [non-predation mortality], and Predation), May–February 2013–2015, northeastern Minnesota. Spikes in distance during the first 5 days were due to capture and handling. An outlier calf that moved up to 29 km from its dam was excluded.

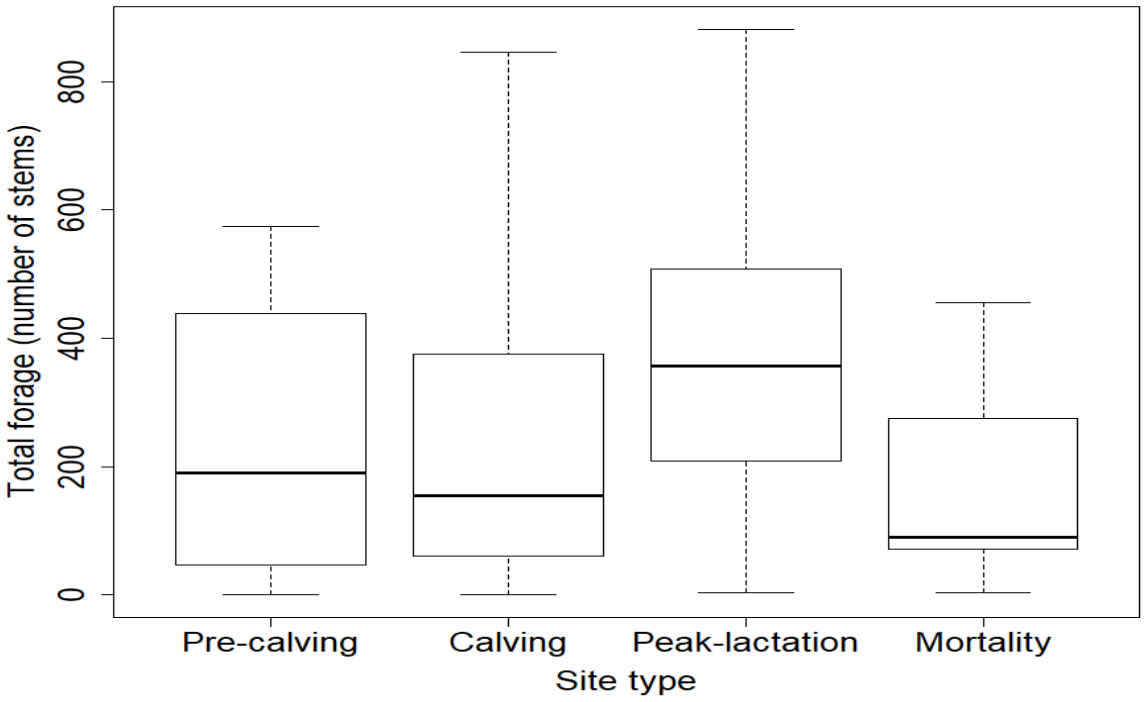


Figure 15. Number of forage stems at pre-calving, calving, peak-lactation, and mortality sites (*n* = 34, 37, 25, and 5, respectively) of moose calves during May–July 2015, northeastern Minnesota. Boxes depict interquartile range and dark lines are median values. *Note increased available forage at peak-lactation sites.

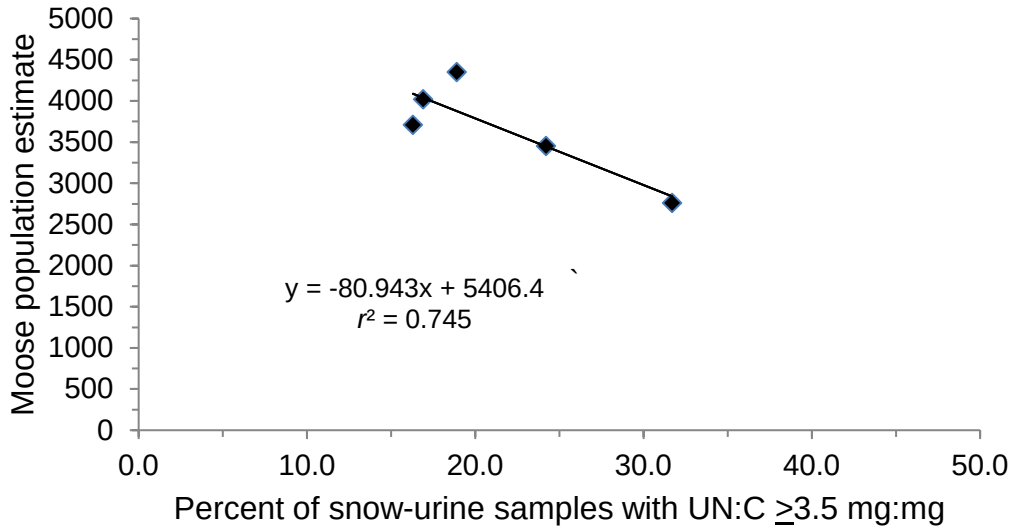


Figure 16. Relationship of the incidence of severe winter nutritional restriction of moose (Jan−Mar 2013−2017), indicated by the percentage of collected samples of urine in snow (snow-urine) with urea nitrogen:creatinine (UN:C) ratios ≥3.5 mg:mg, to annual winter population estimates of moose in northeastern Minnesota.

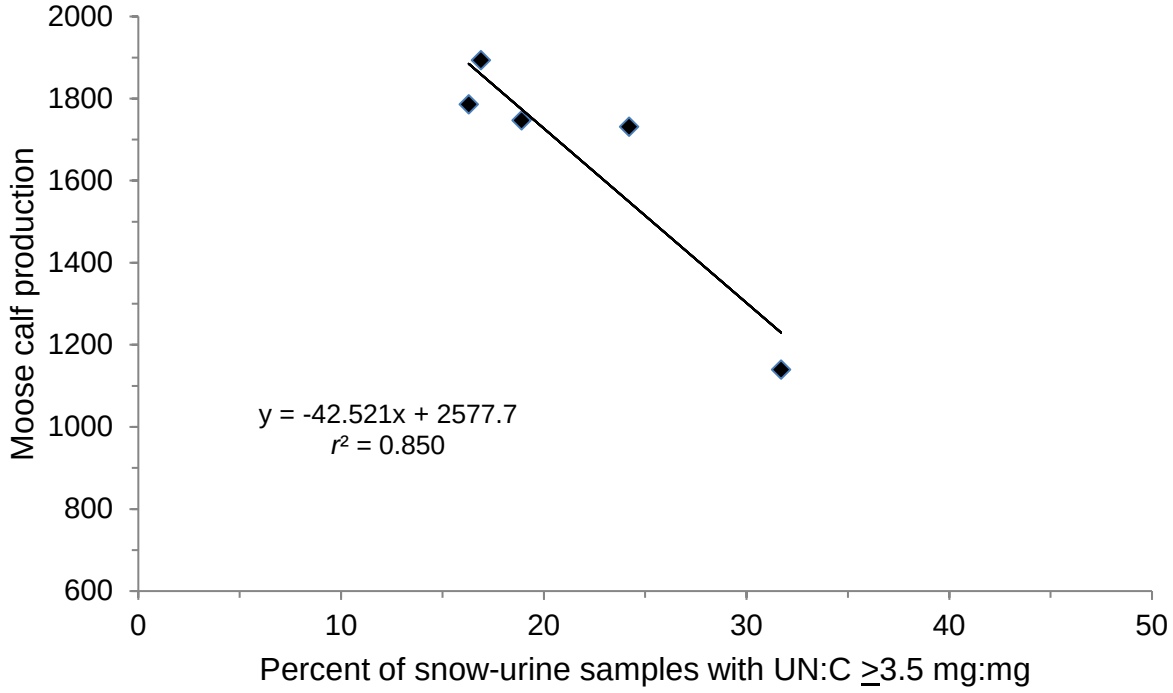


Figure 17. Relationships of the incidence of severe winter nutritional restriction of moose (Jan−Mar 2013−2017), indicated by the percentage of collected samples of urine in snow (snow-urine) with urea nitrogen:creatinine (UN:C) ratios ≥3.5 mg:mg, to annual calf production in northeastern Minnesota.

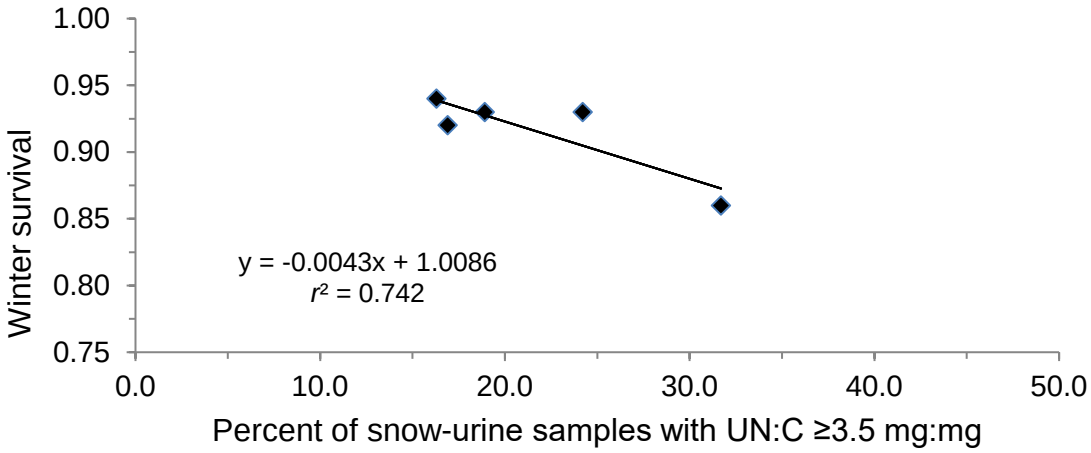


Figure 18. Relationships of the incidence of severe winter nutritional restriction of moose at the population level (Jan–Mar 2013–2017), indicated by the percentage of collected samples of urine in snow (snow-urine) with urea nitrogen:creatinine (UN:C) ratios ≥3.5 mg:mg, to winter (1 Nov–31 May 2013–2017) survival of GPS-collared adult moose in northeastern Minnesota.

V. DISSEMINATION:

Description: Annual research summaries addressing accomplishments to date will be written and available on the MNDNR website. Descriptive reports and articles will be written and submitted for publication in peer-reviewed journals.

Status as of December 2014:
Annual research summaries for the adult and calf components of this project for state fiscal year 2014, which preceded funding under this appropriation but are directly relevant, are available on the MN DNR website (http://www.dnr.state.mn.us/publications/wildlife/index.html).

Glenn DelGiudice provided interviews about the moose calf survival study to reporters from

- Outdoor News (Minnesota and Wisconsin editions),
- Minneapolis Star Tribune,
- Duluth News Tribune,
- St. Cloud Times,
- Cook County Herald,
- Outdoor Life magazine, and
- Minnesota Public Radio.
- Brainerd Outdoor Radio with Brian Moon, aired July 2014.

He also gave presentations at

- 2 meetings of professional wildlife managers and researchers

and public audiences at

- Bear Head Lake State Park,
- the International Wolf Center, and
- Normandale Community College.

Michelle Carstensen gave presentations about the adult moose study at

- Bear Head Lake State Park, Ely, MN: Determining cause-specific mortality in Minnesota's declining moose population, July 2014

- Grand Rapids Public Library, Grand Rapids, MN: Determining cause-specific mortality in Minnesota's declining moose population, August 2014.
- Vermilion Community College (VCC), Student Chapter of The Wildlife Society, Ely, MN: NE MN adult moose mortality – VCC Volunteers, September 2014
- Mind Trekkers Festival, Virginia, MN: Moose project display and Q&A, October 2014
- International Wolf Center, Ely, MN: What is the status of northeastern Minnesota's moose population and what are we learning, October 2014.
- North Star Museum of Boy and Girl Scouting, St. Paul, MN. Display on moose project. November 2014.
- Dodge Nature Center, Bloomington, MN. Determining cause of moose mortality in Minnesota, December 2014.
- Forestry Association Employees, Brainerd, MN. Determining cause of moose mortality in Minnesota, December 2014.

Media coverage for the adult moose mortality project also included the following:

- Brainerd Outdoor Radio with Brian Moon, aired July 12, 13, and 14, 2014.
- The Spokesman-Review: Wild moose chase: Researchers tracking 25 collared moose in NE Washington, October 2014
- Care2: How a tiny brain worm is killing moose across North America, October 2014
- The Spokesman-Review: Study: Wolf impact significant on Minnesota moose, November 2014
- Minneapolis Star Tribune: Are wolves to blame for fewer Minnesota moose, November 2014
- Rick Kupchella's Bring Me The News: Federal officials ask for help to solve illegal killing in NW Minnesota, November 2014
- Ithaca Journal: Cornell on lookout for Adirondack moose, December 2014
- Science Recorder: New York State to launch three-year study of moose, December 2014
- Bennington Banner: Biologists study moose after die-offs, December 2014
- Hamodia: Researchers assess NY moose after die-offs, December 2014
- New Hampshire Voice: Researchers look into moose die-offs in Minnesota, December 2014
- Mankato Free Press: Mankato Area Lifelong Learns hosts class on Minnesota moose, December 2014
- Mankato Free Press: Mankato group talks Minnesota moose population decline, December 2014
- First for Wildlife: Studies show relationship between wolves and Minnesota moose population decline, December 2014
- The Barre Montpelier Times Argus: Researchers assess Adirondack moose after die-offs, December 2014
- Concord Monitor: Researchers assess Adirondack moose after die-offs, December 2014

Status as of June 2015:

Peer-reviewed publications from previous years of the moose calf research

- Severud, W. J., G. D. DelGiudice, T. R. Obermoller, T. A. Enright, R. G. Wright, and J. D. Forester. 2015. Using GPS collars to determine parturition and cause-specific mortality of moose calves. Wildlife Society Bulletin 39: 616-625.
- DelGiudice, G. D., W. J. Severud, T. R. Obermoller, R. G. Wright, T. A. Enright, and V. St-Louis. 2015. Monitoring movement behavior enhances recognition and understanding of capture-induced abandonment of moose neonates. Journal of Mammalogy 96: 1005-1016.

Glenn DelGiudice provided interviews about the moose calf survival study to reporters from

- OUTDOORS, April 2015, Joseph Friedrichs
- The Wall Street Journal, May 2015, Joe Barrett
- Minneapolis StarTribune, April 2015, Josephine Marcotty
- Pioneer Press, February 2015, John Myers
- Duluth News Tribune, February 2015, John Myers

Glenn DelGiudice and Ph.D. graduate student, Bill Severud, also gave presentations at

- DelGiuidice, G. D., W. J. Severud, and T. R. Obermoller. Studying moose calf survival in a declining population on the cutting-edge of technology: overcoming the inevitable challenges before reaching that "Sweet Spot." 49th North American Moose Conference and Workshop, Granby, CO. 28 April 2015.
- DelGiudice, G. D. Status and trends of Minnesota's moose populations. 49th North American Moose Conference and Workshop, Granby, CO. 28 April 2015.
- DelGiudice, G. D. Status, trends, and research of Minnesota's moose populations. Cottonwood County Game and Fish Protective League, Spring Forum. 26 March 2015.
- DelGiudice, G. D., W. J. Severud, T. R. Obermoller, and R. G. Wright. 2015. Determining an effective approach for capturing moose neonates and minimizing capture-related abandonment in northeastern Minnesota. 2015 Joint Annual Meeting of Minnesota & Wisconsin Chapters of The Wildlife Society, Duluth, MN. 19 February 2015.
- Severud, Bill and Glenn DelGiudice. Cause-specific mortality of moose calves: an update from northeastern Minnesota. 49th North American Moose Conference and Workshop, Granby, CO. 28 April 2015.
- Severud, Bill. Cause-specific mortality of moose calves in northeastern Minnesota, 2013 and 2014. 3rd Annual Natural Resources Association of Graduate Students Research Symposium, St. Paul, MN. 22 April 2015.
- Severud, Bill and Glenn DelGiudice. Cause-specific mortality of moose calves in northeastern Minnesota, 2013 and 2014. 2015 Joint Annual Meeting of Minnesota & Wisconsin Chapters of The Wildlife Society, Duluth, MN. 19 February 2015.
- Severud, Bill and Glenn DelGiudice. Cause-specific mortality of moose calves in northeastern Minnesota, 2013 and 2014. Conservation Biology Lunch Seminar, University of Minnesota, St. Paul, MN. 10 February 2015.
- Severud, Bill and Glenn DelGiudice. What is the status of northeastern Minnesota's moose population and what are we learning? Normandale Community College Slice of Life Lecture Series, Bloomington, MN. 3 February 2015.

Radio Shows About the Adult Moose Project:

- The Ticket FM, Angler Hunter Radio, live interview, 14 January 2015.
- Minnesota Public Radio: Moose and climate change, February 2015.
- The Ticket FM, Angler Hunter Radio, topic coverage on our captures, 25 February 2015.
- WTIP, Environment: Dr. Seth Moore on the state of moose and moose research, 25 March 2015.
- WTIP, Lake Superior Project: The Role of Collaring in Moose Research, 26 March 2015.
- The Ticket FM, Angler Hunter Radio, update on moose mortalities and moose collaring, 13 May 2015.

Presentations About the Adult Moose Project:

- Silver Bay Veterans Center, January 2015.
- Minnesota Veterinary Medical Association, February 2015.
- Retired Vets: Determining Cause specific mortality in Minnesota declining moose population, 6 February 2015.
- Dordt College Field Trip/Presentation, 6 February 2015.
- Kanabec Adult Hunter Ed Program, February 2015.
- MIFC, Annual Aviation Workshop, Grand Rapids; interagency cooperation on slinging moose, 25 February 2015.
- Mora Adult Hunter Education Class, 26 February 2015.
- Wood Lake Nature Center, March 2015.
- School of Environmental Studies, April 2015.
- North American Moose Conference, April 2015.

- NE Regional Managers Meeting, Moose Project Update, 13 April 2015.
- Iron Range Science and Engineering Festival, 21-23 April 2015.
- Minnesota Pollution Control Agency, 3 June 2015.
- Bear Head Lake State Park, Tower/Soudan K-6 Field Day, 27 May 2015.
- Two Harbors High School, 27 May 2015.

Media Coverage of the Adult Moose Project:

- Star Tribune: Landwehr, What's gone right in the first four years, 3 January 2015.
- Alexandria Echo Press: Updated, Moose spotted near Brandon, 6 January 2015.
- CBS Local: Walleyes, deer, wolves and moose among topics of DNR event, 16 January 2015.
- Austin Daily Herald: Walleyes, deer, wolves and moose among topics of DNR event, 17 January 2015.
- Pioneer Press: DNR's 'Roundtable' hits on pines, potatoes, deer stands and more, 24 January 2015.
- Rick Kupchella's Bring Me The News: Moose that wandered to southern Minnesota had a brain worm, DNR says, 30 January 2015.
- Star Tribune: Sleepy Eye moose died from brain worm infection, 30 January 2015.
- Minnesota Public Radio News: What climate change means for Minnesota moose, 3 February 2015.
- OutdoorHub: Minnesota's Famous Wandering Moose Was Killed by Brain Worms, 6 February 2015.
- Duluth News Tribune: Winter survey shows Minnesota moose numbers still low, 17 February 2015.
- Minnesota Public Radio News: DNR, moose count confirms continuing decline, 17 February 2015.
- Minnesota Outdoor News: Minnesota's moose population remains at low levels, 17 February 2015.
- INFORUM: Annual Minnesota winter moose survey shows big drop from last year, 17 February 2015.
- Alexandria Echo Press: DNR aerial survey indicates more low numbers for Minnesota's moose population, 17 February 2015.
- KDAL: Minnesota moose population remains low, 17 February 2015.
- WDSM: Minnesota moose population remains low, 17 February 2015.
- Rick Kupchella's Bring Me The News: New numbers show MN's moose population is down to just a few thousand, 18 February 2015.
- KTTC: DNR, moose count confirms continuing decline, 18 February 2015.
- WDAZ: Minnesota moose population still down, 18 February 2015.
- Minnesota Outdoor News: No end to declining trend in northeast moose herd, 19 February 2015.
- Hometown Focus: Minnesota's moose population remains at low levels, 20 February 2015.
- SW News Media: Minnesota DNR, Moose population stays at low levels, 20 February 2015.
- Brainerd Daily Dispatch: Outdoor Notes, 20 February 2015.
- St. Cloud Times: Moose researchers fear they are running out of time, 21 February 2015.
- Crow River Media: State's moose population remains at low levels, 26 February 2015.
- Star Tribune: Minnesota's moose numbers drop again; DNR says 'decline will likely continue', 19 April 2015.
- Tower Timberjay News: DNR suspends adult moose captures early, 22 April 2015.
- Minnesota Outdoor News: Moose collaring in state is over, but not research, 28 May 2015.

Status as of December 2015:

Peer-reviewed publications from previous years of moose research:

- Severud, W. J., and G. D. DelGiudice. 2016. Potential vertical transmission of winter ticks (Dermacentor albipictus) from moose (Alces americanus) dams to neonates. Journal of Wildlife Diseases 52(1) DOI: 10.7589/2015-06-166 (early on-line access).

Agency reports of the moose research projects (http://www.dnr.state.mn.us/publications/wildlife/index.html):

- Carstensen, M., E. C. Hildebrand, D. Plattner, M. Dexter, C. Jennelle, and R. G. Wright. Determining cause-specific mortality of adult moose in northeast Minnesota. Pages 161–171 in L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research

findings, 2014. Minnesota Department of Natural Resources, Wildlife Populations and Research Unit, St. Paul, MN.

- DelGiudice, G. D., and W. J. Severud. 2015. Blood profiles and associated birth characteristics of free-ranging moose (*Alces americanus*) neonates in a declining population in northeastern Minnesota, 2013. Pages 109-122 in L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2014. Minnesota Department of Natural Resources, Wildlife Populations and Research Unit, St. Paul, MN.
- Severud, W. J., G. D. DelGiudice, T. R. Obermoller, R. J. Ryan, and B. D. Smith. 2015. An alternate method to determine moose calving and cause-specific mortality of calves in northeastern Minnesota. Pages 93-108 in L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2014. Minnesota Department of Natural Resources, Wildlife Populations and Research Unit, St. Paul, MN.

Glenn DelGiudice provided interviews about the moose population and calf survival study to reporters from

- Outdoor News… Moose population and calf research, interviewed 11 Nov 2015, Javier Serna
- CBC… Moose population comparisons to Manitoba, moose adult and calf research, interviewed 2 Nov 2015, Angela Johnston
- Minnesota Conservation Volunteer… status of the calf research, interviewed 18 Sep 2015, Mike Kallok
- Minnesota Conservation Volunteer…status of the moose population and moose research, interviewed 31 August 2015, Mike Kallok

Glenn DelGiudice gave presentations of the moose calf research:

- Third Annual Minnesota Moose Research and Management Meeting… Presentations on the status of Minnesota's moose population and another on the status and progress of the moose calf survival and cause-specific mortality research. 6 August 2015, Carlos Avery Wildlife Management Area, Forest Lake, MN.
- Northwest Wildlife Managers Meeting… Presentation on the status of Minnesota's moose populations, adult and calf studies of survival, cause-specific mortality, and reproductive success. 9 September 2015, Beltrami Electric Cooperative, Bemidji, MN.
- "Becoming an Outdoor Woman" Retreat… Presentation on the status of Minnesota's moose populations, adult and calf studies of survival, cause-specific mortality, and reproductive success. 12 September 2015, GunFlint Trail Lodge, Grand Marais, MN.

Bill Severud gave a presentation of the moose calf research:

- The Wildlife Society's 22nd Annual Conference… Presentation (and abstract) on using GPS collars to determine parturition and cause-specific mortality of moose calves. 20 October 2015, Winnipeg, Manitoba, Canada.

Presentations About the Adult Moose Project:

- Bear Head Lake State Park, Ely, MN; Determining cause-specific mortality in Minnesota's declining moose population, 15 July 2015.
- Wrong Days in Wright Festival, Wright, MN; moose display booth, 18 July 2015.
- Vermillion Sportsman's Club, Tower, MN; Determining cause-specific mortality in Minnesota's declining moose population, 15 August 2015.
- Vermilion Community College, Moose Ecology Class; Field necropsy discussion and telemetry field exercise, 4 October 2015.
- Iron Range Mine Trekkers, Eveleth, MN; telemetry display booth, 23 October 2015.
- MPCA permit writers meeting; Determining cause-specific mortality in Minnesota's declining moose population, 27 October 2015.
- Conservation Biology Seminar, What's causing Minnesota's moose decline? University of MN, St. Paul, October 2015.

- Special Symposium: Role of Arthropods in Wildlife; Entomology conference, Role of Parasites in Minnesota's Moose Decline, November 2015
- University of St. Thomas, St. Paul, MN; comparative zoology class, 24 November 2015.
- William Kelley High School, Silver Bay, MN; Determining cause-specific mortality in Minnesota's declining moose population, 30 November 2015.

Media Coverage of the Adult Moose Project:

- Mesabi Daily News: Moose killed in accident was sick, 3 July 2015.
- Grand Forks Herald: Environmental groups want protection for Midwest moose, 9 July 2015.
- Star Tribune; took reporter Josephine Marcotty and camerman Brian in on a field moose response (false alarm) 19 August 2015.
- Ames Tribune: Tracking the decline of Minnesota's moose population, 21 August 2015.
- Timberjay: High-tech tracking, 27 August 2015.
- Star Tribune; reporter Josephine Marcotty and Brian participated in VDL moose necropsy, October 2015.
- Star Tribune; took reporter Josephine Marcotty and camerman Brian in on a field moose response (false alarm), 2 November 2015.
- Outdoor News: Update on adult moose mortality research, November 2015.
- Star Tribune; Josephine and Brian participated in a moose extraction near Ely, 15 November 2015.
- The Wildlife Society: MN Chapter Meets with Governor's Office Regarding Moose, 20 November 2015.
- Star Tribune; Josephine and Brian visit Carlos Avery to film staff and learn more about the Adult Moose Mortality Project, 15 December 2015.

Status as of June 2016:

Peer-reviewed publications related to the adult moose project:

- Kinsley AC, Moon RD, Johnson EK, Carstensen M, Neitzel D, Craft ME. 2016. Mosquitos in moose country: A mosquito survey of northern Minnesota. *Journal of the American Mosquito Control Association* 32(2):83–90.
- Grunenwald, C. M., M. Carstensen, E. Hildebrand, J. Elam, S. Laaksonen, A. Oksanen, and R. W. Gerhold. 2016. Epidemiology of the lymphatic-dwelling filarioid nematode *Rumenfilaria andersoni* in free-ranging moose (*Alces alces*) and other cervids of North America. Parasites and Vectors: *in press.*

Peer-reviewed publications from previous years of the moose calf research:

- DelGiudice, G. D., and W. J. Severud. 2016. Blood profiles and associated birth characteristics of free-ranging moose (*Alces americanus*) neonates in a declining population in northeastern Minnesota. Alces: *in review*.
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. 2016. Minimizing mortality of moose neonates from capture-induced abandonment. Alces: *in review*.

Presentations on the Adult Moose Mortality Project:

- Audubon Center of the North Woods, Sandstone, MN. January 5, 2016
- Itasca Community College and North Country Trail Association, Grand Rapids, MN. January 20, 2016
- The Minnesota Chapter of The Wildlife Society, 2016 Annual Meeting, Mankato, MN; What's killing Minnesota's moose, 11 February 2016.
- 148th Fighter Wing – Environmental and safety awareness fair, 11 February 2016.
- International Wolf Center, Ely, MN; Determining cause-specific mortality in Minnesota's declining moose population, 16 February 2016.

- Tettegouche Visitor's Center, Silver Bay, MN; Moose population (survey) and mortality study update, DNR Parks & Enforcement staff presentation, 24 February 2016.
- Camp Ripley, Annual Aviation Workshop, Little Falls, MN; Aviation assistance on the adult moose mortality project, 24 February 2016.
- Zoo Rounds at University of Minnesota, College of Veterinary Medicine, Overview of adult moose mortalities, role of parasites is moose deaths, and capture myopathy. April 2016.
- Breck School, Golden Valley, MN; Minnesota's disappearing moose, 26 April 2016.
- Iron Range Science and Engineering Festival, Chisholm, MN; The use of radio-telemetry for wildlife research, 26-28 April 2016.
- Ontario Ministry of Natural Resources, Dryden, Ontario. Overview of adult moose mortality research project with MNR resource staff. May 6, 2016.
- Kenora District Campowners' Assocation, Waldof, Ontario. What's killing Minnesota's moose? May 6, 2016.
- 2016 Midwest Furbearer Workshop, Ely, MN; What's killing Minnesota's moose, 25 May 2016.

Presentations about the Moose Calf Survival and Cause-specific Mortality Study:

- Annual Forest and Wildlife Research Review Meeting, Cloquet Forestry Center, Cloquet, MN : Updates on the status of the 1) moose population in northeastern Minnesota, 2) calf and adult survival and cause-specific mortalities studies, 3) assessment of winter nutritional restriction of moose study, and 4) management options, 12 January 2016.
- Minnesota Ecology and Conservation Biology, Metropolitan State University, St. Paul, MN: Minnesota's moose research, 29 January 2016.
- 2016 Annual Meeting of The Minnesota Chapter of The Wildlife Society, Mankato, MN: An alternate method to determine moose calving and cause-specific mortality of calves in northeastern Minnesota, 10 February 2016.
- Invited presentation: Minnesota Deer Hunters Association, Vermillion Chapter, Tower, MN: Status of the moose population and moose research in northeastern Minnesota, 7 April 2016.
- Invited presentation: 2016 Midwest Wolf Stewards Meeting, Grand Rapids, MN: Status of the moose population and moose research in northeastern Minnesota, 25 April 2016.
- Invited presentation: Bemidji State University, Bemidji, MN: Status of the moose population and moose research in northeastern Minnesota, 2 May 2016.
- Two invited presentations: (1) Long Prairie High School and (2) Town of Long Prairie, MN: Status of the moose population and moose research in northeastern Minnesota, 18 May 2016.
- American Society of Mammalogists 2016 Meeting, Minneapolis, MN: Assessing calf survival and cause-specific mortality in the declining moose population in northeastern Minnesota, 27 June 2016.

Radio Shows and Live Interviews:

- WTIP North Shore Community Radio: Hard times continue for Minnesota's dwindling moose population, 20 January 2016.
- KAXE Grand Rapids, Northern Community Radio Show, January 20, 2016
- Twin Cities PBS Video: Drinking water quality, disappearing moose, political panel, aired 12 February 2016.
- WTIP North Shore Community Radio: Moose health influences DNR's deer management strategy, 22 February 2016.
- WTIP North Shore Community Radio: Dead moose on popular mid-Gunflint Trail lakes an unwelcome sight for paddlers, 6 June 2016.

Media Coverage of Adult Moose Mortality Research:

- Outdoor News: DNR completes year three of moose mortality study, 15 January 2016.
- Northland's News Center: Researchers race to save Minnesota's dwindling moose population, 20 January 2016.
- Minneapolis Star Tribune: New DNR data gives hints on what's killing Minnesota's moose, 26 January 2016.
- CBS Local: Data showing DNR researchers what's killing Minnesota's moose, 26 January 2016.
- Fox21 Online: New DNR data gives hint on what's killing Minnesota's moose, 26 January 2016.
- Y94: New DNR data gives hints on what's killing Minnesota's moose, 26 January 2016.
- Washington Times: New DNR data gives hints on what's killing Minnesota's moose, 26 January 2016.
- St. Cloud Times: DNR data gives hints on what's killing moose, 27 January 2016.
- Duluth News Tribune: Parasites, health problems killing Minnesota moose, 27 January 2016.
- Nature World News: Minnesota moose, researchers reveal what's causing population declines, 27 January 2016.
- Twin Cities Pioneer Press: New DNR data gives hints on what's killing Minnesota's moose, 27 January 2016.
- ESPN Twin Cities: Minnesota moose population dying due to disease and poor health, 27 January 2016.
- Lakeland Public Television: New DNR moose population data, 27 January 2016.
- Post Bulletin: New DNR data gives hints on what's killing moose, 27 January 2016.
- KDAL 610: Minnesota DNR looking into moose mortality, 28 January 2016.
- WNMT AM 650: Minnesota DNR looking into moose mortality, 28 January 2016.
- Northland Outdoors: What's killing Minnesota moose, 28 January 2016.
- Watertown Public Opinion: Minnesota DNR believes it knows why moose are dying, 28 January 2016.
- My 95.7.com: Minnesota DNR looking into moose mortality, 28 January 2016.
- Quetico Superior Foundation: Minnesota's moose beleaguered by warm winters and poor health, 2 February 2016.
- Tower Timberjay: DNR says health problems main cause of moose decline, 3 February 2016.
- Minneapolis Star Tribune (Video): What's killing Minnesota's moose, 7 February 2016.
- Minneapolis Star Tribune: Can our moose be saved, 7 February 2016.
- North County Trail Association: Moose in danger in the North Country, 9 February 2016.
- Tower Timberjay: Research suggests high deer numbers behind moose decline, 11 February 2016.
- Voice of Alexandria: Moose population remains low; 5-year population decline improves, 16 February 2016.
- Rick Kupchella's Bring Me The News: DNR, moose population still low - and decline could continue, 16 February 2016.
- Minneapolis Star Tribune: Latest moose count provides little good news, 16 February 2016.
- CBS Local: Despite slower decline, Minnesota's moose numbers remain low, 16 February 2016.
- Shoreline Media Group: Minnesota moose numbers remain low despite slower decline, 16 February 2016.
- Outdoors with Sam Cook: Winter survey shows Minnesota moose holding their own, 16 February 2016.
- Minnesota Public Radio News: DNR, moose count finds herd not recovering in NE Minnesota, 16 February 2016
- WTBX.com: Moose count in NE Minnesota is up slightly but remains low, 16 February 2016.
- Duluth News Tribune: Minnesota moose numbers hold steady, 16 February 2016.

- Minneapolis Star Tribune: Minnesota moose numbers remain low despite slower decline, 16 February 2016.
- The Republic: New data show Minnesota's moose population remains low despite a slower population decline, 16 February 2016.
- KROCAM: Minnesota moose census was inconclusive, 16 February 2016.
- KAALtv.com (ABC 6 News): Minnesota moose population is down, 17 February 2016.
- WDAY: Minnesota moose numbers remain low despite slower decline, 17 February 2016.
- MSN.com (WCCO 4 News): Minnesota's moose population remains low, 17 February 2016.
- Albert Lea Tribune: DNR, moose count finds herds are not recovering, 17 February 2016.
- KARE 11: Minnesota moose numbers remain low despite slower decline, 17 February 2016.
- AmmoLand Shooting Sports News: Moose population remains low in Minnesota; 5-year population decline improves, 17 February 2016.
- Tower Timberjay: Moose numbers stable for now, 18 February 2016.
- Minnesota DNR News Release: Possibility of better moose health, desire for more deer prompt permit area changes in northeastern Minnesota, 22 February 2016.
- Minneapolis Star Tribune: To protect Minnesota moose, DNR may tweak deer hunting boundaries, 23 February 2016.
- CBS Local: DNR seeks to protect moose with deer hunting boundary proposal, 23 February 2016.
- Outdoors with Sam Cook: DNR to propose deer permit area changes to benefit moose, 24 February 2016.
- WDAZ.com: Deer hunting boundary proposal seeks to protect moose, 24 February 2016.
- Outdoor News: Proposal: Reduce deer herd in moose range, 25 February 2016.
- Duluth News Tribune: DNR proposal would change some deer permit areas in primary moose range, 25 February 2016.
- NFW.org: Saving moose from carbon pollution, 2 March 2016.
- The Kenyon Leader.com: Minnesota DNR updates, 3 March 2016.
- The LandOnline.com: Malnutrition may be causing moose decline, 4 March 2016.
- Minnesota Public Radio News: Grand Portage Band, state diverge on collaring moose, 11 March 2016.
- Duluth News Tribune: Grand Portage Band, state divided on collaring moose, 12 March 2016.
- Duluth News Tribune: More forest fires, more moose, 28 May 2016.
- Northland Outdoors: More forest fires, more moose, 31 May 2016.
- Duluth News Tribune: Feds consider Minnesota moose for endangered list, 2 June 2016.
- Minnesota Public Radio News: Beleaguered moose population may warrant endangered species protection, 2 June 2016.
- Northland Outdoors: Feds consider Minnesota moose for endangered list, 2 June 2016.
- JSOnline: Moose in Upper Midwest might need protection, 2 June 2016.
- Outdoor News: Midwest moose headed toward ESA listing, 2 June 2016.
- The Bemidji Pioneer Press: Minnesota moose may be headed for endangered list, 2 June 2016.
- Rick Kupchella's Bring Me The News: Will MN's struggling moose get 'endangered species' protections, 3 June 2016.
- Tower Timberjay: Moose may get federal protection, 3 June 2016.
- Wide Open Spaces: Minnesota moose considered for endangered list, 7 June 2016.
- Outdoor News: USFWS accepts petition to list moose, 9 June 2016.

Media coverage of the Moose Calf Survival and Cause-specific Mortality Study:

- The Land, a farm publication owned by Mankato Free Press: Interview regarding the status of the moose population in northeastern Minnesota, what prompted all of the latest research, highlights of findings, preliminary potential recommendations for management, and future objectives for research and management, interviewed by Tim King, 11 January 2016.
- Outdoor News: Formation of the DNR's Moose Management Committee, working group(s), the process of making preliminary recommendations, and physiological assessments of winter nutritional restriction via the serial collection and chemical analysis of urine in snow, and various important preliminary relationships, interviewed by Javier Serna.
- MPR (Duluth), Update on the moose population and calf research, interviewed by Dan Kraker.
- Rochester Post Bulletin: Deer and moose in northern Minnesota, how they survive winter, and moose research, interviewed by John Weiss, 4 Feb 2016.
- Associated Press: This included updates on findings of adult moose survival, calf survival, and winter nutritional assessment studies, interviewed by Steve Karnwski, 26 Jan 2016. .
- Duluth News Tribune: Status of the moose population in northeastern MN and update summary of findings for adult, calf, and winter nutritional assessment findings, interview by Sam Cook, 27 January 2016.
- Grand Forks Herald: Status of the moose population in northeastern Minnesota and update summary of findings for adult, calf, and winter nutritional assessment studies, interviewed by Sam Cook, 27 Jan 2016.
- Timberjay: Status of the moose population in northeastern Minnesota and the role of calf survival and wolf densities versus adult cause-specific mortality, interviewed by Marshall Helmberger, 4 Feb 2016.
- Timberjay: Further coverage of status of the moose population in northeastern MN and the role of calf survival and wolf densities versus adult cause-specific mortality, interviewed by Marshall Helmberger, 11 February 2016.
- MPR (Duluth): 2016 Moose Survey results, status of the population, and how the research findings related to what the survey showed, interviewed by Dan Kraker, 16 Feb 2016.
- Minneapolis Star Tribune: 2016 Moose Survey results, status of the population, and how research findings (adult and calf) relate to the survey results, interviewed by Josephine Marcotty, 17 Feb 2016.
- MPR (Duluth): Discussed the winter study assessing moose nutritional status, the value of GPS collars to the moose calf and adult studies and what can be learned, and how we're limited without them, interviewed by Dan Kraker, 25 Feb 2016.

Status as of December 2016:

Agency reports:

- Carstensen, M., E. C. Hildebrand, D. Plattner, M. Dexter, C. Jennelle, and R. G. Wright. Determining cause-specific mortality of adult moose in northeast Minnesota. *In* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of Wildlife Research Findings 2015, Minnesota Department of Natural Resources, St. Paul, Minnesota.
- Herberg, A., V. St-Louis, M. Carstensen, and J. Forester. 2016. Calibration of a rumen bolus to measure internal body temperature in moose. *In* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of Wildlife Research Findings 2015, Minnesota Department of Natural Resources, St. Paul, Minnesota.
- DelGiudice, G. D., and W. J. Severud. 2016. Climate change, winter nutritional restriction, and the decline of moose in northeastern Minnesota, winters 2013–2016. *In* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of Wildlife Research Findings 2015, Minnesota Department of Natural Resources, St. Paul, Minnesota.
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. 2016. Survival, cause-specific mortality, and space use of moose calves in a declining population. *In* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of Wildlife Research Findings 2015, Minnesota Department of Natural Resources, St. Paul, Minnesota.

- Obermoller, T. R., G. D. DelGiudice, W. J. Severud, B. D. Smith, J. L. Goethlich, and R. A. Willaert. 2016. Using movement behavior of adult female moose to estimate survival and cause-specific mortality of calves in northeastern Minnesota. *In* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of Wildlife Research Findings 2015, Minnesota Department of Natural Resources, St. Paul, Minnesota.

Publications:

- Grunenwald, C. M., M. Carstensen, E. Hildebrand, J. Elam, S. Laaksonen, A. Oksanen, and R. W. Gerhold. 2016. Epidemiology of the lymphatic-dwelling filarioid nematode *Rumenfilaria andersoni* in free-ranging moose (*Alces alces*) and other cervids of North America. Parasites and Vectors 9:450-550.
- Verma, S. K., M. Carstensen, R. Calero-BernalDubey, S. Moore, T. Jiang, C. Su, and J. P. Dubey. 2016. Seroprevalence, isolation, first genetic characterization of Toxoplama gondii, and possible congenital transmission in wild moose from Minnesota, USA. Parasitology Research 115:687-690.
- Solden, L. M., D. W. Hoyt, W. B. Collins, J. E. Plank, R. A. Daly, E. Hildebrand, T. J. Beavers, R. Wolfe, C. D. Nicora, S. O. Purvine, M. Carstensen, M. A. Lipton, D. E. Spalinger, J. L. Firkins, B. A. Wolfe, and K. C. Wrighton. 2016. First genomic insight into the enigmatic BS11 gut group reveals roles in hemicellulose degradation. ISME 11(3): 691-703.
- DelGiudice, G. D., and W. J. Severud. 2016. Blood profiles and associated birth characteristics of free-ranging moose (*Alces americanus*) neonates in a declining population in northeastern Minnesota. Alces 52:85–99.
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. 2016. Minimizing mortality of moose neonates from capture-induced abandonment. Alces 52:73–83.

Media interviews for the Adult Moose Mortality study:

- WTIP North Shore Community Radio: Public opinion varies on moose, elk hunts in Minnesota, 5 December 2016.

Media interviews for the Moose Calf Survival and Cause-specific Mortality study:

- The Timberjay, Ely, MN (Marshall Helmberger). Published June 23, 2016. An update on the calf study.
- Outdoor News (Joe Albert). Published July 1, 2016. Primarily addressed the current status and future of the moose calf research, as well as the implications.

Media Coverage of the Adult Moose Mortality study:

- Fox9.com: Minnesota moose population's rapid decline worries scientists, 27 June, 2016.
- Cook County Minnesota: Finding the Minnesota Moose and other wildlife, 5 July 2016.
- Tower Timberjay: Moose calf survival hopeful, 6 July 2016.
- Outdoor News: Study looks at where moose and deer habitat overlap, 29 July 2016.
- Tower Timberjay: Voyageurs moose numbers remain stable, 29 July 2016.
- Outdoor News: Moose hunt on tap for FDL band, 16 September 2016.
- National Geographic: Should We Be Worried About North American Moose, 17 September 2016.
- Minnesota Public Radio News: Fond du Lac Band to hold fall moose hunt over state objections, 21 September 2016.
- Twin Cities Pioneer Press: Minnesota DNR objects, but tribe to hold moose hunt this fall, 22 September 2016.
- Duluth News Tribune: Fond du Lac Band will hold moose hunt this fall, 22 September 2016.
- Northland Outdoors: Fond du Lac Band will hold moose hunt this fall, 30 September 2016.
- Star Tribune: Chippewa tribes renew hunting of Minnesota moose, 19 October 2016.
- Climate Signals.org: North American Moose Decline 2006 - ongoing, 28 October 2016.
- Outdoor News: MN DNR agrees to allow bands to kill 10 more moose, 31 October 2016.

Presentations about the Adult Moose Mortality study:

- Bear Head Lake State Park, Ely, MN; What's killing Minnesota's moose, 27 July 2016.
- University of Minnesota - Research Day for the College of Veterinary Medicine, St. Paul, MN, July 2016.
- Department of Natural Resources (DNR) Regional Meeting, Grand Rapids, MN, August 2016.
- 2016 Merial Summer Veterinary Scholar Symposium, Ohio State University, August 2016.
- North American Moose Conference, Brandon Manitoba, Canada, September 2016.
- North American Moose Conference, Brandon Manitoba, Canada; poster on "Blood profiles of free-ranging moose", September 2016.
- North American Moose Conference, Brandon Manitoba, Canada; poster on "Calibration of a Rumen Bolus to Measure Internal Body Temperature in Moose", September 2016.
- DNR Career Day, St. Paul, MN, September 2016.
- DNR Human Resources, St. Paul, MN, September 2016.
- Vermilion Community College - Moose Ecology Class, Ely, MN; Adult Moose Mortality Project Update, 29 September 2016.
- Iron Range STEM Showcase Event, Hibbing, MN; Wildlife research telemetry booth, 7 October 2016.
- Vermilion Community College - Moose Ecology Class, Ely, MN; Adult Moose Telemetry Field Day, October 2016.
- University of St. Thomas, St. Paul, MN, October 2016.
- The Wildlife Society Annual Conference, Raleigh, NC; Calibration of a Rumen Bolus to Measure Internal Body Temperature in Moose, October 2016.
- Minnesota Lottery News Conference, Lake Superior Zoo, Duluth, MN, 16 December 2016.

Presentations about the Moose Calf Survival and Cause-specific Mortality Study:

- MN DNR Northeast Regional Management Team, Grand Rapids, MN. August 1, 2016. Status of the moose population, calf research, and preliminary recommendations for management.
- Elk and Moose Workshop, Thief River Falls, MN. August 10, 2016. Status of the moose population, calf research, preliminary management recommendations, and the possibility of and background for moose being listed under the U.S. Endangered Species Act.
- 50th North American Moose Conference and 8th International Moose Symposium, Brandon, Manitoba, Canada. September 9, 2016. Blood profiles and associated birth characteristics of free-ranging moose (*Alces americanus*) neonates in a declining population in northeastern Minnesota.
- 50th North American Moose Conference and 8th International Moose Symposium, Brandon, Manitoba, Canada. September 9, 2016. Ecological relationships of winter nutritional restriction in a declining moose (*Alces americanus*) population in northeastern Minnesota.
- 50th North American Moose Conference and 8th International Moose Symposium, Brandon, Manitoba, Canada. September 9, 2016. Minimizing mortality of moose neonates from capture-induced abandonment.
- 50th North American Moose Conference and 8th International Moose Symposium, Brandon, Manitoba, Canada. September 11, 2016. Evaluation of an expandable GPS collar for moose neonates in northeastern Minnesota.
- 50th North American Moose Conference and 8th International Moose Symposium, Brandon, Manitoba, Canada. September 11, 2016. Assessing calf survival and cause-specific mortality in northeastern Minnesota's declining moose population.
- 50th North American Moose Conference and 8th International Moose Symposium, Brandon, Manitoba, Canada. September 11, 2016. Status and trends of Minnesota's moose population.
- The Wildlife Society Annual Conference, Raleigh, North Carolina. October 16, 2016. Assessing calf survival and cause-specific mortality in the declining moose population in northeastern Minnesota.
- Minnesota Pacahamama Community Conservation Group, St. Paul, MN. December 1, 2016. Understanding the status and trend of Minnesota's moose population.

Status as of June 2017:

Peer-reviewed publications:

- Minicucci, L., M. Carstensen, J. Crouse, J. Arnemo, and A. Evens. 2017. A technique for deployment of rumen bolus transmitters in free-ranging moose (*Alces alces*). Zoo and Wildlife Medicine: *in review*.
- Grunenwald, C. M., M. Carstensen, A. Wünschmann, R. Moon., E. C. Hildebrand, E. Butler, M. D. Brand, and R. W. Gerhold. 2016. Emergence of the arterial worm *Elaeophora schneideri* in moose (*Alces alces*) host and fly vectors in Minnesota, USA. Parasites and Vectors: *in review*.
- Street, G., J. Fieberg, A. R. Rodgers, M. Carstensen, R. Moen, S. A. Moore, S. K. Windels, and J. D. Forester. 2016. Habitat functional response mitigates reduced foraging opportunity: implications for animal fitness and space use. Landscape Ecology 31 (9): 1939-1953.
- DelGiudice, G. D., W. J. Severud, T. R. Obermoller, and V. St-Louis. 2017. Gaining a deeper understanding of capture-induced abandonment of moose neonates. Journal of Wildlife Management: *In Press*.
- Obermoller, T. R., G. D. DelGiudice, and W. J. Severud. 2017. Assessing expandable GPS collars for moose neonates. Wildlife Society Bulletin: *In review*.

Agency reports:

- Carstensen, M. E. Hildebrand, D. Plattner, M. Dexter, V. St-Louis, C. Jennelle, and R. G. Wright. 2017. Determining cause-specific mortality of adult moose in northeast Minnesota: February 2013 to July 2017. In L. Cornicelli, M. Carstensen, N. Davros, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2016. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- Herberg, A., V. St-Louis, M. Carstensen, and J. Forester. 2017. Are moose getting warm and how do they respond behaviorally? Validation for an approach for remotely monitoring moose behaviors. In L. Cornicelli, M. Carstensen, N. Davros, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2016. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- DelGiudice, G. D., W. J. Severud, and T. R. Obermoller. 2017. Climate change, winter nutritional restriction, and the decline of the moose population in northeastern Minnesota, 2013−2017. In L. Cornicelli, M. Carstensen, N. Davros, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2016. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. 2017. Moose calf survival, cause-specific mortality, and habitat use. In L. Cornicelli, M. Carstensen, N. Davros, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2016. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- Obermoller, T. R., G. D. DelGiudice, and W. J. Severud. 2017. Using adult female moose behavior to estimate calving and mortality of calves. In L. Cornicelli, M. Carstensen, N. Davros, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2016. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- Obermoller, T. R., G. D. DelGiudice, W. J. Severud, B. D. Smith, J. L. Goethlich, and R. A. Willaert. 2017. Using movement behavior of adult female moose to estimate survival and cause-specific mortality of calves in northeastern Minnesota. Pages 98−109 in L. Cornicelli, M. Carstensen, G. D'Angelo, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2015. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. 2017. Survival, cause-specific mortality, and space use of moose calves in a declining population. Pages 110−123 In L. Cornicelli, M. Carstensen, G. D'Angelo, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2015. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.
- DelGiudice, G. D., and W. J. Severud. 2017. Climate change, winter nutritional restriction, and the decline of the moose population in northeastern Minnesota, 2013−2016. Pages 124−139 in L. Cornicelli,

M. Carstensen, G. D'Angelo, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2015. Minnesota Department of Natural Resources, Section of Wildlife, St. Paul.

Radio/TV Shows and Live Interviews:

- WTIP North Shore Community Radio: Moose Update, July 2, 2017
- Minnesota Public Radio News - Story Audio: DNR - Minnesota moose numbers stabilizing after steep decline, February 28, 2017
- Minnesota News Network Statewide Radio. Moose population status, survey results, and research. February 27, 2017
- WCCO Radio. Moose population status, survey results, and research. February 27, 2017
- Pioneer Public Television. Moose calf and adult research findings, winter nutritional study, wolf predation on moose, and moose population status. June 20, 2017
- WTIP Radio. Moose calf survival and cause-specific mortality research and winter nutritional assessments at the population level. June 28, 2017

Other media interviews:

- Canadian Broadcasting Corporation (CBC). Moose population status, survey results, and research. March 1, 2017.
- Outdoor News. Moose population status, survey results, and research. March 3, 2017.
- Moose population status, survey results, and research. Minnesota Public Radio (MPR). February 27, 2017.
- Outdoor News. Moose calf research and the population status. June 29, 2017.

Other Media Coverage:

- MN Outdoor News: Moose studies winding down as researchers look toward future, 10 July 2017
- Cook County News Herald: Moose Management - Pests, Parasites and Disease, 8 July 2017
- Boundary Waters Blog: Moose news on the Gunflint Trail, 3 July 2017
- Grand View Outdoors: Wolves leading cause of death for Minnesota moose, 30 June 2017
- Tower Timberjay: DNR researcher: Wolves a factor making moose recovery "difficult" - Five year moose study nearing its end, 28 June 2017
- Duluth News Tribune: Parasites, infections, wolves taking toll on Minnesota moose, 27 June 2017
- CBS Minnesota - WCCO: Quick recovery unlikely for declining moose population, 27 June 2017
- Voice of Alexandria: Parasites, infections, wolves taking toll on Minnesota moose, 27 June 2017
- Tower Timberjay: New deer permits areas set in the northeast - Changes should allow better coordination of moose and deer management, 21 June 2017
- Post Bulletin: Glimmer of hope for Minnesota moose? , 4 March 2017
- Hometown Focus: MN's moose population remains low, but stable, 3 March 2017
- Tower Timberjay: Region's moose population may have stabilized, says DNR, 1 March 2017
- Post Bulletin: Minnesota's moose population shows signs of stabilizing, 28 February 2017
- Albert Lea Tribune: Minnesota's moose population shows signs of stabilizing after a decline, 28 February 2017
- Minnesota Public Radio News: DNR - Minnesota moose numbers stabilizing after steep decline, 27 February 2017
- St. Cloud Times: State's moose population stabilizes, 27 February 2017
- Twin Cities Pioneer Press: DNR says Minnesota moose decline has slowed, but recovery still in doubt, 27 February 2017
- The Bemidji Pioneer: Minnesota moose herd stable but still down, 27 February 2017
- The Ely Echo: Moose population remains low, but survey suggests 6-year population stability, 27 February 2017

- GoMN.com: Minnesota moose aren't doing better, but they aren't doing worse either, 27 February 2017
- Duluth News Tribune: Minnesota moose herd stable but still down, 27 February 2017
- Winona Daily News: DNR - Minnesota moose numbers stabilizing after steep decline, 27 February 2017
- Star Tribune: Moose populations - The thick and thin of it, 3 February 2017
- Cook County News Herald: Minnesota moose mystery starting to unravel, 7 January 2017

Presentations:

- North American Moose Conference, Nova Scotia, Aug 28-Sept 1, 2017. Hot or Not? Taking a look at potential causes and effects of abnormally high body temperatures of moose in Minnesota.
- North American Moose Conference, Nova Scotia, Aug 28-Sept 1, 2017. Causes of Moose Deaths: 2013 to 2017. North American Moose Conference, Nova Scotia, Aug 28-Sept 1, 2017.
- North American Moose Conference, Nova Scotia, Aug 28-Sept 1, 2017. Characterization of blood profiles of free-ranging moose in Minnesota.
- Minnesota Pollution Control Agency Conference, Baxter, MN; What's Killing Minnesota's Moose, 28 September 2017
- Eveleth Public Library, Eveleth, MN; What's Killing Minnesota's Moose, 19 September 2017
- Sugarloaf Nature Center, Schroeder, MN; Moose 101 and update on MN DNR NE Moose Mortality Project. Presentation and telemetry demonstration, 22 July 2017
- Audubon Center of the North Woods, Sandstone, MN; What's Killing Minnesota's Moose, 17 June 2017
- Minnesota Department of Transportation District 4 Employee Day, Ottertail, MN; What's Killing Minnesota's Moose, 18 April 2017
- Norman County East High School, Twin Valley, MN; What's Killing Minnesota's Moose, 17 April 2017
- Ely Tuesday Group, Ely, MN; What's Killing Minnesota's Moose, 11 April 2017
- 73rd Annual Upper Mississippi River Conservation Committee, Red Wing, MN; What's Killing Minnesota's Moose, March 21, 2017.
- Dordt College Wildlife Ecology Class, Tower MN; Moose Biology, Research, and Management in Northeastern Minnesota. Presentation and field tour, 24 February 2017
- Long Lake Conservation Center - MN Master Naturalists, Aitkin, MN, 31 January 2017
- Audubon Center of the North Woods, Sandstone, MN; What's Killing Minnesota's Moose, 8 January 2017
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. 2017. Assessing calf survival and cause-specific mortality in the declining moose population in northeastern Minnesota. 77th Fish and Wildlife Conference, 2017, 5–8 February 2017, Lincoln, Nebraska.
- DelGiudice, G. D. Status of moose population, research, and preliminary management recommendations. Voyageurs National Park Naturalist Seminar Series, 12 February 2017.
- Severud, W. J., G. D. DelGiudice, and T. R. Obermoller. Moose calf habitat use: the relative importance of forage, cover, and other habitat characteristics to early survival. 2017 Annual Meeting of the Minnesota Chapter of The Wildlife Society, 14–16 February 2017, Callaway, Minnesota.
- Obermoller, T. R., G. D. DelGiudice, and W. J. Severud. Using movement behavior of adult female moose to estimate survival and cause-specific mortality of calves in northeastern Minnesota. 2017 Annual Meeting of the Minnesota Chapter of The Wildlife Society, 14–16 February 2017, Callaway, Minnesota.
- DelGiudice, G.D. Moose population status and research and deer. 2017. Board of Northern County Land Commissioners, 9 March 2017, Discovery Center, Hibbing, Minnesota.
- DelGiudice, G.D. Moose Population Status and Research and Deer. 2017. Minnesota Deer Hunters Association, Hibbing-Chisholm Chapter, 19 April 2017, Hibbing, Minnesota.

Final Report Summary:

For the moose research projects supported by this funding we have produced 8 peer-reviewed publications, 4 manuscripts currently in review, and several more to come with final analyses of the data. There have been 15 DNR agency reports written. Agency staff and graduate students have given 117 presentations at professional conferences of all levels—state to international—other meetings with professional biologists, and to all manner of public audiences, from school groups to sporting and nature groups to a veterans group.

The lead investigators, Drs. DelGiudice and Carstensen, have participated in 38 interviews with journalists from television, radio, and print outlets, and there have been more than 175 additional instances of media coverage about our research. Media outlets included all major newspapers in Minnesota and 2 adjacent states, many smaller newspapers, the Washington Times, National Geographic, public and commercial radio stations in Minnesota, and public, network, and cable television stations in Minnesota.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 167,758	1 Wildlife Health Specialist ($111,000) – 50% FTE for 3 years to do field work for adult component, analyze data, & do outreach. 4 Field technicians ($56,758) – 2 FTE total to do field work for calf component.
Professional/Technical/Service Contracts:	$ 210,643	Moose capture – Capture & handling 30 adult moose ($31,770). Univ. of Minnesota – Field work & analysis for calf component ($80,326), statistical consulting ($26,795) & diagnostic lab analyses for adult and calf components ($8,997). Satellite data acquisition – transmission of location, temperature, heart rate, & mortality data from adult moose ($60,000) and calves ($2,755). $175/month plus a per-transmission fee.
Equipment/Tools/Supplies:	$ 31,519	Mortality implant transmitters ($25,698) – Record body temperature & heart activity data from 30 adult moose. Pharmaceuticals ($5,821) – Drugs for immobilization of captured moose & reversal.
Travel Expenses in MN:	$ 94,520	Fleet, mileage, lodging, & meals for project managers & field staff ($82,420). Room, fleet, & board for volunteer technician to do field work for calf component ($12,100).
Other: Aircraft services	$ 76,407	DNR aircraft for moose capture operations and tracking ($34,167) and fall-winter aerial surveys ($42,240).
Other: Direct & Necessary costs	$ 19,153*	DNR Direct & Necessary services to support this appropriation (**see footnote).
Other: Unallocated	$ 0	Unallocated portion of ENRTF appropriation
TOTAL ENRTF BUDGET:	**$ 600,000**	

* Due to the budget amendment approved on 6/11/2015 Direct and Necessary expenses increased to $26,211, but DNR agreed to limit those costs for this project to the original amount of $21,766.

** Direct and Necessary expenses include both Department Support Services (Human Resources $2,480, IT Support $2,750, Safety $613, Financial Support $5,999, Communications Support $1,141, Planning Support $704, and Procurement Support $235) and Division Support Services ($5,231). Department Support Services are described in the agency Service Level Agreement, and is billed internally to divisions based on rates that have been developed for each area of service. These services are directly related to and necessary for the appropriation. Department leadership services (Commissioner's Office and Regional Directors) are not assessed. Division Support Services include costs associated with Division business offices and clerical support. Those elements of individual projects that put little or no demand on support services such as large single-source contracts, large land acquisitions, and funds that are passed-thru to other entities are not assessed Direct and Necessary costs for those activities. For this work plan, activities contracted to the University of Minnesota with associated costs of $115,795 have not been assessed Direct and Necessary costs.

Explanation of Use of Classified Staff: Funds will not be used to pay for classified staff.

Explanation of Capital Expenditures Greater Than $5,000: NA

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 3.50 FTE

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.7 FTE

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
University of Minnesota, Veterinary Diagnostic Laboratory;(pathologists at 0.09 FTE for 2 yrs)	$ 48,800	$ 48,800	disease and health screening for dead moose
1854 Treaty Authority	$ 25,000	$ 25,000	capture & field necropsy support, supplies, equipment, spotter plane costs
Fond du Lac Resource Management Division	$ 20,000	$ 20,000	capture support, field necropsy support
Natural Resources Research Institute: Ron Moen	$ 10,000	$ 10,000	field necropsy support, data analyses
State			
MNDNR Wildlife Health Program: Michelle Carstensen; 24 mos, 50% effort	$ 75,450	$ 98,955	project management, field necropsies, analyze, write, outreach
MNDNR Forest Wildlife Populations & Research Group: Glenn D. DelGiudice; 24 mos, 50% effort	$ 95,250	$ 130,747	project management, fieldwork, data analysis, writing, outreach
MNDNR Wildlife Health Program: Erik Hildebrand; 24 mos, 25% effort	$ 25,990	$ 57,501	field data collection, field necropsies, outreach
MNDNR Wildlife Health Program: David Pauly/Dawn Plattner; 24 mos, 57% effort	$ 87,730	$ 66,644	field data collection, field necropsies, outreach
MNDNR Wildlife Health Program: Other	$ 0	$ 379,572	Staff time, travel, supplies, etc. in support of Activity 1
MNDNR Forest Wildlife Populations & Research Group: Other	$ 0	$ 165,141	Staff time, travel, supplies, etc. in support of Activity 2
TOTAL OTHER FUNDS:	**$ 388,220**	**$1,002,360**	

VII. PROJECT STRATEGY:

A. Project Partners:

Lead investigators—Dr. Michelle Carstensen (adult component, $0 from the ENRTF appropriation) and Dr. Glenn D. DelGiudice (calf component, $0), MN DNR.

Co-investigators—Natural Resources Research Institute ($0) and University of Minnesota Department of Fisheries, Wildlife, & Conservation Biology ($106,795).

Collaborators—Fond du Lac Resource Management Division ($0), University of Minnesota Veterinary Diagnostic Laboratory ($10,000), 1854 Treaty Authority ($0), Minnesota Deer Hunters Association ($0).

B. Project Impact and Long-term Strategy:
The results of serological screening for diseases; serum analyses for pregnancy testing, chemistry profiles, and metabolic hormones; and complete and differential blood cell counts will contribute to quantifying rates of exposure to diseases, pregnancy rates, and assist with assessment of overall health and physiological status. We will assess these results relative to seasonal and annual survival and cause-specific mortality rates.

Specific causes of death of collared moose (adults and calves) that die during the study period will be determined, contributing to our understanding of the specific role health-related factors and other mortality forces (e.g., undernutrition, predation) are playing in the overall decline of the NE moose population. Once the specific causes of mortality and major influential factors (i.e., nutritional condition, seasonal weather conditions) are identified, appropriate population and habitat management actions may be taken to address the population's decline.

The primary goal of our 3-year study is to thoroughly investigate how ambient temperatures relate to moose productivity, reproductive success, and survival in NE MN by applying an unprecedented field approach and comprehensive data collection methods. No other study has documented a relationship between ambient temperature, body temperature (measured in free-ranging moose), and other variables which may influence this relationship (e.g., activity, habitat use). However, our study design also will allow us to re-examine and extend survival relationships reported by Lenarz et al. (2009, 2010). After a 6-year study of adult moose in NE MN, Lenarz et al. (2009) documented lower annual survival rates (relative to non-anthropogenic sources of mortality) of moose compared to populations ranging farther north. They also reported several significant inverse relationships between annual and seasonal survival rates and increasing ambient temperatures, and they observed higher mortality rates than expected during non-winter months. Those findings implicated climate change as a potentially significant factor influencing the decline of Minnesota's NE moose population (Lenarz et al. 2009, 2010). The additional survival data generated from our study, increased study period, and re-examinations of relationships between survival and ambient temperatures, coupled with the behavioral data and habitat needs identified by the current moose study of Moen (2009), will provide insight into whether the statistical relationships previously reported are real and ecologically significant, or spurious, perhaps attributable to limited sample sizes and data collection over a relatively brief period of time. Improved understanding of how climate, diseases, parasites, nutrition, and habitat needs may be influencing the population performance of moose will be key to the development of future population and habitat management strategies. Sharing what we conclude from these expanded data analyses and the information synthesized at professional meetings and through publication in peer-reviewed, scientific journals will likely expand the value of the study to other geographic regions, as well as to the scientific study and management of other species.

C. Spending History:

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14
M.L. 2011 ENTRF funding for "Determining causes of death in declining moose population"				$ 600,000	
MNDNR, Wildlife Health Program for Adult Mortality Study				$ 163,141	$ 58,359
MN DNR, Section of Wildlife for Calf Mortality Study				$ 220,000	$ 221,397
TOTAL SPENDING HISTORY:				**$ 983,141**	**$ 279,756**

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. VISUAL ELEMENT or MAP(S): See attached map.

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A

XI. RESEARCH ADDENDUM: See attached Research Addendum.

XII. REPORTING REQUIREMENTS:
Periodic Work Plan status update reports will be submitted not later than December 2014, June 2015, December 2015, June 2016, December 2016, and June 2017. A final report and associated products will be submitted between June 30 and August 15, 2017 as requested by the LCCMR.

Environment and Natural Resources Trust Fund

Final M.L. 2014 Project Budget

Project Title: Moose Decline and Air Temperatures in Northeastern Minnesota

Legal Citation: *M.L. 2014, Chp. 226, Sec. 2, Subd. 5m*

Project Manager: Michael A. Larson

Organization: Minnesota Department of Natural Resources

M.L. 2014 ENRTF Appropriation: $600,000

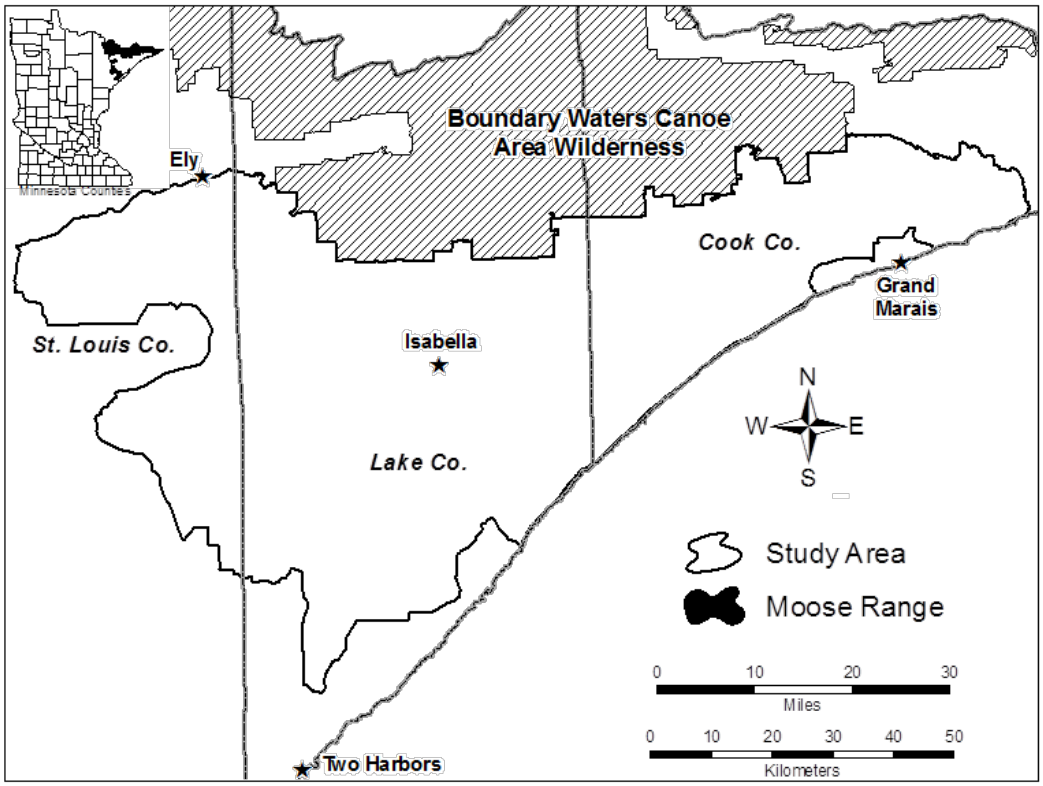
Project Length and Completion Date: 3 Years, June 30, 2017

Date of Report: August 11, 2017

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM								
Personnel (Wages and Benefits)								
Wildlife Health Specialist ($74,000) - 1 person, 0.5 FTE year-round for 3 years, 75% salary & 25% benefits; Field technicians ($57,000) - 2 people for 180 days (0.69 FTE each) during spring/summer 2015, 1 person for 240 days (0.92 FTE) during fall 2015, & 0.33 FTE during 2016	$111,000	$110,746	$254	$56,758	$56,758	$0	$167,758	$254
Professional/Technical/Service Contracts								
Wildlife helicopter capture company to capture & handle 30 adult moose, competitive bid	$31,770	$31,770	$0				$31,770	$0
Univ. of Minnesota for graduate student (0.5 FTE for 2 years) to lead field work & analyses for calf component				$80,326	$80,326	$0	$80,326	$0
Univ. of Minnesota for statistical consultant (0.21 FTE, 83% salary & 17% benefits, spread across 3 years) for data analysis and modeling	$13,400	$13,400	$0	$13,395	$13,395	$0	$26,795	$0
Univ. of Minnesota Veterinary Diagnostic Lab for analyses of samples from captured and dead moose.	$5,000	$5,000	$0	$3,997	$3,997	$0	$8,997	$0
Satellite data acquisition for locations, heart rates, temperatures, & mortalities of adult moose; competitive bid	$60,000	$59,766	$234				$60,000	$234
Satellite data acquisition for locations & mortalities of calf moose, competitive bid				$2,755	$2,755	$0	$2,755	$0
Equipment/Tools/Supplies								
30 Mortality implant transmitters to record heart activity & body temperatures of adult moose	$25,698	$25,698	$0				$25,698	$0
Pharmaceuticals for immobilization of capured moose	$5,821	$5,821	$0				$5,821	$0
Travel expenses in Minnesota								
Fleet, mileage, lodging, & meals for project managers and field staff	$59,187	$57,238	$1,949	$23,233	$23,233	$0	$82,420	$1,949
Lodging, fleet, & meals for 5 volunteer technicians (typically recent graduates wanting experience)				$12,100	$12,100	$0	$12,100	$0
Other								
Aerial surveys for calves				$42,240	$40,543	$1,697	$42,240	$1,697
Airplane flights for moose captures & tracking	$34,167	$27,782	$6,385				$34,167	$6,385
Direct & necessary services to support this appropriation	$9,935	$9,934	$1	$9,218	$9,218	$0	$19,153	$1
COLUMN TOTAL	**$355,978**	**$347,155**	**$8,823**	**$244,022**	**$242,325**	**$1,697**	**$600,000**	**$10,520**

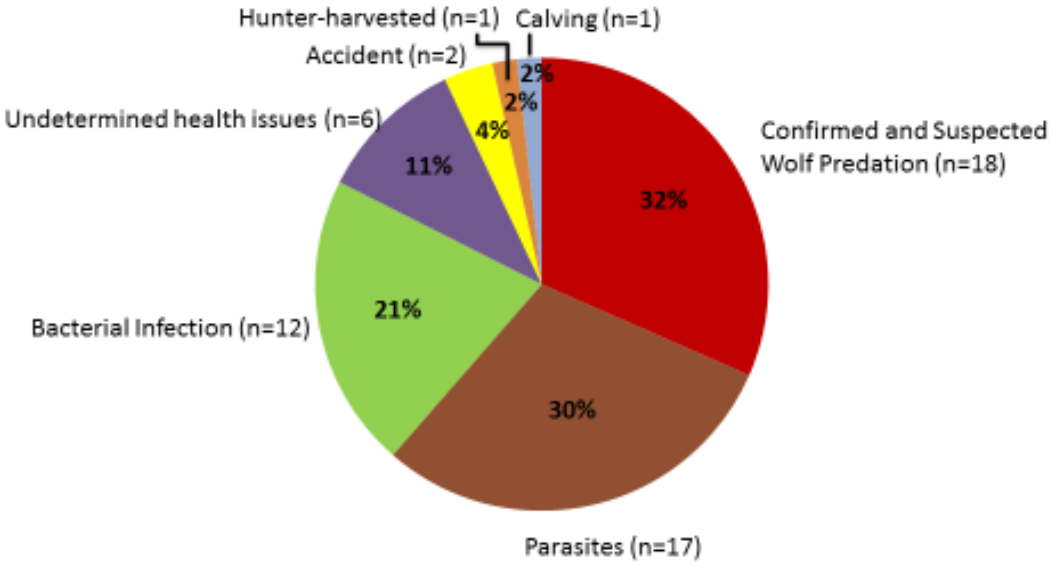
Environment and Natural Resources Trust Fund (ENRTF)
2014 Final Visual Illustrations
Project Title: Moose decline and air temperatures in northeastern Minnesota

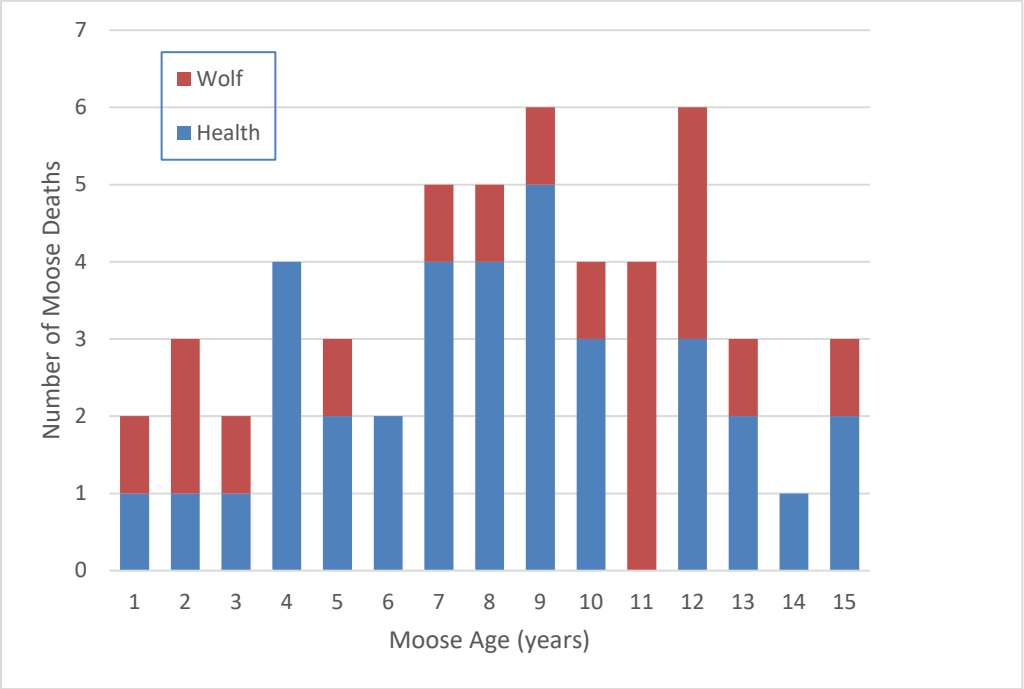
MAP of the study area for the "Moose Decline and Air Temperatures" project in northeastern Minnesota



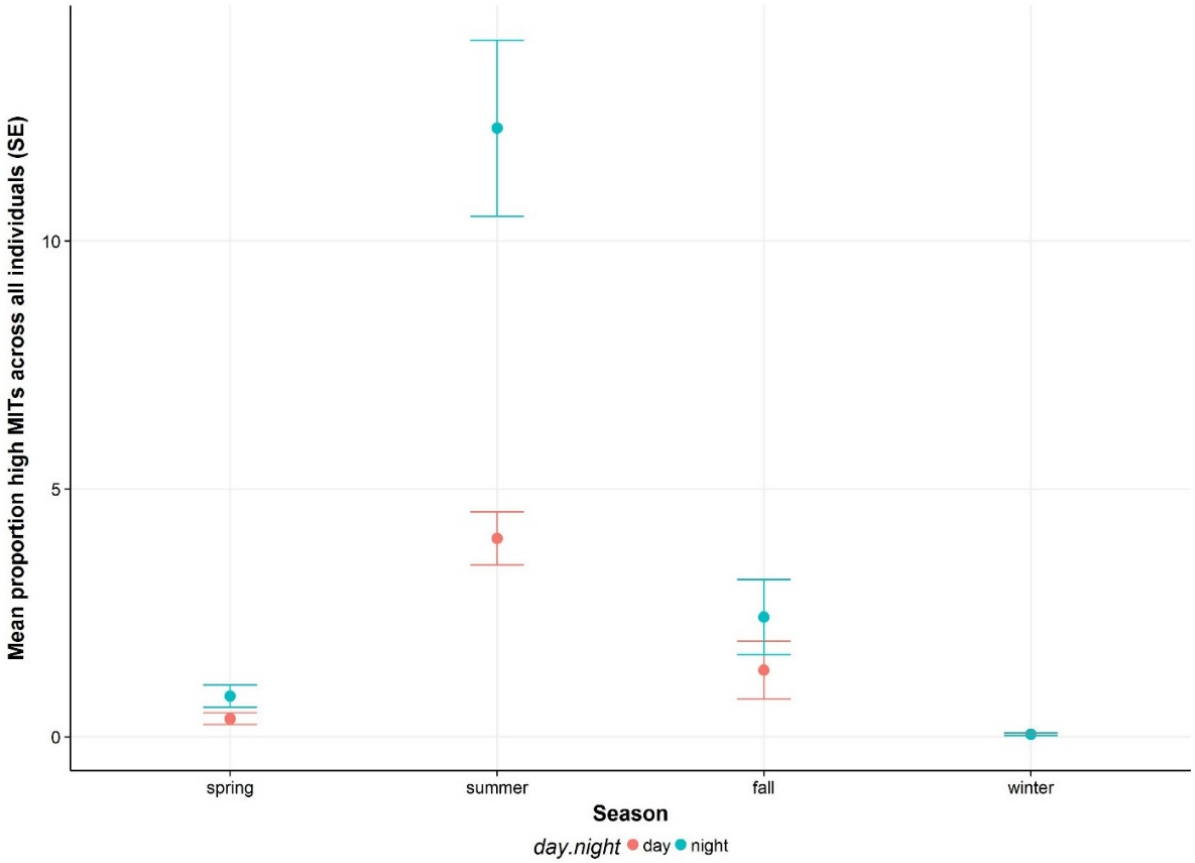
Proximate Causes of Adult Moose Mortalities

Feb 2013-June 2017 (*n=57*)

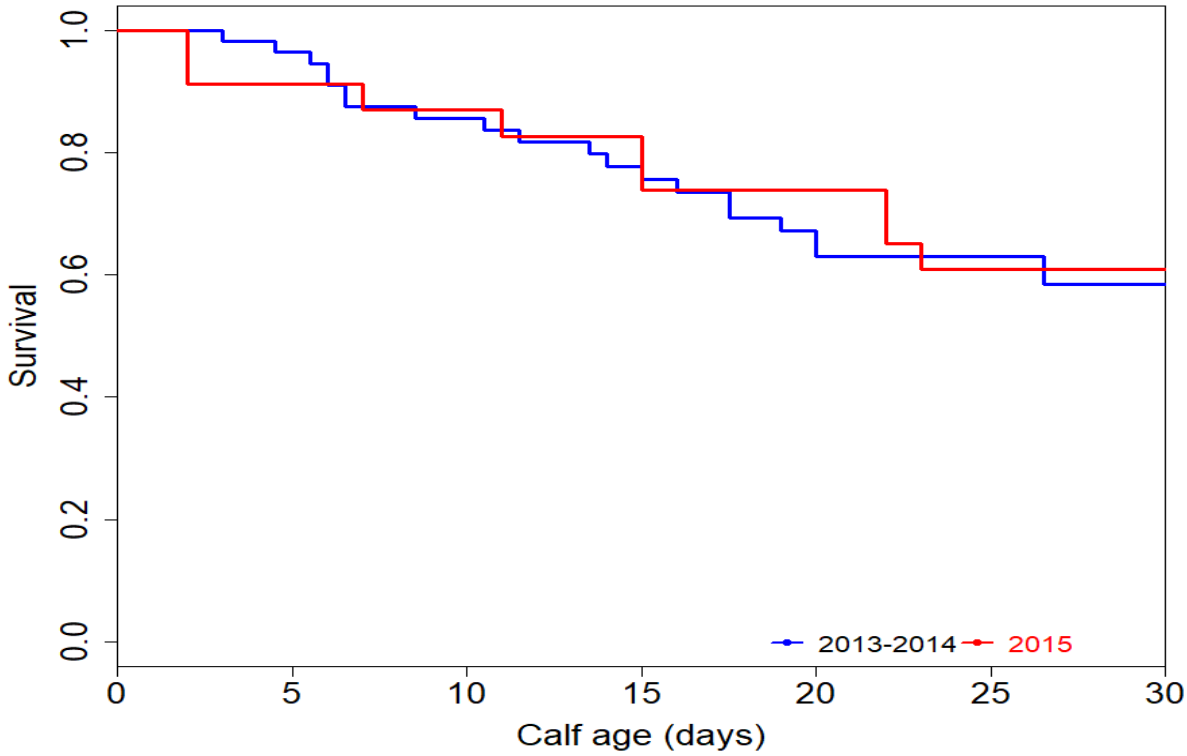


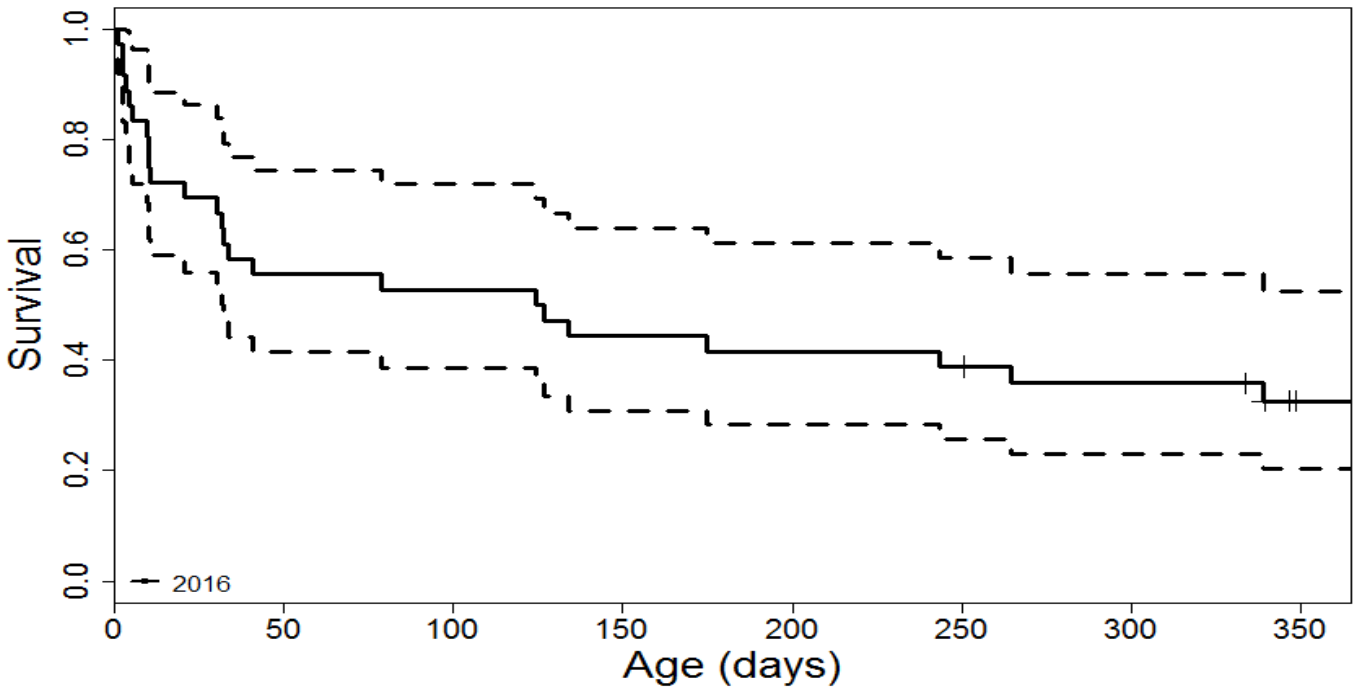


Average proportion of MIT-recorded temperatures that were considered high (>39.2 degrees C, *n* = 25 moose).



Estimates of calf survival based on GPS-collared calves (2013–2014) and monitoring the movements of GPS-collared dams with calves (2015 and 2016).





Incidence of severe winter nutritional restriction of moose during January–March 2013–2017 was inversely related to winter survival of adults and production of calves the subsequent spring.