# Environment and Natural Resources Trust Fund

## Research Addendum for Peer Review

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Project Title:  Moose Decline and Air Temperatures in Northeastern Minnesota

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**ABSTRACT**

Until recently, 2 geographically distinct moose (*Alces alces*) populations occurred in Minnesota (MN), one in the northwest (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, 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, however, 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 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.  Recently, a minimally invasive telemetry system for ruminants, called a mortality implant transmitter (MIT), has been developed to allow near continuous monitoring of body temperature with a battery lifetime of ≥2 years.  Using -these MITs and global positioning system (GPS) collars on adult moose will allow us to correlate ambient temperature with adult female physiology, behavior (habitat use, activity), and fitness (survival and reproduction).  This study will be the first to examine these relationships in a way that includes monitoring body temperature.  The results of this study will be critical to an improved understanding of if, when, and how moose are able to successfully modulate their internal body temperature.  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.

**BACKGROUND**

Until recently, 2 geographically distinct moose (*Alces alces*) populations occurred in Minnesota (MN), one in the aspen parklands of the northwest (NW) and the other in the northeastern (NE) boreal forests (Fuller 1986). However, from the mid-1980s to the present, the NW population decreased precipitously from an estimated 4,000 to <100 moose (Murray et al. 2006, Lenarz 2007). The NE population has been exhibiting a similar pronounced decline (69%) since 2006, from an estimated 8,840 moose to the current (2013) estimate of 2,760 (Lenarz 2007, DelGiudice 2013). Additionally, mean annual mortality rates of adults were similarly high in the NW and the NE (21%, Murray et al. 2006, Lenarz et al. 2009) compared to mortality rates (8-12%) reported for populations in the core of continental moose range (Mytton and Keith 1981, Larsen et al. 1989, Ballard et al. 1991, Stenhouse et al. 1995, Modafferi and Becker 1997). Annual non-hunting mortality rates of adult moose in NE MN have continued at about 20% (R. Moen, Natural Resources Research Institute [NRRI], personal communication; Butler et al. 2013a). The long-term stochastic growth rate for the NE population has been estimated at 0.85 (i.e., 15% decline per year) and was most sensitive to adult survival rates (Lenarz et al. 2010). Other indicators of herd productivity, including calving rates, calf:cow ratios, twinning rates, and hunter success also are decreasing (Lenarz et al. 2010, DelGiudice 2013).

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 or negative rates of population change (Murray et al. 2006; Lenarz et al. 2009, 2010). Diseases, parasites, seasonal nutritional restriction, and predation also have been documented as factors negatively impacting moose survival (Murray et al. 2006, Butler et al. 2013b). The relationships between all of these factors can be very complex, and moose numbers may be influenced by interactions among them (DelGiudice et al. 1997, Murray et al. 2006). Poor body condition, potentially related to nutritional deficiencies, was reported for some NE moose (Lenarz et al. 2009), and DelGiudice et al. (2011) reported that 21% of radiocollared adult females may have been seriously challenged by poor condition in 2003. Further, body condition was assessed on 103 moose that were captured and radiocollared during January 2013; nearly a third of those moose were classified as thin or very thin (Butler et al. 2013a). In NW Minnesota, Murray et al. (2006) identified pathogens, including liver flukes (*Fascioloides magna*) and brainworm (*Paralaphostrongylus tenius*), and malnutrition as contributing factors to the high mortality rates. In the NE specific causes of natural mortality of moose had remained largely (89%) unknown (Lenarz et al. 2009, 2010), but many of the deaths appeared health-related, with prime age animals dying during unusual times of the year and many carcasses being found intact with little evidence of scavenging. Evidence of exposure of NE moose to a variety of disease agents (e.g., West Nile Virus, eastern equine encephalitis, and malignant catarrhal fever) has been documented from health assessments of hunter-harvested moose (Butler et al 2013). But even less is known about the survival rates and cause-specific mortality of moose calves in NE MN (Lenarz et al. 2010), although we know that low and highly variable annual rates of recruitment of calves into the adult population can have a pronounced effect on the dynamics of ungulate populations (Gaillard 1998, 2000). Presently two aggressive companion studies are investigating specific causes of mortality and survival rates of adults and calves, and their quantitative impacts on performance of the NE population (Butler et al. 2013a; DelGiudice et al., unpublished data; Severud et al. 2013).

The marked warming trend in the earth's ambient temperatures is expected to continue, and its effects on precipitation patterns is likely to increase in intensity over the next century (Houghton et al. 2001). In the Great Lakes region, spring and summer temperatures may increase 1.5$^{o}$ to 2$^{o}$ C by 2025-2035, and autumn and winter temperatures may increase as much as 5$^{o}$ to 8$^{o}$ C during the next century (Union of Concerned Scientists 2003). Such climate changes could significantly alter the distribution, mortality, and reproductive rates of many wildlife species, such as moose, presently residing on the southern periphery of their continental ranges (Humphries et al. 2004). Kelsall and Telfer (1974) identified food supply, climate, and habitat composition as key factors affecting the biogeographical distribution of moose. There has been little study of the effects of warming temperatures on moose, but limited research has reported that winter temperatures >-5$^{o}$ C and summer temperatures >14$^{o}$ C were associated with increased metabolic, heart, and respiratory rates, reduced food intake, and body weight (Belovsky and Jordan 1978; Renecker and Hudson 1986, 1990). Ambient temperatures >20$^{o}$ C have been associated with open-mouthed panting in moose attempting to regulate their core body temperature (Renecker and Hudson 1986). Ambient temperatures beyond these thresholds and the inability of moose to sufficiently thermoregulate may lead to increased body temperatures and energy expenditures required to stay cool, which over time could have consequences on body condition and survival.

Relative to the annual nutritional cycle of moose, late-winter and early-spring temperatures may have the greatest direct and indirect adverse effects on these animals, particularly the pregnant females. As they emerge from winter's nutritional bottleneck they are in poorest condition, still retain their winter pelage as ambient temperatures are increasing, and are in the final third of pregnancy when their fetuses are most nutritionally-demanding and must accumulate the greatest mass to help assure birth-weights which will best support early survival (Schwartz 2007). Further, evidence suggests that the annual variability in the availability of quality spring forage can be critical to reproductive success (Brown 2011). Nonetheless, the availability of nutrition and the effects of temperature on an animal's ability to maintain energy balance during each season have both immediate and long-term impacts on their body condition and survivability (Murray et al. 2006, Lenarz et al. 2009, Brown 2011). Additionally, studies of cattle have associated heat stress with reduced white blood cell counts, which suggests reduced immunocompetence and lowered resistance to infection by environmental pathogens associated with a variety of diseases and parasites (Morrow-Tesch et al. 1996, Hahn 1999). Marginal availability of thermal refugia (i.e., dense forest cover), aquatic habitat, quality forage, or their spatial arrangement, may restrict the ability of moose to forage efficiently and maintain energy balance and condition while staying cool enough to protect themselves from the consequences of warming temperatures and possibly "heat stress." This suggests that management of optimum habitat may be an increasingly critical factor for the population performance of moose.

Caution must be exercised in drawing conclusions of cause-and-effect from correlations of warming temperatures and decreased survival of adult moose (Murray et al. 2006, Lenarz et al.

2009, 2010). Currently, no data exist to support the direct adverse effects of ambient temperature on the physiology, survival, or reproduction of free-ranging moose, in part, due to the limitations of technology. However, recently, a minimally invasive telemetry system for ruminants has been developed to allow nearly continuous monitoring of body temperature with a battery lifetime of ≥2 years (Signer et al. 2010). Using this mortality implant transmitter (MIT) and global positioning system (GPS) collars on adult moose will allow examination of ambient temperature relative to adult physiology, behavior, and fitness (condition, survival, and reproduction). We believe this study will yield the first data directly addressing the potential role of ambient temperature in the decline of the NE moose population.

## HYPOTHESES

Our hypotheses are:

1) Seasonal ambient temperatures have measurable effects on the internal body temperature of adult female moose.
2) Seasonal ambient temperatures have measurable effects on the activity (e.g., foraging, bedding, movement rates) of adult female moose.
3) Seasonal ambient temperatures have measurable effects on habitat use (e.g., forage openings, dense thermal cover, aquatic habitat) by adult female moose.
4) Ambient temperatures have measurable effects on calf production (fertility [pregnancy rates], fecundity) of adult female moose.
5) Ambient temperatures can have measurable effects on birth-weights of moose calves.
6) Ambient temperatures can have a measurable effects on survival of adult moose or calves.

Additionally, there may be various biologically significant interactions between these variables (e.g., body temperature relative to habitat use, activity), such as resting in dense cover or foraging in the open, and ambient temperature (Figure 1).

Upon fitting adult female moose with Iridium GPS collars (with external ambient temperature sensors) and MITs, our objectives are to:

1) Assess their winter physical condition and reproductive status at capture.
2) Simultaneously monitor ambient temperature and body temperature year-round.
3) Monitor their diurnal and nocturnal activity (e.g., resting, moving, foraging), movement rates, and use of habitat.
4) Monitor fertility (i.e., calving activity) of adult female moose during the spring calving interval.
5) Determine calf production and fecundity (i.e., singletons versus twins) of collared females.
6) GPS-collar 50 newborn calves of collared and implanted (MIT) adult females.

7) As part of our ongoing studies, we will continue to monitor the survival and determine the specific causes of mortality (and contributing factors) of all collared adults and calves.

Additionally, we will use these data to test the following predictions based on findings from Lenarz et al. (2009, 2010):

- Overall annual survival of moose in the NE MN population is lower than the average reported for moose elsewhere in their continental range.

- Non-anthropogenic mortality is having a greater impact on the overall annual survival of moose than human-related causes (e.g., hunting, vehicle and train collisions).

- Seasonal mortality rates of adult moose will be highest in late-winter and early-spring, but consistent with Lenarz et al. (2009) they will be higher than expected (i.e., compared to reports elsewhere in continental moose range) during non-winter months.

- Annual mortality rates will be consistent with regression predictions (Lenarz et al. 2009) of higher mortality rates (likely health- or nutrition-related) associated with higher winter and other seasonal temperatures.

- Non-anthropogenic mortality rates of adult moose will be affected by age.

## METHODOLOGY

### Study Area

Our 6,068-$km^2$ study area is located between 47°06' N and 47°58'N latitude and 90°04'W and 92°17'W in NE MN (Figure 2). The study area is classified as the Northern Superior Upland region (MNDNR 2007) and is characterized by a variety of wetlands, including bogs, swamps, lakes, and streams; lowland conifers, including northern white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), and tamarack (*Larix laricina*); and upland conifers, including balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), white pine (*P. strobes*), and red pine (*P. resinosa*). Trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*) occur on the uplands, often intermixed with conifers. Potential predators of moose include gray wolves (*Canis lupus*) and black bears (*Ursus americanus*) (Fritts and Mech 1981, Erb and Sampson 2013, Lenarz et al. 2009; Garshelis and Noyce 2011, Patterson et al. 2013). White-tailed deer (*Odocoileus virginianus)* share most of the study area with moose; their pre-fawning densities are managed at <10 deer per square mile (MNDNR 2011).

Limited annual moose hunting has occurred within the study area, with tags issued to State and Tribal hunters; however, the State and Tribal harvests were suspended indefinitely in 2013. Approximate moose densities within the study area have been estimated at 0.02–0.08 moose/$km^2$ (MNDNR, unpublished data).

Weather data (e.g., temperature, precipitation, dew point, and humidity) are recorded daily at National Weather Service weather stations within the study area, including Ely, Grand Marais, Isabella, and Silver Bay. Additionally, ambient temperature loggers will be placed in 6-8 open sites within the study area.

## Moose Capture and Handling

### *Adults*

In February 2015, we will capture 30 moose (22 females, 8 males) by aerial darting with 0.3 mg/kg thiafentanil (A-3080©) from a helicopter (Quicksilver Air, Inc., Fairbanks, AK); immobilizations will be reversed with 1 mg/kg of naltrexone (Kreeger et al. 2005, Kreeger and Arnemo 2012). Blood (serum and whole blood) will be collected at capture by venipuncture of the jugular vein. Serum will be screened for evidence of moose exposure to 10 disease agents following the protocol described by Butler et al. (2013b). Additionally, serum will be analyzed for chemistries and metabolic and reproductive hormones (i.e., progesterone) to assess physiological status, overall health, and pregnancy status (Franzmann and LeResche 1978, Haig et al. 1982, Duncan et al. 1994). Whole blood in ethylenediaminetetraacetic acid (EDTA) will be used to make blood smears, and complete and differential blood cell counts will be performed, which may be indicative of condition and health status (Duncan et al. 1994), presence of tick-borne illnesses, and evaluation for the presence of microfilaria. We will remove an incisor for aging by cementum annuli (Sergeant and Pimlott 1959). A general fecal floatation examination for parasites will be performed, as well as a culture for *Mycobacterium paratuberculosis*. We will measure maximum rump fat thickness (Maxfat, cm) by ultrasound to assess body condition and nutritional status (Cook et al. 2010, DelGiudice et al. 2011). A thorough physical examination will be performed, including assessment of winter tick load and hair loss using several standard methods and metrics. We will measure total body length, chest girth, and hind leg length (cm) (Franzmann et al. 1978), use them to estimate body weight of moose and to standardize estimates of ingesta-free body fat (IFBF) from Maxfat (Stephenson et al. 1998, Cook et al. 2010).

We will fit moose with Iridium Global Positioning System (GPS) radiocollars (Vectronic Aerospace, Berlin, Germany). Collars will be programmed to obtain a location every 4 hours with an increased location frequency (hourly) during the May calving period. Battery life of 3-4 years is expected. Collars include a mortality signal triggered by a motion-sensitive switch. In turn, the mortality signal will trigger a text message to alert the research team of the mortality and carcass (i.e., collar) location (GPS coordinates). A program also was developed to analyze locations, and if they are within a 20-m radius, a “localization notification” is generated. This is useful in detecting sick animals that are potentially moribund. Mortality implant transmitters (MITs, Vectronic Aerospace, Berlin, Germany) will be placed orally into the reticulum of all captured moose. These devices will record internal temperatures every 15 minutes and transmit a subset of the data to the collar. Additionally, MITs are designed to provide immediate notification of mortality via detection of minimal internal activity (e.g., lack of a heart beat), and this notification also is made via text message to our response team. A temperature logger

(Hobo TibdbiTv2) will be affixed to each GPS collar and programmed to collect ambient temperature every 60 minutes.

***Calves***

Beginning 1 May 2015, we will closely monitor the locations and movements of the GPS-collared adult female moose that are pregnant (maximum of 22). This sample of females will include those fitted with GPS collars and MITs during January 2015 and all other surviving adult females that were collared during previous years for a cause-specific mortality study (Butler et al. 2013a). Our primary monitoring objective will be to record when and where individual pregnant females make their "calving move" (Bowyer et al. 1999; McGraw et al., in review). This is a variable but atypical, long-distance move that occurs an estimated 12 hours before calving, after which the dam's movements become very clustered, or localized, for up to 7-10 days. Our previous calf captures have demonstrated this indicator to be highly reliable. We expect ≥80% of moose calving in northeastern Minnesota to occur during the middle 2 weeks of May (Patterson et al. 2013; DelGiudice and Severud, unpublished data; Moen, unpublished data). Use of a helicopter to facilitate calf captures is essential for obtaining an adequate sample size of newborns during the relatively brief moose calving period in remote areas of NE MN. However, ground captures (no helicopter) of 5-10 calves will be conducted during early May and again in late May. These combined with helicopter capture of 30-40 calves during the calving peak, will allow us to learn more about helicopter use as a potential "disturbance factor" relative to dams abandoning their calves after capture. We will begin ground captures (no helicopter) on about 7 May 2015 with a 4- to 5-person team. Once dams have made their calving moves, they typically calve within 12 hours. We will allow an additional 48 hours for bonding between the dam and her calf or calves for an estimated minimum total bonding time of 48-60 hours. We have several ongoing monitoring methods for this purpose (Severud et al. 2013). Once monitored females have calved and are allowed this bonding time, the calves will be identified as ready for capture and handling.

After a week of ground captures the helicopter capture crew (Quicksilver Air, Inc., Fairbanks, AK) will capture 30-40 calves. We will provide the capture crew a daily list of collared females (and their recent GPS coordinates) which have been allowed 48-60 hours of bonding time. The capture crew will locate the target dam and her calves from the air and then land some distance away to allow the handler(s) to disembark and approach calves on foot. The experienced helicopter crew will plan the approach and landing to minimize the disturbance as much as reasonably possible. The calf handling protocol will include slipping an expandable Globalstar GPS collar (440 g, programmed to record location fixes hourly, Vectronic Aerospace, Berlin, Germany) over the head; fixing ear-tags; collecting 25 ml of blood by syringe from the jugular vein into 1 EDTA tube for hematology and into 2 serum tubes for laboratory analyses for chemistries, metabolites, electrolytes, and metabolic and reproductive hormones; weighing the calf to the nearest 0.5 kg; recording several morphological measurements (hind leg length, body length, girth, and neck circumference) and a rectal temperature ($^{o}$F); a physical examination to record any noteworthy injuries or abnormalities; and releasing the calf where it was found.

Time expended in attempting to capture a calf for handling will be limited to 6 minutes. During capture of 49 calves during May 2013 all of our study calves were captured without a chase, and all twins (18 sets) were captured, handled, and released together, which helps to limit capture-related abandonment (Keech et al. 2011). We plan to limit the complete handling protocol to 5-6 minutes per calf to minimize separation time from the dam (Keech et al. 2011), and in the case of twins, we will attempt to handle and release both calves together. All captures and handling protocols followed requirements of the Institutional Animal Care and Use Committee for the University of Minnesota (Protocol 1302-30328A).

Adult and calf location fixes will be transmitted 3-4 and 6 times per day, respectively, to a base station computer. We will have 3 sources of data and information for monitoring the hourly locations and movements of the GPS-collared dams and calves. These include a shared network computer drive with all location coordinates and calculated hourly movement distances of all of the GPS-collared adult moose; the Vetronics website, which allows us to observe the locations (and associated information) overlaid on GoogleEarth maps and aerial imagery at various scales; and an automated report produced by J. Forester (University of Minnesota, St. Paul), which plots mean hourly distances moved for up to 10 days at a time and GPS coordinates of fixes and paths of movement for the most recent 5 days. This report is updated every 4 hours and provides locations and paths of movement for the past 24 hours overlaid on GoogleEarth coverage, as well as calculations of speed and displacement distance (Severud et al. 2013). Using fixes and hourly distances moved, we will calculate and graph the average hourly distances moved by pregnant females by 3-hour intervals (R. A. Moen and A. McGraw, NRRI, Duluth, MN, personal communication), which will enable us to identify times of the calving move and capture for estimating bonding times and will allow us to closely monitor adults and calves post-release from capture.

**Monitoring Survival and Determining Causes of Mortality**

***Adults***

Collared moose will be monitored daily for the life of the collars to ensure collars are functioning as designed and transmissions are being received. A team of highly trained responders (e.g., DNR biologists, project collaborators) will be stationed throughout NE Minnesota. An on-call schedule will be developed with a minimum of 3 responders per moose mortality notification; these responders will investigate mortalities within 24 hours of receiving the mortality text message. If a moose is found to be alive, but obviously ill, it will be euthanized via gunshot. Extensive site investigations will occur to determine cause of death and document (i.e., photographs, video) the mortality site. We will make every effort to remove the entire carcass intact and submit it to the Veterinary Diagnostic Laboratory (VDL) at the University of Minnesota, for a complete necropsy by a board-certified veterinary pathologist. When carcasses cannot be removed intact, we will perform a complete field necropsy guided by an established protocol. Tissue samples from all of the major organs, including the eyes and the entire brain, will be collected and samples will be split between preservation methods (formalin and chilling) and submitted to the VDL as soon as possible for diagnostics. Appropriate samples also will be shipped to project collaborators to test for microfilarial and tick-borne illnesses. Any mortality events that occurred within 2 weeks of the capture date will be censored from the study.

***Calves***

We will monitor each collared calf daily until mortality or until its collar drops off (designed to be about 400 days). The collars will send a mortality alert notification to our cell phones via text message (i.e., SMS) when mortalities occur. As a backup, we also will use the Vectronic website and GPS Plus X software to check the distance status of calf collars relative to their dam's collars and to determine whether any calf collars are in mortality mode. Each morning all dam and calf groups will be checked and monitored closely throughout the day if separated by more than 100 m.

When we receive a mortality alert or determine a mortality may have occurred, we will dispatch a trained necropsy team to collect the collar and carcass remains to determine the cause of death (Ballard et al. 1979). To avoid possible investigation-induced abandonment, investigations are delayed if the dam is still in the area, especially if she is with a twin. Our primary field objective is to recover the entire carcass and deliver it to the University of Minnesota's VDL for necropsy. If the carcass cannot be extracted and transported, we will perform a detailed field necropsy. If scavenged, fresh organ and tissue samples will be collected and shipped to the VDL whenever possible (Butler et al. 2011).

Investigation of the site also will include photographs of tracks and scat and collection of scat when identification is uncertain. We will note the presence of puncture wounds on the neck, skull, or hind quarters and claw marks across the body and will take photographs of all wounds. When the hide is present, we will note if it is inverted, which may indicate a bear was feeding on the carcass. We will document the consumption of viscera, the rumen, or its contents. Wolves may chew on ribs and ends of long bones, whereas bears are more likely to cache pieces of the carcass. To determine if the calf was alive or dead when consumed, we will look for subdermal hemorrhaging or sprays of blood on the collar or on broken or matted vegetation. We will take note of the position of the carcass (lateral or sternal) and the distribution of body parts (scattered or near the carcass). An odor of decomposition or many fecal pellets in the area may indicate scavenging versus predation.

If we find a GPS collar without a carcass or other evidence of predation, we will backtrack to the last known locations of the calf and its dam to expand our search. The Iridium collars on adult moose are more accurate than the calf collars, so we will use the cow's locations from the approximate time of death of the calf to look for a kill-site or evidence of the cause of mortality. We will determine a collar to be slipped rather than a possible mortality if the breakaway section was frayed or the bolts holding the breakaway section were loose, coupled with both an absence of blood on the collar and lack of evidence within a 30-m radius of the collar.

**Habitat Use by Adult Moose**

We will examine behavioral (e.g., movement rates, habitat use, activity) responses of moose to changing ambient temperatures. Moose home ranges, habitat types (e.g., mixed hardwood, conifer, regeneration, wet bog, and open), and activity bouts (e.g., resting, feeding, and moving) will be calculated and classified similar to methods described by Moen et al. (NRRI, personal communication) to allow for comparative data analyses between studies. Habitat layers, including cover types, disturbance, and remote sensing (LIDAR) will be made available by Moen et al. (NRRI, personal communication).

**Data Analyses**

Cause-specific mortality rates will be estimated using cumulative incidence functions (CIFs) to account for left-truncation (DelGiudice et al. 2002, Heisey and Patterson 2006). Cox proportional hazard models will be used to examine if covariates measured at the time of capture (e.g., body mass, blood constituents, rump fat) are associated with mortality. Moose with slipped collars or lost signals will be censored from analyses at time of last contact. Linear regression will be used to characterize the relationship between female age and estimated body mass and to model blood characteristics as a function of age and body mass.

We will use a series of regression models to characterize the relationships between ambient temperature, moose-specific ambient temperatures, moose behavioral responses (use of particular habitat types, activity levels), and moose physiological responses (internal body temperature) depicted in Figure 1. The following are sets of independent and dependent variables for each regression model:

1. Dependent variable = Ambient temperature; Independent variables = habitat type (open, water, mixed forest, etc.), ambient temperature.
2. Dependent variables = activity level (time spent foraging, bedded, moving), movement rate; Independent variables = ambient temperature.
3. Dependent variable = internal body temperature; Independent variables = ambient temperature, activity level (time spent foraging, bedded, moving) and movement rate.

In the first two models, we also will include additional explanatory variables (e.g., time of day, Julian date) to control for background diurnal and seasonal patterns. We will use mixed effects models (Pinhiero and Bates 2000) to account for repeated measures taken on the same individuals and also consider autoregressive error structures for within-individual errors as necessary.

Lastly, we will apply the same methods as Lenarz et al. (2009, 2010) to estimate annual survival rates, non-anthropogenic mortality rates, and to test the predictions outlined in the Hypotheses section regarding relationships between age and ambient temperature versus annual and seasonal survival rates. We will examine pregnancy and calf production as a function of habitat use (proportion of time spent in specific habitat types) and ambient temperatures using a heat stress index (HSI) calculated according to Lenarz et al. (2009) and moose metabolic thresholds (days exceeding thresholds) reported by Renecker and Hudson (1986), or by using thresholds established using our study's MIT data.

We will use discrete choice/multinomial regression models (similar to DelGiudice et al. 2013) to explore use of discrete habitat types as a function of ambient temperature while controlling for diurnal and seasonal patterns. The same types of models will be used to estimate the probability of choosing among a discrete number of activities (bedding/resting, moving, foraging) as a function of ambient temperature, time of day, and season.

## RESULTS AND DELIVERABLES

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 causes 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.

## TIMETABLE

February 2015- Capture and radiocollar 22 female and 8 male adult moose. All moose will receive mortality implant transmitters.

April 2015- Formulate conclusions about the nutritional condition, health, and overall well-being of moose at the start of winter. Receive results on pregnancy status of captured and collared adult females.

May 2015- Capture and radiocollar 50 newborn calves of collared cows.

June 2016- Determine specific causes of mortality of moose that die during the study period; quantify rates of exposure to disease, toxicity, and nutrition deficiency levels; formulate conclusions about how ambient temperatures contribute to specific causes of death.

June 2017- Recover remaining collars and summarize cause-specific mortality of animals that remained in the study beyond 2016.

## BUDGET

| BUDGET ITEM | AMOUNT |
|---|---|
| **Personnel:** | |
| Wildlife Health Specialist, field data collection, analyze, field necropsies, outreach, 2 years @ 43.5% funding (1 FTE = $85,000/year) | $ 74,000 |
| Spring/summer field technicians (2): Full-time 120-day temporary hires to help with the calf capture operations, mortality investigations and necropsies, and habitat fieldwork | $ 20,000 |
| Fall Field technician (1): Full-time 120-day temporary hire to help with moose calf mortality investigations | $ 8,200 |
| **Contracts:** | |
| Wildlife helicopter capture company: Adult moose capture & handling (30 moose @ $1,600) | $ 48,000 |
| Wildlife helicopter capture company: Moose calf capture & handling (40 calves @ $1,450) | $ 58,000 |
| Univ. of Minnesota graduate student stipend (2 years) Leads fieldwork for capture operations, investigations of calf mortalities, and calving habitat analyses | $ 80,000 |
| University of Minnesota biometrician for statistical consulting (2.5 months @ 83% salary and 17% fringe) | $ 26,795 |
| University of Minnesota, Veterinary Diagnostic Laboratory: diagnostic laboratory analyses associated with moose captures and necropsies | $ 10,000 |
| Iridium satellite adult moose data acquisition: transmission of location, temperature, heart rate data, and mortality messages (approx. $175/month + per-transmission fee) | $ 35,000 |
| Globalstar satellite moose calf data acquisition: transmission of location and mortality messages (approx. $175/month + per-transmission fee) | $ 15,000 |
| **Equipment/Tools/Supplies:** | |
| GPS adult moose collars (25 @ $3,000/each); collect location data, transmit temperature data and mortality notifications; competitive bid process to select vendor | $ 75,000 |
| GPS calf collars (50 @ $1,100/each); collect location data, transmit mortality notifications; competitive bid process to select vendor | $ 55,000 |
| Mortality Implant Transmitters (MITs, 30 @ $900/each) | $ 27,000 |
| Ambient temperature loggers for adult moose collars (30 @ $150/each) | $ 4,500 |
| Capture drugs: $250/moose for 24 moose (drugs for additional moose acquired as needed with other funds); immobilization and reversal | $ 6,000 |
| **Travel:** | |
| Travel to study area by adult and calf moose project management and field staff (fleet @$0.55/mi, estimated 22,250 miles) | $ 12,239 |
| Calf study fieldwork volunteer: room and board only | $ 3,000 |
| **Additional Budget Items:** | |
| Spotter plane to be used during adult and calf capture efforts ($205/hour, 100 hours | $ 20,500 |
| Direct and Necessary Services required to support this appropriation | $ 21,766 |
| **TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =** | $ 600,000 |

**CREDENDTIALS**

**<u>Michael A. Larson</u>, Ph.D. – Project manager**

**Education**

Ph.D. 2001. Wildlife Ecology & Management. *University of Missouri*, Columbia, MO.

M.S. 1998. Wildlife Ecology & Management. *Michigan State Univ.*, East Lansing, MI.

B.A., *Magna Cum Laude*. 1995. Biology. *Gustavus Adolphus College*, St. Peter, MN.

**Experience**

2012–present. Group Leader, *Forest Wildlife Populations & Research, Minnesota Department of Natural Resources*, Grand Rapids, MN. Manage budgets and 8 permanent staff for MN DNR research and monitoring programs for moose, deer, bears, wolves, other furbearers, & grouse in Minnesota.

2007–present. Adjunct Assistant Professor; Fisheries, Wildlife & Conservation Biology; *University of Minnesota*.

2004–2012. Research Scientist, *Minnesota Department of Natural Resources*. Conducted research studies, coordinated population monitoring surveys, and provided expertise in the ecology and management of Ruffed Grouse, Spruce Grouse, Sharp-tailed Grouse, and Greater Prairie Chickens in Minnesota. Also provided expert consultation to other DNR units on topics related to decision analysis and climate change adaptation.

2003–2004. Ecologist, Quantitative Methods Group, *USGS Patuxent Wildlife Research Center*, Laurel, MD.

**Selected publications**

Kouffeld, M. J., M. A. Larson, and R. J. Gutiérrez. 2013. Selection of landscapes by male ruffed grouse during peak abundance. *Journal of Wildlife Management* 77(6):1192–1201.

McGowan, C. P., M. C. Runge, and M. A. Larson. 2011. Incorporating parametric uncertainty into population viability analysis models. *Biological Conservation* 144(5):1400–1408.

Larson, M. A., F. R. Thompson, III, J. J. Millspaugh, W. D. Dijak, and S. R. Shifley. 2004. Linking population viability, habitat suitability, and landscape simulation models for conservation planning. *Ecological Modelling* 180(1):103–118.

Larson, M. A., M. E. Clark, and S. R. Winterstein. 2003. Survival and habitat of ruffed grouse nests in northern Michigan. *Wilson Bulletin* 115(2):140–147.

Larson, M. A., M. R. Ryan, and R. K. Murphy. 2002. Population viability of piping plovers: effects of predator exclusion. *Journal of Wildlife Management* 66(2):361–371.

Larson, M. A., M. E. Clark, and S. R. Winterstein. 2001. Survival of ruffed grouse chicks in northern Michigan. *Journal of Wildlife Management* 65(4):880–886.

**<u>Glenn David DelGiudice</u>, Ph.D. – Principal investigator, moose calf component**

Moose Research Project Leader, Forest Wildlife Populations & Research Group, MNDNR, since September 2011, lead moose research, orchestrate the annual aerial moose survey for estimating the northeastern Minnesota population, and monitor the annual harvest to assess population dynamics.

Deer Project Leader, Forest Wildlife Populations and Research Group, MNDNR, since October 1990 conducting long-term, comprehensive studies examining the relationships of winter severity and conifer stands to the winter distribution, movements, food habits, condition, survival, and reproduction of white-tailed deer in northern Minnesota.

Adjunct Associate Professor and member of the graduate faculty since 1992, Wildlife Conservation Program, Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul.

**Education**

University of Minnesota, Ph.D., Wildlife Conservation, 1988

University of Arizona, M. S., Renewable Natural Resources, 1982

Cornell University, B. S., Renewable Natural Resources/Biology, 1977

**Experience**

2011-Present Lead principal investigator of a study of survival, cause-specific mortality, and intrinsic and extrinsic contributing factors for moose calves in northeastern Minnesota.

Co-principal investigator in a study of the survival, contributing factors and specific causes of mortality, and recruitment of moose in the declining population in northeastern Minnesota.

2007-2011 Lynx Conservation Plan and Incidental Take Application – lead position in developing the MNDNR's conservation and incidental take plan for Minnesota (please see MNDNR reports under Publication List below).

2003-2005 Lead researcher investigating the role of winter condition of moose in the performance of this declining population in northeastern Minnesota.

1988-1997 Principal investigator with Dr. Rolf O. Peterson, Michigan Technological University, in a 9-year study of winter nutrition of free-ranging moose related to winter severity, habitat differences, and winter tick infestation in Isle Royale National Park.

**Selected Research Publications**

DelGiudice, G. D., J. R. Fieberg, and B. A. Sampson. 2013. A long-term assessment of the variability in winter use of dense conifer cover by female white-tailed deer. PLoS ONE 8(6): e65368. Doi: 10.1371/journal.pone.0065368

DelGiudice, G. D., B. A. Sampson, and J. H. Giudice. 2013. A long-term assessment of the effect of winter severity on the food habits of white-tailed deer. Journal of Wildlife Management. 77:1664-1675

DelGiudice, G. D., B. A. Sampson, M. S. Lenarz, M. W. Schrage, and A. J. Edwards. 2011. Winter body condition of moose (*Alces alces*) in a declining population in northeastern Minnesota. Journal of Wildlife Diseases 47: 30-40.

Fieberg, J., and G. D. DelGiudice. 2008. Exploring migration data using interval-censored time-to-event models. Journal of Wildlife Management 72: 1211-1219.

DelGiudice, G. D., M. S. Lenarz, and M. Carstensen Powell. 2007. Age-specific fertility and fecundity in northern free-ranging white-tailed deer: evidence for reproductive senescence? Journal of Mammalogy 88: 427-435.

DelGiuduce, G. D., J. Fieberg, M. R. Riggs, M. Carstensen Powell, and W. Pan. 2006. A long-term age-specific survival analysis of female white-tailed deer. Journal Wildlife Management 70: 1556-1568.

DelGiudice, G. D., B. A. Sampson, D. W. Kuehn, M. Carstensen Powell, and J. Fieberg. 2005. Understanding margins of safe capture, chemical immobilization, and handling of free-ranging white-tailed deer. Wildlife Society Bulletin 33: 677-687.

DelGiudice, G. D., M. R. Riggs, P. Joly, and W. Pan. 2002. Winter severity, survival and cause-specific mortality of female white-tailed deer in north central Minnesota. Journal of Wildlife Management 66: 698-717.

DelGiudice, G. D., R. Moen, F. J. Singer, and M. R. Riggs. 2001. Physiological responses of Yellowstone elk and bison to winter nutritional restriction and simulated body condition before and after the fires of 1988. Wildlife Monographs No. 147. 60pp.

DelGiudice, G. D., K. D. Kerr, L. D. Mech, M. R. Riggs, and U. S. Seal. 1998. Urinary 3-methylhistidine and progressive winter undernutrition in white-tailed deer. Canadian Journal of Zoology 76: 2090-2095.

DelGiudice, G. D. 1998. Surplus killing of white-tailed deer by wolves in northcentral Minnesota. Journal of Mammalogy 79: 227-235.

Doenier, P. B., G. D. DelGiudice, and M. R. Riggs. 1997. Effects of winter supplemental feeding on browse consumption by white-tailed deer. Wildlife Society Bulletin 25: 235-243.

DelGiudice, G. D., R. O. Peterson, and W. M. Samuel. 1997. Trends of winter nutritional restriction, ticks, and numbers of moose of Isle Royale. Journal of Wildlife Management 61: 895-903.

DelGiudice, G. D. 1995. Assessing winter nutritional restriction of northern deer with urine in snow: considerations, potential and limitations. Wildlife Society Bulletin 23: 687-693.

DelGiudice, G. D., U. S. Seal, and L. D. Mech. 1991. Indicators of severe undernutrition in urine of free-ranging elk during winter. Wildlife Society Bulletin 19: 106-110.

DelGiudice, G. D., L. D. Mech, and U. S. Seal. 1990. Effects of winter undernutrition on body composition and physiological profiles of white-tailed deer. Journal of Wildlife Management 54: 539-550.

**Michelle Carstensen, Ph.D. – Principal investigator, adult moose component**

**Education**

University of Minnesota, Ph.D. Wildlife Conservation, December 2004.

University of Minnesota, M.S. Wildlife Conservation, January 2002.

Cornell University, B.S. Animal Science, January 1996.

*Academic Honors* : Cornell Tradition Fellow, Dean's List

**Experience**

Minnesota Department of Natural Resources**,** *Wildlife Health Program Supervisor*.......... 2006-present

Direct the state's wildlife health program to address diseases threatening the state's game species including Chronic Wasting Disease (CWD), bovine tuberculosis (TB), and Newcastle Disease. Direct the work of program staff, including a wildlife veterinarian, a wildlife health specialist, a moose health specialist, and 3 part-time support staff. Design and coordinated research studies on moose, deer, and wolf health. Design surveillance protocols for disease detection and trend analysis. Provide expertise on wildlife disease issues and provided feedback on national policy issues related the management of disease outbreaks in wildlife. Wrote grants, organized spending plans, and managed a program budget of over one million dollars, which included both state and federal funding. Design the state's bovine tuberculosis management program for white-tailed deer and coordinated activities with state and federal partners. Represent the state agency at local, state, national, and international meetings regarding disease surveillance. Designed the state's response plan for an outbreak of HPAI in wild birds and worked with state and federal partners on emergency preparedness. Trained in Incident Command System and served as Planning Chief during two emergency disease outbreaks. Publish scientific papers in peer-reviewed journals.

Minnesota Department of Natural Resources**,** *NR Specialist-Wildlife Diseases…………………..*2004-2006

Coordinated the state's Chronic Wasting Disease (CWD) surveillance program and provided expertise on wildlife disease issues. Trained agency personnel, veterinary students, and volunteers on tissue extraction and the proper handling of biological samples. Organized equipment, work schedules and field logistics. Created and maintained a database of statewide CWD samples collected from hunter-killed white-tailed deer and tracked test results to provide the public with accurate and timely reports. Analyzed spatial distribution of sampling data and applied statistical tests to ensure an accurate probability of disease detection. Collaborated with wildlife professionals on epidemiological modeling of CWD. Refined the state's CWD contingency plan. Represented the state agency at public meeting and planning session regarding tuberculosis surveillance. Presented disease surveillance findings at regional scientific meetings.

University of Minnesota**,** *Graduate Research Assistant* ...................................................... 1999-2004

Participated in a Minnesota Department of Natural Resources study investigating the effects of winter severity and deer nutrition on fawning characteristics. Worked closely with state agency personnel, and trained and supervised interns and volunteers. Gained experience in large animal capture and handling techniques, immobilizing drugs, *in vivo* body composition determination using isotope dilution, blood and urine sampling, tooth extraction, and ultrasonography. Experienced in radio-tracking animals from the ground and fixed wing aircraft. Interpreted spatial data using a variety of software programs including XY-Log, LOAS, and ArcView GIS. Experienced in aerial photo interpretation. Performed extensive laboratory analyses including blood lyophilization; fat, nitrogen, and ash extraction of carcass samples; and infrared spectroscopy. Presented research findings at national meetings of wildlife professionals and local meetings of funding organizations. Submitted research findings for national publication to peer-reviewed journals.

Institute for Local Self-Reliance**,** *Research Associate/Program Manager* ............................ 1996-2000

Investigated and promoted the use of value-added agricultural products as substitutes for petroleum-based industrial products as a pollution prevention strategy. Provided technical assistance to industrial manufacturers, state agencies, environmental groups, and community organizations through workshops, personal consultations and written materials. Managed program budget and gained experience in grant writing and reporting to funding organizations. Researched and published a series of pollution prevention fact sheets, industry reports, and articles for national trade magazines and peer-reviewed, environmental journals. Organized and coordinated planned events. Gave presentations at local, regional and national meetings and served as an invited speaker at numerous events. Consulted farmer-owned cooperatives on business plan development. Created and managed program website. Served as a judge for the Governor's Award for Pollution Prevention. Appointed to the Listed Metals Advisory Council, created to oversee the state's mandate on reducing the use of heavy metals in specified products.

**Professional memberships**

Adjunct Assistant Professor, College of Veterinary Medicine, University of Minnesota; Chair of the Midwest Fish & Wildlife Health Committee, Association of Fish and Wildlife Agencies; Wildlife Disease Association, member of Wildlife Disease Committee; member of the Wildlife Society; member of Dean’s Advisory Council, UM-College of Veterinary Medicine; member of Advisory Council for the UM-Veterinary Diagnostic Laboratory

**Selected publications**

White, L. C., H. S. Ip, D. P. Walsh, C. U. Meteyer, J. S. Hall, M. Carstensen, and P. C. Wolf. Spatial and temporal patterns of Newcastle Disease epizootics in double-crested cormorants in the United States. 2013. Avian Diseases: *In review*

Dubey, J. P., P Dennis, S. Verma, S. Chaudhary, L. Ferreira, S. Oliveira, O. Kwok, E. Butler, M. Carstensen, and C. Su. 2013. Epidemiology of toxoplasmosis in white tailed deer (*Odocoileus virginianus*): occurrence, congenital transmission, correlates of infection, isolation, and genetic characterization of *Toxoplasma gondii*. Veterinary Parasitology: *In press*

Dubey, J. P., M. C. Jenkins, O. C. H. Kwok, L. R. Ferreira, S. Choudhary, S. K. Verma, L. Villena, E. Butler, and M. Carstensen. 2013. Congenital transmission of *Neospora caninum* in white-tailed deer (*Odocoileus virginianus*). Veterinary Parasitology 96: 519–522.

Dubey, J. P, S. Choudhary, L. R. Ferreira, O. C. H. Kwok, E. Butler, M. Carstensen, L. Yu, and C. Su. 2013. Isolation and RFLP genotyping of *Toxoplasma gondii* from the gray wolf (*Canis lupis*). Veterinary Parasitology 197: 685–690.

Carstensen, M. and M. W. DonCarlos. 2011. Preventing the establishing of a wildlife disease reservoir: a case study of bovine tuberculosis in wild deer in Minnesota, USA. Veterinary Medicine International, Volume 2011, Article ID 413240, 10 pages, doi:10.4061/2011/413240.

Carstensen, M. D. J. O'Brien and S. M. Schmitt. 2011. Public acceptance as a determinant of management strategies for bovine tuberculosis in free-ranging U.S. wildlife. Veterinary Microbiology 151 (2011): 200–204, doi:10.1016/j.vetmic.2011.02.046

Carstensen M., G. D. DelGiudice, B. A Sampson, and D. W. Kuehn. 2009. Survival, birth characteristics, and cause-specific mortality of white-tailed deer neonates. Journal of Wildlife Management 173(2): 175–183.

Dubey, J. P, M. C. Jenkins, O.C.H. Kwok, R. L. Zink, M. L. Michalski, V. Ulrich, J. Jill, M. Carstensen, and P. Thulliez. 2009. Seroprevalence of *Neospora caninum* and *Toxoplasma gondii* antibodies in white-tailed deer (*Odocoileus virginianus*) from Iowa and Minnesota using four serologic tests. Veterinary Parasitology 161: 330–334.

Dubey J. P, G. V. Velmurugan, V. Ulrich, J. Gill, M. Carstensen, N. Sundar, O. C. H. Kwok, P. Thulliez, D. Majumdar, and C. Su. 2008. Transplacental toxoplasmosis in naturally-infected white-tailed deer: isolation and genetic characterization of *Toxoplama gondii* from fetuses of different gestational ages. International Journal of Parasitology 38: 1057–1063.

Carstensen Powell, M., G. D. DelGiudice, and B. A Sampson. 2005. Low risk of marking-induced abandonment in free-ranging white-tailed neonates. Wildlife Society Bulletin 33 (2): 643–655.

Carstensen Powell, M. and G. D. DelGiudice. 2005. Birth, morphological and blood characteristics of free-ranging white-tailed deer neonates. Journal of Wildlife Diseases 41: 171-183.

Carstensen, M. and G. D. DelGiudice. 2003. Using doe behavior and vaginal implant transmitters to capture neonate white-tailed deer in north central Minnesota. The Wildlife Society Bulletin 31: 634–641.

**John R. Fieberg, Ph.D**. – Statistical consultant

John joined the faculty in the Department of Fisheries, Wildlife, and Conservation Biology at the University of Minnesota in the fall of 2013. Prior to that, he served as the Wildlife Biometrician for the Minnesota DNR for 10 years. He has developed considerable expertise in analyzing wildlife data and has published multiple applied and methodological papers on topics directly related to this study (e.g., wildlife survival analysis, models of habitat selection). He has worked in the past with the other PIs and project collaborators on research pertinent to this proposal, including the 7-year moose telemetry study and the Minnesota moose population surveys that motivated the need for additional moose demographic research.

**Education**

PhD 2000 North Carolina State University, Biomathematics

MS 1996 University of North Carolina-Chapel Hill, Biostatistics

BA 1993 Westminster College, Mathematics, summa cum laude, May 1993.

**Professional experience**

2013-present University of Minnesota, Dept. of Fish., Wildl, and Cons. Bio., Assistant Professor.

2009-2013 University of Minnesota, Dept. of Fish., Wildl, and Cons. Bio., Adj. Asst. Prof.

2003-2013 Minnesota Department of Natural Resources, Wildlife Biometrician.

2000-2003 Northwest Indian Fisheries Commission, Biometrician III.

**Selected publications** (from a total of 56)

Fieberg, J., M. Alexander, S. Tse, and K. St. Clair. 2013. Abundance estimation with sightability data: a Bayesian data augmentation approach. *Methods in Ecology and Evolution* 4:854–864.

Aarts, G, J. Fieberg, S. Brasseur, and J. Matthiopoulos 2013. Quantifying the effect of habitat availability on species distributions. *Journal of Animal Ecology* 82:1135-1145.

Fieberg, J. and M. Ditmer. 2012. Understanding the causes and consequences of animal movement: a cautionary note on fitting and interpreting regression models with time-dependent covariates. *Methods in Ecology and Evolution* 3:983-991.

Giudice, J., J. Fieberg, and M. Lenarz. 2012. Spending degrees of freedom in a poor economy: a case study of building a sightability model for Moose in northeastern Minnesota. *Journal of Wildlife Management* 76:75-87.

Fieberg, J. R. and M.S. Lenarz. 2012. Comparing stratification schemes for aerial moose surveys. *Alces* 48:79-87.

Aarts, G., J. Fieberg, and J. Matthiopoulos. 2012. Comparative interpretation of count, presence-absence and point methods for species distribution models. *Methods in Ecology and Evolution* 3:177-187.

Matthiopoulos, J., M. Hebblewhite, G. Aarts, and J. Fieberg. 2011. Generalized functional responses for species distributions. *Ecology* 92:583-589.

Fieberg, J., J. Matthiopoulos, M. Hebblewhite, M.S. Boyce, J. L. Frair. 2010. Correlation and studies of habitat selection: problem, red herring, or opportunity? *Philosophical Transactions of the Royal Society*, Series B 365:2233-2244.

Fieberg, J., and G. D. DelGiudice. 2009. What time is it? Choice of time origin and scale in extended proportional hazards models. *Ecology* 90:1687-1697.

**DISSEMINATION AND USE**

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. Also, we will prepare news releases and conduct interviews with the news media. Audiences will include agency staff making decisions about moose conservation, non-governmental organizations involved in moose conservation, other scientists doing similar and subsequent studies, and the general public.

**REFERENCES**

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Belovsky, G. E., and P. A. Jordan. 1978. The time-energy budget of a moose. Theoretical Population Biology 14:76-104.

Brown, G. S. 2011. Patterns and causes of demographic variation in a harvested moose population: evidence for the effects of climate and density-dependent drivers. Journal of Animal Ecology doi: 10.1111/j.2041-210X.2009.00010.x

Butler, E. A., M. Carstensen, and G. D. DelGiudice. 2011. Determining causes of death in a declining moose population. Environment and Natural Resources Trust Fund, Research Addendum for Peer Review. Project number 009-A1, St. Paul, MN. USA.

Butler, E. A., M. Carstensen, E. C. Hildebrand, J. Giudice. 2013b. Northeast Minnesota moose herd health assessment 2007-2012. Pages 86-96 *in* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2012. Wildlife Populations and Research Unit, Minnesota Department of Natural Resources, St. Paul, USA.

Butler, E. A., M. Carstensen, E. C. Hildebrand, and D. C. Pauly. 2013a. Determining causes of death in Minnesota's declining moose population: a progress report. Pages 97-106 *in* L. Cornicelli, M. Carstensen, M. D. Grund, M. A. Larson, and J. S. Lawrence, editors. Summaries of wildlife research findings, 2012. Wildlife Populations and Research Unit, Minnesota Department of Natural Resources, St. Paul, USA.

Cook, R. C., J. G. Cook, T. R. Stephenson, W. L. Myers, S. M. McCorquodale, D. J. Vales, L. L. Irwin, P. Briggs Hall, R. D. Spencer, S. L. Murphie, K. A. Schoenecker, and P. J. Miller. 2010. Revisions of rump fat and body scoring indices for deer, elk, and moose. Journal of Wildlife Management 74:880-896.

DelGiudice, G. D. 2013. 2013 aerial moose survey. Wildlife Populations and Research Unit, Minnesota Department of Natural Resources, St. Paul, USA. http://files.dnr.state.mn.us/outdoor_activities/hunting /moose/moose_ survey_2013.pdf>.

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Duncan, J. R., K. W. Trasse, and E. A. Mahaffey. 1994. Veterinary laboratory medicine. Third edition. Iowa State University, Ames, USA.

Erb, J., and B. A. Sampson. 2013. Distribution and abundance of wolves in Minnesota, 2012-13. Wildlife Populations and Research Unit, Minnesota Department of Natural Resources, St. Paul, USA. 16pp.

Franzmann, A. W., and R. E. LeResche. 1978. Alaskan moose blood studies with emphasis on condition evaluation. Journal of Wildlife Management 42:334-351.

Fritts, S. H., and L. D. Mech. 1981. Dynamics, movements, and feeding ecology of a newly protected wolf population in northwestern Minnesota. Wildlife Monographs No. 80.

Gailard, J. –M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. Trends in Ecology and Evolution 13:58-63.

Gaillard, J. –M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. Annual Review of Ecology and Systematics 31:367-393.

Garshelis, D., and K. Noyce. 2011. Status of Minnesota black bears, 2010. Final Report to Bear Committee. Wildlife Populations and Research Unit, Minnesota Department of Natural Resources, St. Paul, USA.

Hahn, G. L. 1999. Dynamic responses of cattle to thermal heat loads. Journal of Animal Science 77:10-20.

Haigh, J. C., E. H. Kowal, W. Runge, and G. Wobeser. 1982. Pregnancy diagnosis as a management tool for moose. Alces 18:45-53.

Heisey, D., and B. R. Patterson. 2006. A review of methods to estimate cause-specific mortality in the presence of competing risks. Journal of Wildlife Management 70:1544-1555.

Houghton, J. T., Y. Ding, D. J. Griggs, N. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson. 2001. Contribution of working group 1 to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom.

Humphries, M. M., J. Umbanhowar, and K. S. McCann. 2004. Bioenergetic prediction of climate change impacts on northern mammals. Integrative and Comparative Biology 44:152-162.

Kelsall, J. P., and E. S. Telfer. 1974. Biogeography of moose with particular reference to western North America. Le Naturaliste Canadian (Que.) 1ds01:117-130.

Keech, M. A., M. S. Lindberg, R. D. Boertje, P. Valkenburg, B. D. Taras, T. A. Boudreau, and K. B. Beckmen. 2011. Effects of predator treatments, individual traits, and environment on moose survival in Alaska. Journal of Wildlife Management 75:1361-1380.

Kreeger, T. J., W. H. Edwards, E. J. Wald, S. A. Becker, D. Brimeyer, G. Fralick, and J Berger. 2005. Health assessment of Shiras moose immobilized with thiafentanil. Alces 41: 121-128.

Kreeger, T. J., and J. M. Arnemo. 2012. Handbook of wildlife chemical immobilization. Fourth edition. Tkreeger3.

Larsen, D. G., D. A. Gauthier, and R. L. Markel. 1989. Causes and rate of moose mortality in southwest Yukon. Journal of Wildlife Management 53:548-557.

Lenarz, M. S. 2007. 2007 aerial moose survey. Wildlife Populations and Research Unit, Minnesota Department of Natural Resources, St. Paul, USA. <http://files.dnr.state.mn.us/outdoor_activities/hunting/moose/moose _survey_2007.pdf>.

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Modafferi, R. D., and E. F. Becker. 1997. Survival of radio collared adult moose in lower Susitna River valley, south central Alaska. Journal of Wildlife Management 61:540-549.

Morrow-Tesch, J., N. Woolen, and L. Hahn. 1996. Response of gamma delta T-lymphocytes to heat stress in *Bos Taurus* and *Bos indicus* crossbred cattle. Journal of Thermal Biology 21:101-108.

Murray, D. L., E. W. Cox, W. B. Ballard, H. A. Whitlaw, M. S. Lenarz, T. W. Custer, T. Barnett, and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. Wildlife Monographs No. 166.

Mytton, W. R., and L. B. Keith. 1981. Dynamics of moose populations near Rochester, Alberta, 1975-1978. Canadian Field Naturalist 95:39-49.

Patterson, B. R., J. F. Benson, K. Middel, K. J. Mills, and M. E. Obbard. 2013. Moose calf mortality in central Ontario, Canada. Journal of Wildlife Management 77:832-844.

Pinheiro, J. C.and D. M. Bates. 2000. Mixed-effects models in S and Splus. Springer, New York.

Renecker, L. A., and R. J. Hudson. 1986. Seasonal energy expenditure and thermoregulatory response of moose. Canadian Journal of Zoology 64:322-327.

Renecker, L. A., and R. J. Hudson. 1990. Behavioral and thermoregulatory responses of moose to high ambient temperatures and insect harassment in aspen dominated forests. Alces 26:66-72.

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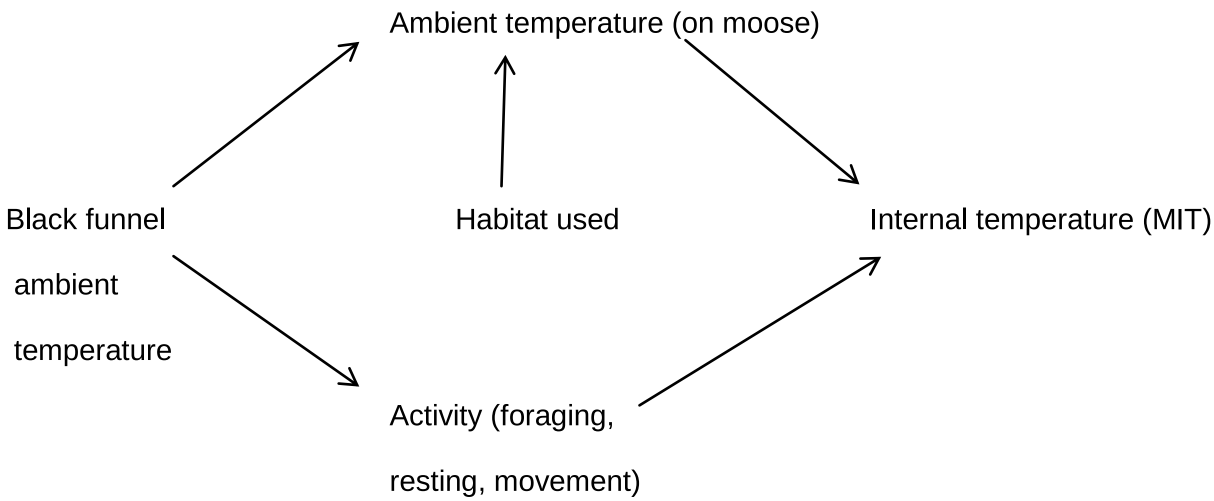


**Figure 1.** Schematic of potential temperature relationships and interactions of variables which may influence fitness (survival and reproductive success) of adult moose (females and males).

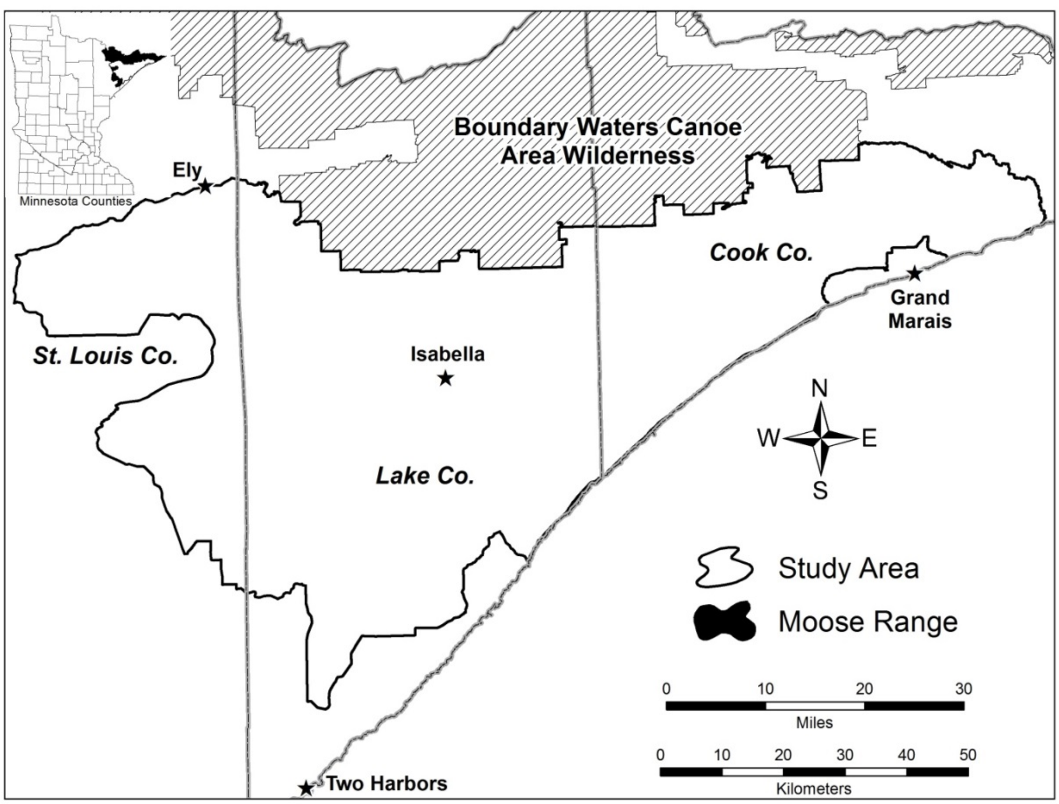


**Figure 2.** Study area for the 2014-2017 ENRT (LCCMR) study examining the potential effect of warming air temperatures on the moose decline in northeastern Minnesota.