Cover Page

Project Title: Identifying Critical Habitats for Moose in Northeastern Minnesota

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Summary/Abstract

Moose are one of Minnesota's most prized wildlife species. In less than 20 years moose in northwestern Minnesota declined from over 4,000 to fewer than 100. The northeastern Minnesota moose population, with over 7,000 moose, may be beginning a similar decline. Higher mortality in radiocollared moose is correlated with warm temperatures. We will use satellite collars to track moose in northeastern Minnesota and collect GPS locations day and night 365 days a year. Specific habitats needed by moose will be identified using the satellite collars. Spatial distribution and availability of habitat types will guide identification of specific sites for enhancement, protection, or acquisition. Development of habitat guidelines will help private and public land managers provide the best possible habitat for moose.

Table of Contents

List of Figures

List of Tables

Rationale and Introduction

During the past two decades, moose density declined dramatically in NW Minnesota, from at least 4,000 to fewer than 100 animals (Fig. 1). Annual moose mortality was high, at 21%, and moose pregnancy and recruitment rates were very low in the late 1990s in northwestern Minnesota (Murray *et al*. 2006). Essentially, Minnesota lost one of two relatively disjunct populations of moose in the state. The precipitous decline in the NW continued even after the cessation of hunting in 1996. Mortality was attributed to poor nutritional condition and parasitism. These health-related issues were correlated with increased summer and winter temperatures (Murray *et al.*, 2006).

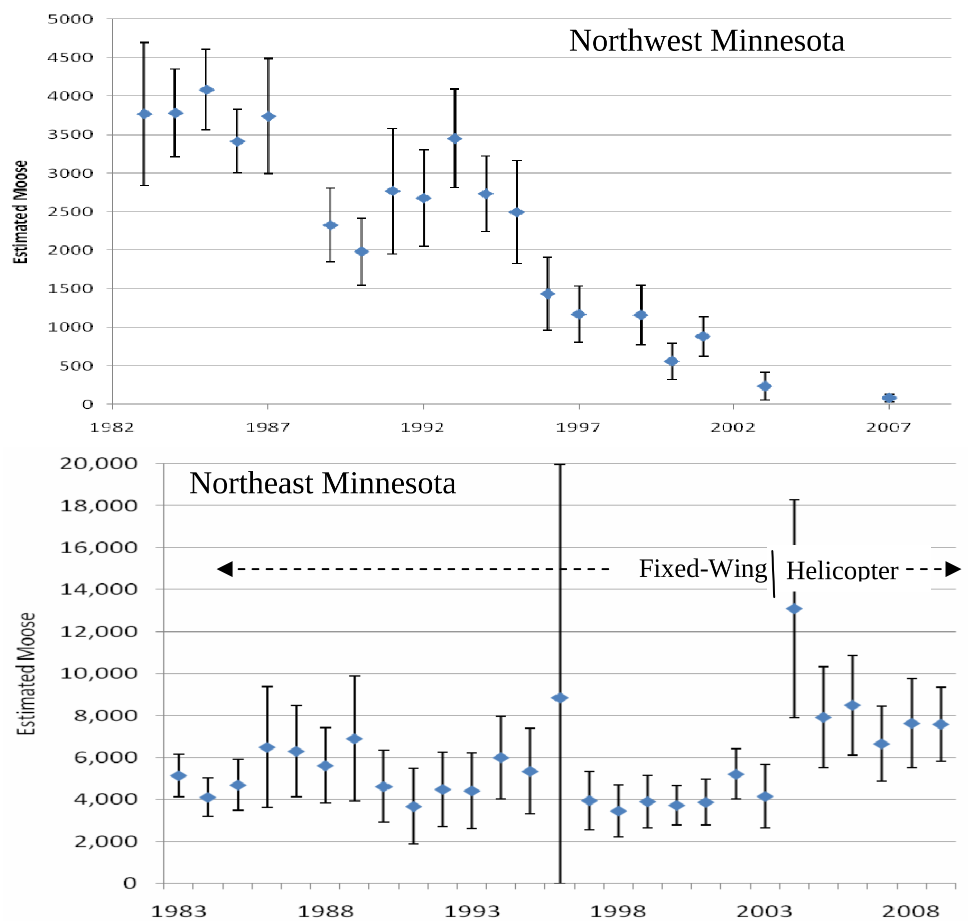

Figure 1. Estimates of the number of moose in the NE and NW MN populations (Lenarz, 2007*a*; Murray *et al.*, 2006). The sharp increase in NE MN moose in 2004 is a statistical artifact. Different methods used from 1985-2004 and 2005-2007 in NE MN mean time periods are not comparable (Lenarz, 2007).

In part because of the decline in the NW Minnesota moose population, moose research and monitoring were intensified in NE Minnesota through a cooperative effort by the DNR, tribal authorities, and federal and academic researchers beginning in 2002. Over 150 moose were radiocollared with VHF collars that could be used to determine home ranges, estimate annual mortality, document reproduction, and improve the aerial survey. Annual mortality of adult moose in the NE was comparable to mortality rates in the NW when the population declined, and there was some evidence of declining recruitment of moose calves. Survival of moose radiocollared in northeastern Minnesota was negatively correlated with ambient temperatures in January and the spring months (Lenarz *et al.*, 2009). Annual aerial surveys in the NE do not indicate a significant population decline (Fig. 1), but high mortality from health-related stressors and a positive correlation between annual mortality and winter temperatures (Lenarz *et al*. 2009) suggest that a temperature-related population decline may be underway or imminent.

Air temperature is not the only factor, however. Despite rising temperatures in the 1990s, moose populations increased in Maine, New Hampshire, Vermont, New York, and Massachusetts (Timmerman 2003). Even data from Minnesota illustrate that the problem is complicated: the moose population in northwestern Minnesota has dwindled to almost nothing since 1990 (Fig. 1), while the population in northeast Minnesota was stable until 2003 and may have declined since then (Lenarz *et al.*, 2009). North Dakota moose populations show a similar inconsistency, the population closest to the NW MN moose population is declining while 2 other populations in ND are stable or increasing (Maskey & Sweitzer, 2006). Aerial surveys of moose in Ontario adjacent to VOYA showed a decline between 2000 and 2003 (Hilborn, 2004).

Moose Response at Individual Level to Landscape and Climate

Moose are able to survive under very cold conditions (Kelsall & Telfer, 1974), can be heat-stressed in winter at temperatures above 0^{o} C, and can be heat-stressed in summer at temperatures of only 15-20^{o} C (60-70^{o} F) (Renecker & Hudson, 1986). It is rarely possible to directly monitor activity of free-ranging moose, but it is possible to indirectly measure activity and habitat selection patterns with GPS telemetry collars. Activity counts recorded by the collar are correlated with moose behaviors (Moen *et al.*, 2001). Smaller collars with activity counters have been used recently on Canada lynx (*Lynx canadensis*) in NE MN from 2003-2006, these collars record activity counts at 5-minute intervals throughout the day (Moen *et al.*, 2006).

GPS collars provide location (cover type), time, ambient temperature, and activity simultaneously in all weather throughout the day and night. GPS collar locations are precise (3-7 m) and GPS collars have been successfully deployed on moose in Ontario, Quebec, Alaska, and in VOYA (Rempel *et al.*, 1995); Moen *et al.*, 1996; Moen *et al.*, 2001; (Dussault *et al.*, 2004). After data are downloaded from the collars the locations are linked to cover type using GIS analyses.

In this research project we will deploy GPS collars on moose in NE MN to evaluate changes in habitat use and activity as related to fine-scale changes in ambient temperature. Moose GPS collar locations will be the link we use to understand how cover types are used differentially as ambient temperature increases. The proposed research will address several research recommendations made by the Moose Advisory Committee (Peterson et al. 2009) convened by the Minnesota DNR to make recommendations for future moose management in Minnesota. These recommendations include improving habitat, developing best management practices for habitat management, and increasing understanding of factors affecting moose populations.

Objectives

Our basic approach is to estimate habitat use and activity from GPS collars deployed on moose, and to measure the thermal environment in areas used and not used by moose. Specific hypotheses to be tested based on the LCCMR proposal are listed below. Other testable hypotheses will emerge as we analyze data after the first year, and from the results of additional work with partners and collaborators. These other hypotheses will be non-habitat related (e.g., blood chemistry).

1. Fine scale habitat use hypotheses to be tested:
   - H_1: Moose will selectively use specific cover types (e.g., wet bog) as a thermal refuge when ambient temperatures are high.
   - H_2: Moose activity and movement rate will decrease under higher ambient temperatures, and will shift to be nocturnal rather than diurnal at the highest summer temperatures (Dussault *et al.*, 2004).
   - H_3: No preliminary data exists but we will also test for changes in moose activity and movement rate in the winter when temperatures are higher than normal. This hypothesis could lead to a mechanism for the observed correlation between higher winter temperatures and moose mortality later in the year (Lenarz *et al.*, 2009).
   - H_4: Annual mortality rates will be consistent with regression predictions (Lenarz *et al.*, 2009) of higher mortality rates when there are higher winter temperatures.
   - H_5: Cover types selected by moose will have lower operative temperatures than adjoining vegetation types that are not used in hot weather (DeMarchi & Bunnell, 1993);(Dussault *et al.*, 2004).

H_6: Temperature, wind, and humidity conditions can predict movements into or out of habitat types.

H_7: Temperatures measured in specific cover types and locations used by moose during warm and hot weather periods are consistent with habitat-based thermal refugia.

2. Coarse scale hypotheses testing consistency in time using previous VHF telemetry study

   H_8: Size of home ranges will be similar between previous VHF telemetry study and this project

   H_9: Cover type composition of moose home ranges in ENRTF project will be similar to home ranges of moose wearing VHF collars in NE MN.

Hypotheses 1 to 9 are all part of the overall goal of developing Habitat management guidelines and best management practices (BMPs) for moose. Fine scale hypotheses (1-7) use GPS locations from radiocollared moose to test the immediate response of moose to warm weather events. Through analysis of GPS locations, activity, temperature, cover types, and home ranges, we will develop and quantitatively describe the spatial context within which moose in NE Minnesota are able to survive and reproduce. This spatial context will be used to develop the range of possible values for BMPs considering cover type composition and the spatial arrangement of cover types within a home range.

Coarse-scale hypotheses ensure that the large-scale patterns in home range composition are consistent between the VHF telemetry project in northeastern Minnesota and this new GPS collar project. It is not possible to use results from the previous VHF telemetry project to address fine-scale hypotheses.

The list of hypotheses above will enable us to develop habitat management guidelines and BMPs for moose presented in the work plan. Additional research questions and hypotheses will be tested during this project. For example, necropsies on dead moose will continue to be done, and the use of satellite GPS collars will enable us to reach mortalities much quicker than was possible in the past. Another example is evaluation of blood and feces collected during moose captures. Collaborators with the MN DNR Wildlife Health Program will enable standard blood chemistry profiles and testing for some diseases.

We have presented the hypotheses above as if the ENRTF satellite GPS collar project were stand-alone, but concurrent research projects in Voyageurs National Park and on the Grand Portage Indian Reservation using the same methods will strengthen and complement all results from the ENRTF project. The

Voyageurs National Park and Grand Portage Indian Reservation projects essentially double the sample size of satellite GPS collared moose against which fine-scale hypotheses (1 to 7) can be tested.

Methods

Study Site Location. Moose will be radiocollared in the area of moose distribution in the southern part of the moose range (Fig. 2).

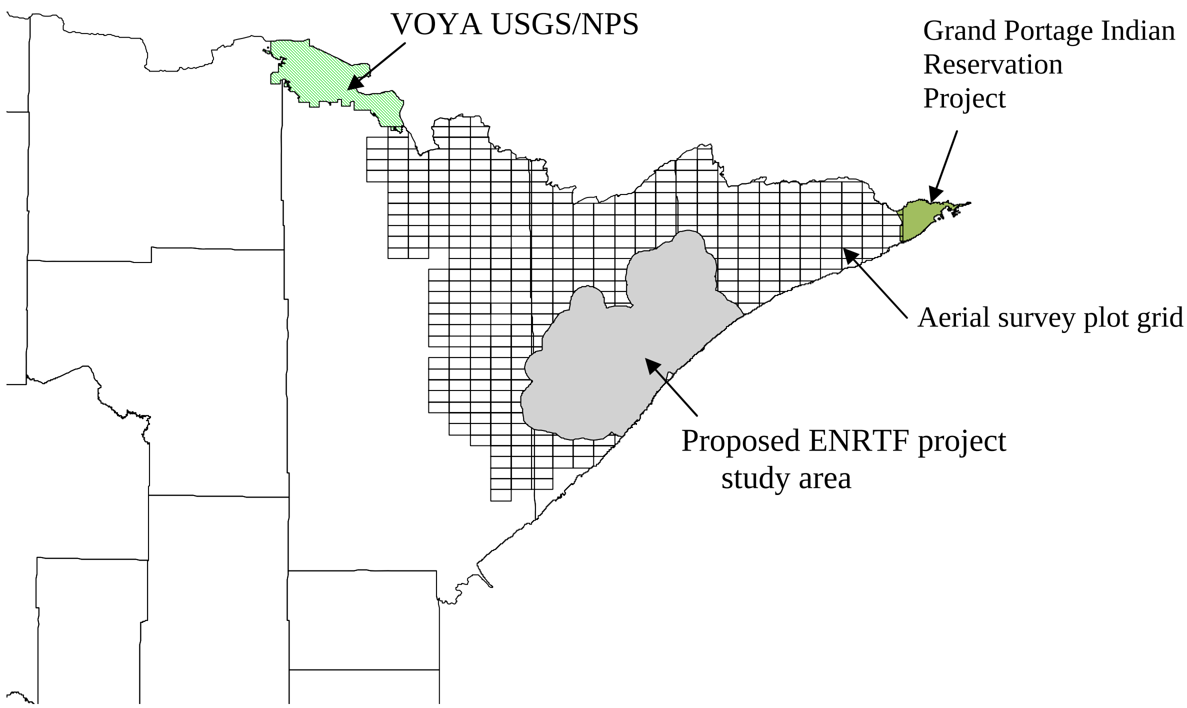

Figure 2. Study site location. The proposed ENRTF GPS collar project study area is based on home ranges of moose in the ongoing VHF collar study. This VHF study in the southern portion of moose range provides baseline data on home range size and mortality from 150 moose with VHF collars. We may expand study site into the Gunflint Trail area, east of the Grand Portage Indian Reservation Project.

GPS radiocollars. In January of 2011 and in January of 2012 we will capture up to 24 moose by aerial darting or net-gunning following protocols used by the NE MN moose project from 2002-2007, and the current work in Voyageurs National Park and on the Grand Portage Indian Reservation. We will collar both bulls and cows. Moose will be anesthetized by aerial darting (Kreeger *et al*. 2002; (Gogan *et al.*, 1997) or manually restrained when captured with a net gun (Carpenter & Innes, 1995). In each year we will program collars to obtain locations every 15 minutes and recover collars in the following winter.

Collars will record about 35,000 locations from each radiocollared moose in each year. Collars will also record temperature and activity at one minute intervals.

Collars will have a satellite upload link, and each day will automatically upload the most recent GPS collar locations to the Argos satellite system. We will obtain uploaded GPS locations from the satellites each day and use locations (over the past ~4 – 5 hours) and GPS signal patterns to determine if each collared moose is alive. This daily download of GPS locations will enable deployment of temperature loggers in locations that are used by moose, and adjacent areas not used by moose (see below).

Moose will be recaptured in 2012 to change collar batteries, download data, and reaffix collars. Collars deployed in 2012 will have a timed drop-off, eliminating the need to recapture moose the following year.

Blood and Fecal Sample Collection. We will collect blood and fecal samples to assess condition and pregnancy following methods described in Murray *et al*. (2006). Results will be directly comparable to analyses of blood and fecal samples from 150 moose captured in NE MN for a VHF collar study because the same methodology and analyses will be conducted. We have discussed the protocols and data-sharing issues with Dr. Erika Butler, MN DNR Wildlife Veterinarian. We will also discuss the possibility of using a portable ultrasound to measure body fat reserves with Dr.Glenn DelGiudice (MN DNR). Trade-offs to consider will be the additional time required to take measurements against the value of the information gained.

Detecting and Responding to Mortalities. With the satellite upload of locations daily we should be able to respond to moose mortalities within 24-36 hours. We will download satellite locations daily and will have personnel available to respond to mortalities immediately. This approach is faster than any alternative method to rapidly respond to moose mortalities, except for methods that are not logistically feasible, such as flying and listening to signals every day.

GIS Analysis. Home ranges will be calculated for all moose using ArcView and the Animal Movement extension (Hooge & Eichenlaub, 2000) or another home range software package. We will use ArcMap and ArcView to determine cover type use from two classified LandSat images from the mid-1990s which have been successfully used in a Canada lynx GPS collar project in NE MN (Moen *et al.*, 2006; Burdett *et al.*, 2007; McCann, 2006). These classifications have an overall classification accuracy rating of over 80%. We will use analysis of aerial photos taken in recent years (2004 – 2008) to detect changes (primarily harvest) that has occurred in areas moose are using. In addition, we have available a time-series of classified LandSat images (1985, 1990, 1995, 2000) that could prove useful for predictive purposes (Pastor *et al.*, 2005). Our experience with the work on Canada lynx is that using 2 or more independently-derived satellite image classifications that give consistent results leads to improved support for habitat use conclusions.

Temperature loggers. The GPS collar locations of moose indicate what cover types are being used during hot weather (and other weather conditions as well) but do not tell us why. In preliminary testing under other funding, one of Moen's Graduate Students (Amanda McGraw) has been measuring operative temperatures in different cover types within the proposed ENRTF study area. HOBO pendant temperature data loggers were programmed to take a temperature measurement every five minutes from June to October 2009 in aspen, wet bog, conifer, and mixed cover types. Data loggers were placed in copper bulbs painted black to act as black globe thermometers (Ackerman 1987) and placed 75 cm above ground level, representing the shoulder height of a moose while lying down. Despite using random locations within these cover types (vs. GPS collar locations from moose) we detected significant differences in temperature among these cover types in 2009.

We will use wind and humidity data from NWS stations in and near collared moose areas. It is not feasible to obtain data in the field for the extended duration of the project because of the wide range that moose will be collared in. This requires an assumption that wind and humidity conditions can be interpolated between weather stations, and will test this with portable weather stations

Analyzing Available and Used Habitats. Analyzing use and availability of habitats is intuitively simple, but there are disagreements in the peer-reviewed literature on measuring and statistically testing for preference of specific habitats. There are seven characteristics of the GPS collar data set we will obtain that improve our ability to detect habitat selection and use in a manner which has been impossible in the past:

1. Number of locations. For moose that survive the entire year, we will have about 35,000 locations with a precision on the order of meters. The sheer number of sample points increases confidence that significant results are not the result of unusual behavior. We avoid psuedoreplication (Hurlbert, 1984) by the next characteristic.
2. Treating individual animal as experimental unit. We will use the individual animal as the experimental unit, rather than GPS locations. Thus, when testing for habitat use, the question

being addressed is not whether all GPS locations indicate preference, instead we ask whether individual moose are showing the same preferences.

3. Trends across gradients. With the large number of locations, we can test for differences in cover type selection driven by larger scale factors such as temperature. For example, we will compare cover types used by each moose when temperatures are 20º C and 30º C in summer. If each moose shows a similar response by increasing use of a cover type such as Wet Bog when temperatures are 30 º C, this supports the hypothesis that the temperature gradient can be used to predict changes in cover type use by moose.
4. Additional supporting data. Activity counts can be used to indicate if moose are active or inactive in each cover type at different temperatures. Another type of data that can be used as supporting information is the distance moved since the last location when moose are active. For example, if movement rates are reduced whenever hot temperatures occur, this is an indication that moose may be heat stressed at some threshold temperature.
5. Independent supporting information from temperature loggers. Temperature loggers deployed in locations used by moose (from GPS collars) will enable us to estimate the range of temperatures a moose can experience based on microsite level habitat selection. As indicated above, we detected differences in temperatures in random locations in 2009 in cover types used by moose. We would expect differences in temperature at locations selected by moose if high air temperatures affect choice of bedding locations.
6. Repetition across years. Data collected from year 1 will be used to generate predictions on cover type use that can be tested with GPS data collected in year 2.
7. Repetition across sites. As indicated above, the independent but identical project in Voyageurs National Park and Grand Portage provide additional support for any conclusions drawn on the ENRTF project when results are consistent.

Recent advances in technology with GPS collars and activity sensors will enable us to obtain a more accurate understanding of moose habitat use and responses to temperature than has been possible.

We will also use traditional methods to evaluate habitat use by moose. Three general experimental designs to detect habitat selection are use-availability, site-attribute, and demographic response (Garshelis, 2000). The GPS collar data fits a use-availability design. For example, we would compare the number of locations in the Wet bog cover type relative to the amount of the Wet bog cover type available in a home range. Because of the large number of locations from the GPS collars (about 35,000 locations per moose in each year), we will be able to identify trends in proportions of cover types used at different temperatures. As described above, an increasing number of locations in the Wet bog habitat at higher temperatures would indicate that moose are changing behavior as temperature increases and selecting for wet bog.

The use-availability design identifies habitats that are selected for, but it does not directly indicate why a habitat might be used, which is what the site-attribute design can address. The temperature logger data fits a simplified site-attribute design because it can test for the physiological basis for selection of cover types in response to rising temperatures, with the over-riding hypothesis being that there will be a detectable response by moose to changes in temperatures at the level of satellite-derived cover types.

For use-availability analyses, we will determine available cover types at two spatial scales: 1) those within individual moose home ranges and 2) all cover types within a minimum convex polygon containing the home ranges of all individual moose (Cobb *et al*, 2004). We will also use standard ratios of habitats used:habitats available to interpret individual moose use of different cover types. Finally, we will be able to use compositional analysis to detect differential cover type use by moose between seasons and between temperature ranges with >10 individuals per group (Aebischer *et al.*, 1993).

The experimental design does not have adequate sample size or a long enough duration to use the demographic response analysis. While we believe the demographic response design would be desirable, it is practically impossible to implement at the scale of funding of wildlife studies. Thus, we need to use indirect methods to infer a demographic response rather than direct methods to test for a demographic response.

Statistical Design and Analysis. From a generic experimental design perspective the approach we have taken considers moose biology, sample size issues, VOYA specific limitations, technological limitations and abilities of GPS collars, and other factors. The specifications for data collected from each experimental unit (moose) are straightforward:

1. Deploy GPS collars on enough moose to retain a sample size of at least 10 animals given maximum natural mortality rates observed in the VHF telemetry study in NE MN.
2. Collect locations as frequently as possible given battery power limitations (15-minute resolution)
3. Collect activity data simultaneously at 1-minute resolution
4. Collect ambient temperature data simultaneously at the same 1-minute resolution
5. Deploy temperature dataloggers in sites used by moose and adjacent control sites
    a. Temperature datalogger sampling resolution same as GPS collars

The data set from GPS collars and dataloggers meeting these specifications could be analyzed multiple ways. For example, a previous reviewer mentioned developing Resource Selection Functions as a possible analytical method. We have reviewed papers using the RSF approach, one of Moen's graduate students explored the technique for his dissertation, and we will consider this approach to analyze the ENRTF moose data. Another possibility is using conditional logistic regression, applied to GPS telemetry data on Canada lynx by Moen's student (Burdett 2007). A third possibility is to use a Euclidean distance-based analysis method for the habitat-use analysis (Conner and Plowman 2001, Conner *et al*. 2002), recently used for Canada lynx (Vashon *et al*. 2008) and Indiana bats (Menzel *et al*. 2005). We believe other statisticians could identify other methods to analyze the new ENRTF moose data set, and this project could even lead to development of new statistical testing methods for telemetry data on free-ranging animals. In this section we list some of the statistical tests we will use for hypotheses listed above (Table 1), but would like reviewers to keep in mind that there are alternative methods that we will explore in consultation with statisticians prior to our data analysis. One reviewer suggested that Dr. John Fieberg, MN DNR statistician, would be a valuable resource. We will consult with Dr. Fieberg and bring him into the project to the extent possible. This is logical since one of us (Lenarz) is with the MN DNR.

One important aspect of the proposed work is data redundancy. Even though we will be collecting locations at 15-minute intervals, and we will be collecting activity and temperature data at 1-minute intervals, we do not necessarily need to use data at this resolution to test hypotheses regarding habitat use. The cost of data redundancy is negligible to a moose – collars are 0.525% of body mass with the additional D cell, compared to 0.500% of body mass with 1 less D cell. Yet compared to data collection 20 or even 10 years ago, we now have almost a continuous data set to work with that we can select locations from to test specific hypotheses. This simple experimental design could lead to a paradigm shift where we can use a data set to test multiple questions. One example could be a spectral analysis on the activity count data. We have no plans to do a spectral analysis, but the cyclic nature of moose behavior (feed, ruminate, feed, ruminate, …) might be addressed usefully with spectral analysis. This is another example of why we only provide example statistical tests to illustrate what could be done with the data.

Table 1. Statistical tests to use for each hypothesis.

Hypotheses	Question	Statistical test and brief description
1, 7	Habitat selection	χ^2 test followed by multiple comparison of proportions in 2-row contingency table (Zar 1999). We will also test the suitability of compositional analysis (Aebischer *et al.*, 1993).
2, 3	Activity	Within moose: ANOVA on activity level by temperature Among moose: test for consistent results for each individual.
5	Operative temperature and cover type	Repeated measures ANOVA on operative temperature among cover types with temperature loggers in each cover type.
6	Cover type use across temperature gradient	Logistic regression with temperature as the independent variable and cover type use by moose as the dependent variable.
8	Home range size	ANOVA with collar type (VHF or GPS) as factor
9	Cover type of home range	ANOVA with location, and cover type as factors

Additional Possible Research Projects. There are some other possible research projects that we will try to implement, taking advantage of GPS collar locations. These projects in some cases were suggested by reviewers, and in other cases might be based on what we learn from the GPS collars. The new projects are beyond the scope of the original proposal, and we will try to acquire additional funds to implement them.

For example, one reviewer suggested measuring browsing intensity by moose. Measuring browse consumption is a time-intensive process, but because we will have activity data from these collars, and will know where moose are foraging, we will include some browse measurements to the planned field work. We will also attempt to acquire additional funding to increase the amount of browse measurements we can do. Moen just submitted a project to the Great Lakes Restoration Initiative to measure moose browsing that could be done on GPS collared moose within the Lake Superior Watershed.

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