Research Addendum for Peer Review

Project Manager: **James D. Forester (jdforest@umn.edu)**

Impacts of forest quality on declining Minnesota moose.

Project number: **014-A**

Submitted by:

James D. Forester

Dept. of Fisheries, Wildlife, and Conservation Biology, UMN

David L. Fox

Dept. of Earth Sciences, UMN

Anthony D'Amato

Dept. of Forest Resources, UMN

I. Abstract: The Minnesota moose population is declining dramatically and has become a growing concern for conservation. In addition to being an iconic species of northern Minnesota, moose are keystone herbivores that are an important component of Minnesota's forested ecosystems. The specific mechanism causing their rapid decline has not been fully uncovered because many factors affect how well moose survive and reproduce. Ultimately, the most important tool available to natural resource managers is their ability to manipulate the spatial distribution and diversity of high-quality habitats (Figure 1). Management decisions will clearly benefit from scientific guidance to ensure manipulations have maximum impact on stabilizing the moose population in Minnesota.

The Minnesota Department of Natural Resources (MNDNR), the Grand Portage Band of Lake Superior Chippewa (GPBLSC), and the University of Minnesota began a moose tracking effort in 2013 to determine cause-specific mortality within the moose population (128 GPS collars were deployed). In addition, Dr. Ron Moen (NRRI) is working on a moose habitat restoration project in which he is assessing how food availability, quality, and consumption by moose changes in forests with different disturbance histories. We propose to build upon both of these LCCMR-funded research projects to explore how the landscape context in which individual animals live can directly affect the animals' diet and their subsequent body condition and mortality risk. Understanding how forest age, structure, and composition can affect the distribution of food and cover (and thus impact the movement patterns of moose) is critical to inform broad-scale management efforts that are aimed to improve the forest landscape for moose and thus stabilize the population.

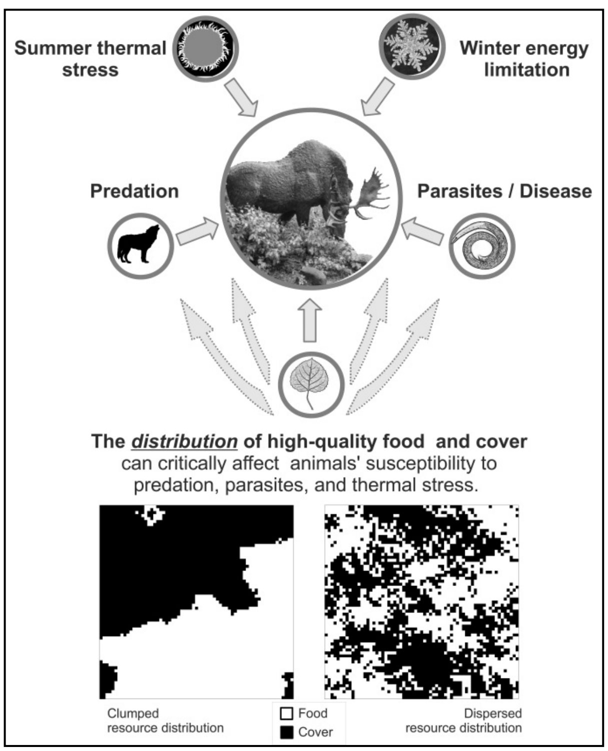

Figure 1: The amount and arrangement of important habitat may affect moose survival.

II. Background: Understanding how both the distribution and abundance of animals change in space and time is a central goal of ecology and wildlife management (Andrewartha and Birch 1954, Wiens 1976). However, conventional demographic and habitat-selection models may not be strongly predictive of future species distributions and population dynamics because these models do not account for how animals will respond to the novel landscapes and new environmental conditions that are expected to arise from changes in climate and human land-use (Parmesan and Yohe 2003). Given these non-equilibrium circumstances, predictive models require a mechanistic understanding of how animals interact with landscapes, and how this interaction can feed back to affect population distributions and demographic rates. A key component of this understanding is how the movement process affects the survival and fecundity of individual animals.

The link between movement behavior and population dynamics is emerging as a critical area of ecological research (Fryxell et al. 2005, Haydon et al. 2008, Revilla and Wiegand 2008); however, making this link is difficult because spatially-explicit movement data are rarely tied to demographic parameters (Nathan et al. 2008, Morales et al. 2010). This is further complicated by the fact that there can be a large degree of individual variability in movement behavior (Forester et al. 2007). This variation may simply be the result of individual animals behaving optimally in different landscapes (MacArthur and Pianka 1966, Charnov 1976); however, variation is expected even within the same landscape because some animal behavioral patterns are learned (Andersen 1991, Fleming et al. 2002), while others are a product of evolutionary processes (Réale and Festa-Bianchet 2003, Wolf et al. 2007). As landscapes and climates change, this variability may be a key factor in population persistence, especially for populations that are near the edge of the bioclimatic range of their species. This raises the question of whether movement behavior can mitigate the physiological effects of persistently high temperatures while allowing for efficient foraging patterns in spatially heterogeneous and temporally dynamic landscapes.

Moose Population Decline: In the upper Midwestern United States, moose populations are quickly becoming a focus of conservation concern. Moose are keystone herbivores that can exert a strong influence on ecosystem structure and function (e.g., Kielland et al. 1997, Moen et al. 1998, Pastor et al. 1998, Kielland and Bryant 1998, Persson et al. 2005); however, the species has been declining in many areas near the southern limit of its range. The moose of Minnesota have existed as two non-contiguous populations since the 1970's (Lenarz et al. 2009), but the northwestern population, which has been closed to hunting since 1996, has been in precipitous decline since the mid 1980's with recent surveys estimating less than 100 individuals remaining (Murray et al. 2006, Lenarz 2007). During much of this period, the northeastern population remained relatively stable; however, over the last eight years the population has decreased from an estimated 8,160 to 2,760, a decline of well over 50% (Lenarz 2012). Further, the mortality rates of radio-collared moose in northeastern MN has recently approached that previously observed in the northwestern population and therefore is cause for serious concern (Lenarz et al. 2010, DelGiudice et al. 2011).

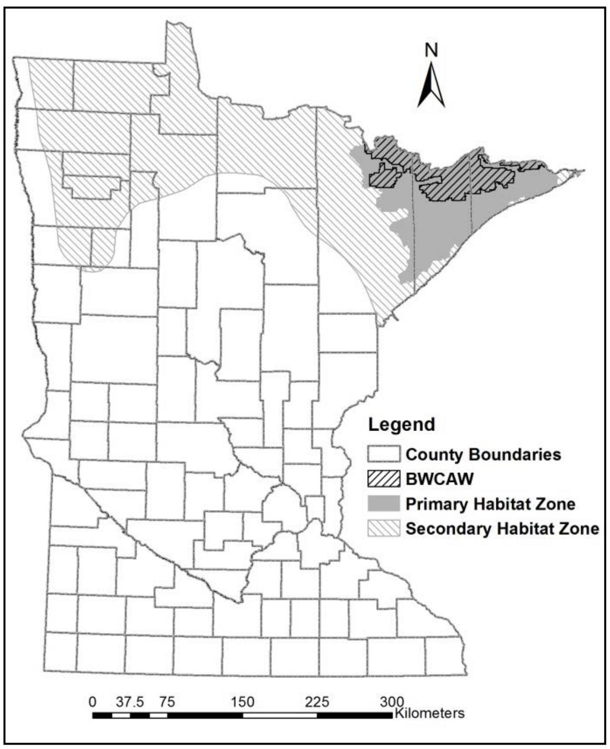

Figure 2: Moose Habitat Zones in Northern Minnesota. Primary habitat zone data (circa 2010) courtesy of Minnesota DNR Data Deli. Secondary habitat zone adapted from Moose Advisory Committee (2009).

While investigating the decline of moose in northwestern Minnesota, Murray et al. (2006) found that the principal cause of the population reduction (among deer-borne pathogens, habitat loss, intra- and interspecific competition, hunting, predation, malnutrition and temperature) was summer heat stress that led to malnutrition and immunosuppression (possibly leading to increased susceptibility to parasites such as liver flukes, *Fascioloides magna*).

Temperature has also been implicated in the decline of the northeastern population (Lenarz et al. 2010); however, the specific mechanism by which temperature impacts demography has not been shown. The upper critical temperature of moose (i.e., the temperature at which moose experience increased metabolism, along with increased heart and respiration rates) is approximately 14° C in the summer and -5° C in the winter (Renecker and Hudson 1986). Energetic costs increase with ambient temperature, and in extreme cases (~ 20° C in the summer) moose begin to pant in an effort to expel excess heat (Renecker and Hudson 1986, Renecker and Schwartz 1998). Moose will seek thermal refuges and alter their movement patterns as ambient temperature increases (Schwab 1991, Dussault et al. 2004); however, this response may be scale and context dependent (Lowe et al. 2010, van Beest et al. 2011). When animals forego feeding bouts in lieu of bedding in shade (Renecker and Hudson 1989), they miss foraging opportunities that are difficult to make up and are expected to lose body weight (Renecker and Hudson 1992). This behavior indicates that moose should select for landscapes that have high interspersion of habitats that provide food or cover.

III. Hypotheses

Our *broad aim* is to link the behavior, diet, and survival of moose to the spatial distribution of food and cover. Our team will build upon existing moose research in the state to address two primary *research goals*:

1) *Regional Scale*: Link regional patterns of moose abundance through time to the geographic distribution and relative forage quality of different land-cover types and forest stand ages.

H1.1 Broad-scale changes in the *abundance* of important cover types (e.g., young and mature forest, wetlands) measured at the level of four townships or larger will not be linked to changes in moose abundance.

H1.2 Broad-scale changes in the *arrangement* of important cover types will be linked to changes in moose abundance. Areas dominated by one cover type (e.g. young forest) will be avoided while areas that contain a mixture of cover types that provide reduced distances between thermal cover and high quality forage will be selected for by the moose.

2) *Local Scale*: Determine if the distribution of resources affects the diet of individual moose and whether dietary differences among animals are associated with variation in body condition or mortality risk.

H2.1 Diets of individual animals will reflect the forage available to them within their home range area.

H2.2 Animals that live in areas with lower quality forage or larger distances between food and cover will have lower body condition and be more susceptible to mortality.

IV. Methodology

<u>Activity 1: Linking moose abundance to broad-scale distributions of food and cover that change across space and through time.</u>

Overview: We will use a combination of USFS Forest Inventory and Analysis (FIA) data and Landsat satellite data (both collected repeatedly over the last 13 years) in conjunction with data from the MNDNR moose survey to examine how the moose population has responded to changes in distributions of resources across its range in NE Minnesota. By revisiting 61 plots we established in 2012, we will characterize the forest communities that represent a range of cover types and known disturbance histories (these sites will complement sites established for the forage quality project led by Dr. Ron Moen). We will relate these community results to land-surface attributes (e.g., soil type, aspect, land cover) and report whether coarse distributions of food and cover are correlated to local estimates of moose abundance – this will directly aid forest management planning.

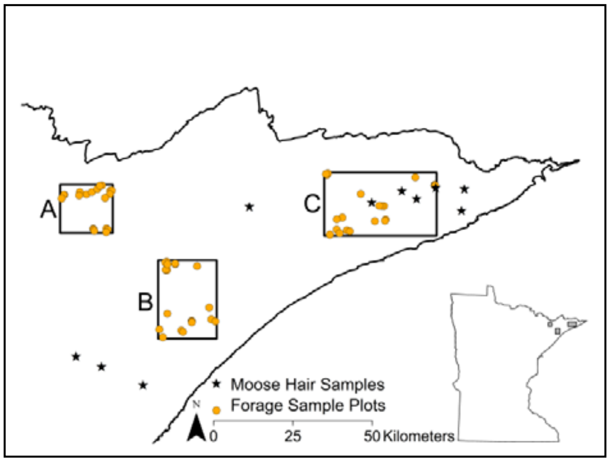

Figure 3. Proposed study area. Boxes indicate stratified sampling regions where preliminary plant samples were collected in June, 2012. Stars indicate locations of preliminary moose hair samples, yellow dots are plant sampling plots

Analysis of FIA and Satellite Data: The USDA Forest Service Forest Inventory and Analysis (FIA) unit gathers data from 1,258 permanent sample plots within Minnesota's primary moose habitat zone (Figure 2) over a 5 year cycle. The current annual inventory began in 1999, with one-fifth of the field plots measured each year. The first full sampling cycle was completed for the 2003 inventory year. Thus, FIA data are an average of conditions over the reporting year plus the previous 4 years. Each FIA plot includes 4 subplots covering 0.0415 acres per subplot (O'Connell et al. 2012). For the cycle ending in 2011, there were 224 FIA plots in the primary moose habitat zone with a non-forested condition code. Of these plots, 92 occurred on non-forested land (152,675 acres), 132 fell on open water, i.e. census and non-census water bodies (348,271 acres), and 37 others were not sampled for various reasons. The FIA database provides numerous variables that can be related to feeding habitat and thermal cover for the moose population. Some of these variables include: amount of young forest (especially aspen and willow) present (Peek et al. 1976, Franzmann and Schwartz 2007), size and/or age class of trees present, forest type and/or species present, tree density/stocking level, and presence/absence of disturbance/harvest events. We will examine data from the 2012 FIA database (Microsoft™ Access version; Miles 2011) in addition to time series of classified Landsat images (classified following the methods of Wolter and White 2002). The FIA data will be analyzed using geographic information system (GIS) techniques described by Miles (2008) to examine differences in the amount and types of habitat available to the moose population in different survey zones. The Landsat data will be analyzed using Fragstats (McGarigal et al. 2002) and texture statistics (St-Louis et al. 2006). The results of these two analyses will then be compared with the relative abundance of moose on plots with differing habitat characteristics. We will focus our initial effort on comparing the endpoints of the time series and then examine trends observed at finer temporal grains.

Plant community sampling. To model the distribution and abundance of preferred forage species in different land cover types, we will make use of an existing network of 61 sites that we established in a range of cover types throughout the moose range (Figure 3). Our sampling methodology is adapted from previous studies in Superior and Chippewa National Forests. Each monitoring stand will contain three 11.3-meter radius circular plots ($400m^2$), located randomly within the stand boundary. Plot centers will be recorded with a GPS unit and monumented with a labeled 60cm length of pvc pipe and small rebar stake. The following metrics will be measured:

- **Overstory tree data**: Record species and diameter on all trees ≥ 2.5cm dbh (1.37m) within 11.3m radius plot.
- **Large sapling/shrub data**: Record species and diameter class at 15cm above ground for woody stems taller than 1.37m but < 2.5cm dbh. Diameter classes are 3, 5, 7, 9, 11, etc. to 29mm+. Plot size is 4m radius ($50m^2$), and nested inside overstory plot with same center.
- **Small sapling/seedling data**: Seedlings (<15cm height) and small saplings (15cm<height<1.37m) of woody species will be tallied by species on six $1m^2$ quadrats located 5m and 10m from plot center at 0, 120, and 240 degrees. The southwest corner of each quadrat will be monumented with a stake/stake whisker.
- **Mineral soil data**: One soil core (4 cm diameter) will be taken to 10cm depth in the center of the herb clip plot, 6m from plot center at 0 degrees (removing herbs/forest floor before sampling mineral soil). Depth of the A-horizon in the sample will also be recorded.
- **Forage Quality**: As part of a related project (in collaboration with Dr. Ron Moen from NRRI), we will analyze the nutritional quality of forage samples by measuring neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin content, tannin concentrations, and calorie and mineral (i.e., ash) content.

We will initially use linear mixed-effects and multivariate models to explore how the distribution and abundance (i.e., biomass) of forage varies among stand types and as a function of abiotic characteristics (slope, aspect, soil type, etc.). Following a similar approach, we will use the forage quality data to understand how the nutritional quality of forage species changes seasonally in different cover types throughout NE MN. We will then spatially extrapolate these results as functions of land-surface attributes (e.g., aspect, land cover) using Bayesian co-kriging (Banerjee et al. 2003) and test whether coarse patterns of land cover and forage availability / quality help to explain local estimates of moose abundance.

Moose population estimation: The MNDNR estimates moose population numbers by flying transects within a stratified random sample of survey plots each year (Figure 4). Stratification classifies individual survey plots as low, medium, or high moose density, with a fourth stratum corresponding to recently disturbed plots. All survey plots are rectangular (5 x 2.67 mi.) and all transects are oriented east to west. Visual obstructions (e.g. trees) limiting the sightability of moose are accounted for using a sightability model developed by Giudice et al. (2012) through analysis of how frequently radio collared moose were observed under different vegetative conditions; this survey methodology was adopted in 2005.

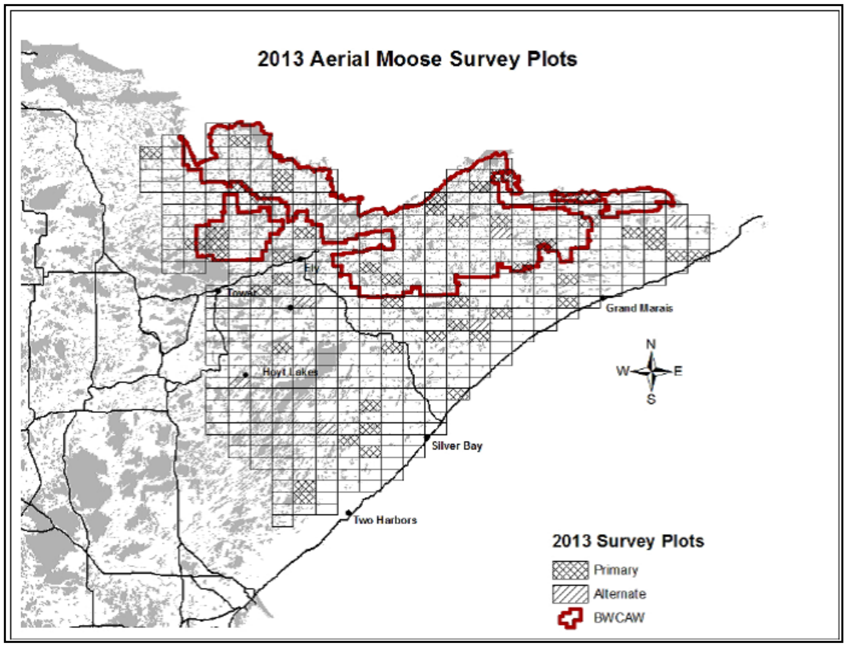

Figure 4. Northeast moose survey area and sample plots (cross hatching) flown in the 2013 aerial moose survey (DelGiudice 2013).

The current study will group moose survey plots into blocks of approximately 8-12 plots in order to capture a sufficient number of FIA inventory plots and surveyed moose plots for reasonable statistical accuracy. Because each FIA plot represents approximately 1,660 acres of forestland on the ground, we expect to capture data from about 60 forested FIA plots on a fully forested block of 12 moose survey plots (approximately 160 square miles or 102,400 acres). In reality, not all area within the moose survey plots is forested, so the actual FIA sample size for each block of moose plots will be less than 60. Based on research by Cobb (2004) indicating that the average moose home range size in northern Minnesota is 37.3 km^2 or 9,316 acres, each block of moose survey plots would encompass an area which could host roughly 10 non-overlapping moose home ranges. While the existing population estimation model was designed to provide a region-wide population estimate, we will collaborate with the MNDNR researchers to refine the model so that it will allow for finer-grained analysis. This approach may require us to make relative rather than absolute predictions of local abundance; however, it will be sufficient to determine if there is spatial variation in local moose population trends and whether this variation is linked to landscape characteristics.

<u>Activity 2: Linking the distribution and quality of food and cover to moose diet, body condition and mortality risk.</u>

Overview: We will use stable isotope analysis to determine how the distribution of food and cover affects diet and whether individual movement behavior (measured as variation in resource selection and movement rates) allows some individuals to have higher quality diets in landscapes with lower quality habitat. Using the biomass results from the plant community analysis in Activity 1 and a separate forage quality analysis (conducted in collaboration with Dr. Ron Moen, NRRI), we will be able to estimate seasonal changes in how the quantity and quality of forage are distributed across the landscape. By analyzing the carbon and nitrogen isotopic ratios of moose body tissues collected at capture and after death, we can assess individual moose diet and habitat use on timescales from several weeks to several years. We will combine these data with GPS locations of the same animals to test if the moose are eating what is available to them (i.e., do moose eat forage species in proportion to their availability, or do they make fine-scale bite selections). This will allow us to determine the degree to which landscape context (e.g., the abundance, spatial distribution, and biochemical signature of land-cover types within an animal's home range) is driving the movement pattern and diet of the animal. We will then determine if dietary differences among individuals can explain variation in mid-winter body condition or mortality risk. These results will provide suggestions on how to change forest management to benefit moose.

Stable isotope approach: Variations in the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope composition of plants within ecosystems are recorded in the composition of consumer tissues with characteristic offsets or enrichments (Deniro and Epstein 1981), and the use of stable isotopes to track variations in diet and habitat use within and among consumer species is now standard in ecology (Gannes et al. 1998, Boecklen et al. 2011). Most terrestrial plants in northeastern Minnesota that make up moose diets are trees, shrubs, forbs, and cool-growing season grasses that use the C_3 photosynthetic pathway, and consequently have lower $\delta^{13}C$ values than warm-growing season grasses that use the C_4 pathway (O'Leary 1981). Variation among C_3 plants is largely controlled by environmental conditions, with light and water stress in open habitats imparting higher than average, and photosynthetic recycling of respired CO_2 in closed forests causing lower than average $\delta^{13}C$ values (Farquhar et al. 1989). During winter, moose mostly consume woody plant tissues that generally have slightly lower $\delta^{13}C$ values but much higher C:N ratios relative to summer forage. During summer, moose also consume aquatic macrophytes (Renecker and Schwartz 1998, Kielland 2001), $\delta^{13}C$ values of which can vary widely and overlap the range of values for terrestrial plants (Cloern et al. 2002). However, aquatic macrophytes in Voyageurs National Park (northeastern MN) have $\delta^{13}C$ values distinctly higher than regional terrestrial vegetation (Severud et al. 2013). Aquatic macrophytes characteristically have much higher $\delta^{15}N$ values than terrestrial plants and so occupy a distinct region of $\delta^{13}C$-$\delta^{15}N$ space relative to terrestrial plants regardless of $\delta^{13}C$ values. Consumer $\delta^{15}N$ values are also influenced by water and nutritional stress, both of which, through different mechanisms, lead to higher $\delta^{15}N$ values (Heaton et al. 1986, Ambrose 1991, Hobson et al. 1993).

Our hypothesis is that the isotope composition of common moose forage species will vary across the landscape in relation to some combination of climate, disturbance history, and physiography, and that resulting variation in moose isotopic compositions will be related to habitat quality, movement patterns, and demography. We will test this through an intensive survey of the isotopic composition of common forage species, both terrestrial and aquatic from the sites identified in Activity 1. To constrain for interannual forage isotopic variation we will revisit a subset of sites in Years 2-3 and also conduct a detailed sampling of plants in known home ranges of individual animals. Finally, we will sample moose tissues collected at the time of capture and collaring and at necropsies and subsequent collar redeployments during Years 2 and 3. All samples will be prepared and analyzed in the Stable Isotope Lab at UM using routine methods.

Previous studies and our own preliminary data document $\delta^{13}C$ and $\delta^{15}N$ variations in common moose forage of 6-9‰ and in various moose tissues of 3-7‰ (Ben-David et al. 2001, Kielland 2001, Tischler 2004, Fox-Dobbs et al. 2007, Drucker et al. 2010), thus we expect substantial landscape variability in plants and in moose. Isotopic variation among moose is necessary in order to link diet with habitat use, behavioral phenotypes, and demography. Some previous studies analyzed potential forage plants (e.g., Kielland, 2001; Tischler, 2004), but none could utilize known movement patterns of individual moose to guide plant sampling as we can for collared animals in this study. We can statistically compare plant and moose composition, but multiple dietary components that vary isotopically and in C and N concentration can also be deconvolved from consumer compositions using various quantitative models (e.g., IsoSource, Phillips and Koch 2002, Phillips and Gregg 2003; SIAR, Parnell et al., 2010). With these data, we will test if diet and nutritional stress (assessed via urinary urea nitrogen:creatine collected from snow urine; DelGiudice et al. 2001) are related to behavioral patterns and land-cover composition, and, using local climatic data, determine if behavioral responses to temperature extremes during the summer (e.g., extended day-time use of aquatic habitat) affect the diet composition of individual animals that leads to their increased nutritional stress and mortality risk in the following winter.

Plant isotope sampling. To constrain effects of local climate, we will analyze plant samples collected at our 61 sites distributed across three study areas (cold, moderate, warm) in which maximum summer temperature spans a 5° C gradient. Treatments in each area, identified using existing GIS map layers of the region, consist of forest stands with different times since last disturbance (three wildfire burns, two clear cut events, two insect defoliation events) and a control plot that has not experienced disturbance in recent history. At each site we will sample common forage species in 10-m fixed radius plots. We have already collected vegetation from the 61 sites in June 2012 and 2013. Based on this experience, we expect to sample multiple individuals of about 10 common forage species across each plot. During Years 1 and 2, we plan four field seasons of unequal duration each utilizing two field teams of two: (1) an early spring trip will focus on the moderate temperature field area and sample leaves and wood of common forage in one replicate plot of each treatment and the control; (2) a late spring trip will revisit the same sites to describe early phenological changes in vegetation quality and isotopic composition; (3) a summer trip will focus on all three temperature regimes, as summer maximum temperature is a critical factor, and sample leaves, wood, and fruiting bodies in three replicates of each treatment and the control in each area; (4) a winter trip will focus on all three areas, as winter temperature and forage quality are likely factors in moose condition and mortality, and sample one replicate of each treatment. As field conditions allow, the winter plots will be the same as those sampled in spring, ensuring seasonal sampling of the same plots over two years, and in each of these plots we will mark specific plants for replicate sampling. For each plant sampled, percent canopy cover, facing angle, and surface slope will be measured as controls for the effects of light and water stress on fractionation during photosynthesis; at each site, species composition and abundances will be recorded (Activity 1). This sampling scheme will control for seasonal and inter-annual variation in forage composition over the course of the project. In Year 2 we will use the movement data collected from the GPS collars to ensure that we sample plants within known home ranges; this may require establishing some new plots. During winter sampling in Year 2, we will also collect snow-urine from and attempt to backtrack moose paths known from collar data to sample consumed vegetation. Given the number of plots and samples planned, flexibility in sampling during Year 2 is possible and will allow us to concentrate on known home ranges without sacrificing the comprehensiveness of sampling. Year 3 will consist of a brief field season where a subset of sites and marked plants are revisited. Although our sampling scheme is ambitious, we are confident that it is feasible because in a 2012 pilot season, a two person team executed a full summer sampling trip, collecting 1-3 tissues from >500 plants in 27 plots in each of the three field areas (including many remote backcountry sites in the Boundary Waters Canoe Area Wilderness).

Moose sampling: The primary tissues we will sample are hair and hoof keratin, although we will opportunistically sample feces, bone, and tooth enamel. The $\delta^{13}C$ of body proteins (bone collagen, keratin in hair and hooves) preferentially record the $\delta^{13}C$ value of dietary protein; apatite in bone and tooth enamel and feces reflect the $\delta^{13}C$ of bulk diet (Coates et al. 1991, Ambrose and Norr 1993). By sampling moose tissues with different elemental turnover times that integrate diet over different intervals and for which isotope enrichments relative to diet are known (e.g., feces, hair, hooves, hair; Coates et al. 1991, Cerling and Harris 1999, Kielland 2001, Sponheimer et al. 2003, Zazzo et al. 2007), we can assess individual moose diet and habitat use on timescales from days to months. Individuals were sampled initially at capture in 2013 (collars recovered from dead animals will be redeployed every winter). While animals were immobilized, the capture team plucked complete hairs from the hump and use a wood-working tool to sample hoof keratin just below the hair line on the same leg of each animal. Cervid hair is shed at the end of the cold season and the new coat grows from late spring to autumn (Franzmann and Schwartz 2007). Hair on the hump grows 0.8-1.0 cm/month (Flynn et al. 1975) and is long enough for up to 10 samples per hair (2-3 week temporal resolution; Drucker et al. 2010). Cervid hooves grow continuously, and while we have not found growth rates for moose hooves, white-tailed deer hooves grow 3.6-7.2 cm/year (Miller et al. 1986, Sikarskie et al. 1988) and a previous isotope study of moose hooves using moderate resolution sampling (11 samples/hoof) documented two complete oscillations in both $\delta^{13}C$ and $\delta^{15}N$ values interpreted as seasonal cycles, implying preservation of two years of hoof growth (Kielland 2001).

During post-mortem necropsies of collared animals, we will remove teeth for later sampling of tooth enamel, a patch of skin with hair from the hump, and a whole hoof for later sampling of bone mineral and collagen, and serial sampling of the hoof distal to the sample groove drilled at capture, which will provide temporal control; hoof sampling will follow the geometry of ungulate hoof growth (Harrison et al. 2007). Bone tissues integrate diet over months to years and are thus not a primary focus, although they will provide a modest adjunct dietary dataset. Feces will be collected as possible at captures and necropsies, opportunistically while plant sampling, and when collecting snow-urine and backtracking known individuals. Fecal isotope composition reflects diet ingested over several days prior to excretion (Coates et al. 1991, Sponheimer et al. 2003), providing our most highly resolved source of dietary information, though one difficult to sample regularly. We will quantify within-animal variation in isotope composition by analyzing repeated measures of each tissue from a subset of animals. Likewise, we will quantify inter-animal variation in isotopic concentrations after controlling for factors such as age and landscape context (e.g., distribution of available forage).

We will use Cox Proportional Hazards models to describe the survival for adult moose as a function of animal characteristics (e.g., age, sex, behavioral phenotype, short- and long-term diet based on stable isotope analysis, etc.) and landscape covariates (e.g., road density, land cover proportions, spatial variation in forage quality and quantity, land cover patch metrics, etc.) calculated within each animal's home range. We will then use these results to develop spatially explicit risk maps that we can compare to the local moose population trajectories developed in Activity 1. Combining these two sources of data will help us understand if the distribution of food and cover are mechanistically linked to the population dynamics of moose in Northern Minnesota.

V. Results and Deliverables

The final product of this project will include (a) a collection of spatial data layers that describe how land cover has changed across NE Minnesota over the last decade, (b) a statistical model that links cover type to moose forage abundance and stable isotope composition, (c) predictive models of how landscape patterns can influence moose movement, diet, and survival.

Activity 1 Outcome	**Completion Date**
1. Analyze data from 1,258 FIA plots and the moose survey data to determine how broad-scale patterns of landscape change are linked to moose population dynamics.	December 2014
2. Develop a stable isotopic signature for moose forage species commonly found in NE MN.	February 2015
3. Produce a new classification of satellite data for NE MN to show how the distribution of high-quality moose habitat has changed over the last 13 years.	September 2015
4. Identify how the species composition of moose forage changes among land-cover types and in response to stand age.	December 2015
5. Publish a spatially-explicit analysis of how moose population density changes in response to availability and arrangement of forage in the landscape.	January 2016

Activity 2 Outcome	**Completion Date**
1. Assess the nutrient quality and stable isotopic concentration of forage available in each collared animal's home range.	November 2015
2. Develop a time series of diet over the previous year for each collared moose (n=129) using stable isotopic analysis of hair collected at capture and after death.	December 2015
3. Assess whether forage availability or diet affect the rates of survival.	December 2016
4. Provide specific forest management recommendations to experimentally improve the landscape for moose in the areas of their range where the animals are most vulnerable.	June 2017

VI. Time Table

Date	**Milestone**
2014 July	Begin initial field season collecting vegetation samples
2014 September	Begin the stable isotopic analysis of plant samples
2014 December	Complete FIA data analysis and begin drafting manuscript from initial findings
2015 January	Begin analysis of satellite imagery.
2015 February	Complete initial plant stable isotope analysis.
	Conduct winter forage sampling and moose snow tracking.
2015 June	Begin second summer field season.
2015 September	Complete analysis of satellite imagery.
2015 November	Complete analysis of home-range specific isotope forage distributions.
2015 December	Develop spatially explicit map of the distribution of moose forage.
2016 February	Conduct winter forage sampling and moose snow tracking.
2016 June	Complete manuscript describing how relative moose density responds to landscape features.
	Begin final summer field season.
2016 November	Complete stable isotopic analysis.
2016 December	Complete analysis relating moose survival to diet and land cover composition.
2017 June	Complete manuscripts and reports from project. Draft management recommendations. Project end.

VII. Budget

The total budget request is $300,000 over a three-year period. These funds will be used to provide partial salary and fringe for lab technicians, one graduate student, one postdoc, and numerous undergraduate research assistants; partial summer salary for two faculty is also included. These funds will also cover lab and statistical analysis of samples and data, field and equipment costs.

BUDGET ITEM *(See "Guidance on Allowable Expenses", p. 13)*	**AMOUNT**
Personnel:	
Field manager - 25% FTE ($55,636) plus 36.8% fringe ($20,474): will lead vegetation sampling effort over two years	$38,055
Faculty (Forester) - 8%FTE = 3mo summer salary over 3yr ($24,040) plus 19.83% fringe ($4,767): will manage project, and take lead on analysis of moose movement data.	$28,808
Faculty (Fox) - 4% FTE = 1.5 mo summer salary over 3 yr ($13,072) plus 19.83% fringe ($2,592): will supervise the stable isotope analyses	$15,664
Lab technician - 8%FTE = 3 mo over 3 yr ($9,559) plus 36.8% fringe ($3,518): will maintain stable isotope lab equipment and assist with analyses.	$13,076
Postdoctoral Fellow (David Wilson) - 8%FTE = 3 wks salary in first year ($3,673) + 36.8% fringe ($1,352): will take lead on collecting and analyzing the FIA data for the moose range.	$3,769
Undergraduate field and lab assistants - 2 students, 40h/wk, 10 wks over 3 yr, $10-15/h ($57,491): will aid graduate student, field manager, and lab technician with data collection and entry.	$28,746
PhD student $21/hr 55% FTE 13 wks summer salary ($18,564) plus 23.1% health and FICA ($4288): will collect plants for stable isotope analysis within animal home ranges, will collect moose browse, hair, and fecal pellets during winter, and will take lead on the analysis of moose isotope concentrations.	$22,852
Contracts:	
Isotope analysis (University of Minnesota Stable Isotope Lab, 7368 samples of moose and plant tissue at $8/sample)	$58,944
GIS and Statistical Consultant, ($26,333 over 3yr) classify historic and current satellite imagery and conduct spatially explicit statistical analyses.	$26,333
Equipment/Tools/Supplies:	
Lab supplies (reagents, weigh tins, gas canisters, and other consumable supplies used for stable isotope analysis)	$9,000
field equipment (measuring tapes, compasses, flagging tape, sample bags, stakes, etc)	$1,200
Map-grade GPS unit for precise location of field samples and accurate ground truthing of satellite imagery	$4,291
Travel:	
Travel to study area by project management staff and technicians 4 months/yr for 3 years (1 fleet truck @$779/month, $0.37/mi, 10000 miles/ yr)	$17,040
Room and board for field crew (3 yr of summer and winter field sessions, 4 months/yr, 2-6 crew members at a time, rent @ $1,500/mo, board@$1,185/mo)	$32,222
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$300,000

OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ Being Applied to Project During Project Period:	none	
Other State $ Being Applied to Project During Project Period:		
Purchase and maintenance of 15 moose GPS collars (Forester startup)	$89,463	*secured*
Graduate Lab Manager (Fox Stable Isotope Lab, 1mo summer salary + 23.1% health and FICA)	$2,400	*secured*
Computer equipment dedicated to data analysis and simulation for this project (Forester startup)	$5,558	*secured*
Foregone ICR funding (52% MTDC, excluding graduate fringe)	$202,908	*secured*
In-kind Services During Project Period: *Salaries for Forester (1% match), D'Amato (1% match)*	$6,550	*Secured*
Remaining $ from Current ENRTF Appropriation (if applicable):	none	
Funding History:	none	

VIII. Credentials

James D. Forester

(a) Professional Expertise

Forester has a broad background in field ecology, having worked on projects related to intertidal community dynamics, terrestrial plant community composition, amphibian population distributions, and the resource selection and movement patterns of large mammals. He has extensive experience with quantitative and computational methods including classical and Bayesian statistics, and parallel processing using high performance computing clusters. His research covers a range of spatial and temporal scales but is primarily focused on how large, mammalian herbivores respond to changing landscapes.

(b) Professional Preparation

Frostburg State University, Wildlife/Fisheries + Biology B.S. 1997

University of Wisconsin – Madison, Zoology M.S. 2002

University of Wisconsin – Madison, Zoology Ph.D. 2005

University of Chicago, Ecology & Evolution, Statistics Post-doc 2005-2008

Harvard University, Organismic & Evolutionary Biology Post-doc 2008-2010

(c) Appointments

Asst. Prof., Dept. Fisheries, Wildlife & Cons. Biol., U. Minnesota July 2010 – present

(d) Publications

(i) Most closely related to the proposed project

Fagan, W. F., M. A. Lewis, M. Auger-Methe, T. Avgar, S. Benhamou, G. Breed, L. LaDage, U. E. Schlaegel, W. Tang, Y. P. Papastamatiou, J. Forester, and T. Mueller. 2013. Spatial memory and animal movement. Ecology Letters 16:1316–1329.

Forester, J. D., H. K. Im, and P. J. Rathouz. 2009. Accounting for animal movement in estimation of Resource Selection Functions: Sampling and data analysis. *Ecology* 90(12):3554–3565.

Anderson, D. P., J. D. Forester, and M. G. Turner. 2008. When to slow down?: Elk residency rates on a heterogeneous landscape. *Journal of Mammalogy* 89(1):105-114.

Forester, J. D., D. P. Anderson, and M. G. Turner. 2007. Do high-density patches of coarse wood and regenerating saplings create browsing refugia for aspen (*Populus tremuloides* Michx.) in Yellowstone National Park (USA)? *Forest Ecology and Management* 253:211-219.

Forester, J. D., A. R. Ives, M. G. Turner, D. P. Anderson, D. Fortin, H. L. Beyer, D. W. Smith, and M. S. Boyce. 2007. State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. *Ecological Monographs* 77(2):285-299.

(ii) Other significant publications

Forester, J. D. 2011. Dispersal from the frying pan to the fire. *Animal Conservation* 14(3): 225-226.

Wootton, J. T., C. A. Pfister, and J. D. Forester. 2008. Dynamical patterns and ecological impacts of changing ocean pH in a high-resolution multi-year dataset. *Proceedings of the National Academy of Sciences* 105(48):18848-18853.

Forester, J. D., D. P. Anderson, and M. G. Turner. 2008. Landscape and local factors affecting northern white cedar (*Thuja occidentalis*) recruitment in the Chequamegon-Nicolet National Forest, Wisconsin (USA). *American Midland Naturalist* 160:438-453.

Anderson, D. P., J. D. Forester, M. G. Turner, J. L. Frair, E. H. Merrill, D. Fortin, J. S. Mao, and M. S. Boyce. 2005. Factors influencing seasonal home-range sizes in elk (*Cervus elaphus*) in North American landscapes. *Landscape Ecology* 20:257-271.

Anderson, D. P., M. G. Turner, J. D. Forester, J. Zhu, M. S. Boyce, H. Beyer, and L. Stowell. 2005. Scale-dependent summer resource selection by reintroduced elk in Wisconsin, USA. *Journal of Wildlife Management* 69:298-310.

(e) Synergistic Activities

Resident Fellow with the Institute on the Environment at the University of Minnesota working to develop collaborations between the College of Food, Agriculture, and Natural Resource Sciences, the College of Veterinary Medicine, and the Minnesota Department of Natural Resources (2011–present).

Working with scientists from the Grand Portage Reservation's Department of Biology and Environment to develop a program that will engage high school students from the Reservation in ecological research (2011–present).

Development of a graduate course that teaches students to design statistical modeling frameworks from scratch. This course will start with simple concepts such as linear regression progress to generalized linear models and conclude with non-linear, hierarchical Bayesian models (2012).

Development of an undergraduate course that focuses on training students to design and carry out independent research projects related to wildlife-habitat interactions (2010).

Participation in the Duke Summer Institute on Uncertainty and Variability in Ecological Inference (2006)

David L. Fox

(a) Professional Expertise
Measurement and interpretation of stable isotope ratios of C, N, and O in animal tissues (collagen, hair, apatite, carbonate) and sedimentary organic matter and pedogenic carbonate to address questions in ecology, paleoecology, paleobiology, and paleoclimate. Modern mammalian biogeography in relation to climate, physiography, and vegetation.

(b) Professional Preparation

Harvard University Biological Anthropology A.B. 1991

University of Michigan Geological Sciences M.S. 1995

University of Michigan Geological Sciences Ph.D. 1999

UC, Santa Cruz Stable isotope paleoecology Post-doc 1999-2001

(c) Appointments

2007-present Associate Professor, Dept. of Earth Sciences, University of Minnesota

2006-present Senior Member, graduate faculty, Dept. of Ecology, Evolution, and Behavior, University of Minnesota

2002-present Research Associate, Science Museum of Minnesota, St. Paul, MN

2001-present Assistant Professor, Dept. of Geology and Geophysics, University of Minnesota

(d) Publications

(i) Most closely related to the proposed project

Fox, D.L., Martin, R.A., Honey, J.G., and Pelaez-Campomanes, P., 2011. Pedogenic carbonate stable isotope record of environmental change during the Neogene in the southern Great Plains, southwest Kansas, USA: carbon isotopes and the evolution of C_4-dominated grasslands. *GSA Bulletin*, doi:10.1130/B30401.1

Fox, D.L., Martin, R.A., Honey, J.G., and Pelaez-Campomanes, P., 2011. Pedogenic carbonate stable isotope record of environmental change during the Neogene in the southern Great Plains, southwest Kansas, USA: oxygen isotopes and paleoclimate during the evolution of C_4-dominated grasslands. *GSA Bulletin*, doi:10.1130/B30402.1.

Rose, P.J., **Fox, D.L.**, Marcot, J.D., Badgley, C., 2011. Flat latitudinal gradient in Paleocene mammal richness suggests decoupling of climate and biodiversity. *Geology* 39: 163-166. doi:10.1130/G31099.1

Rountrey, A.N., Fisher, D.C., Vartanyan, S., and **Fox, D.L.**, 2007. Carbon and nitrogen isotope analyses of a juvenile woolly mammoth tusk: evidence of weaning. *Quaternary International* 169-170: 166-173.

Fox-Dobbs, K., Bump, J.K., Peterson, R.O., **Fox, D.L.**, and Koch, P.L., 2007. Carnivore specific stable isotope variables and variation in grey wolf foraging ecology: case studies from Isle Royale, Minnesota, and La Brea. *Canadian Journal of Zoology* 85: 458-471.

(ii) Other significant publications

Matson, S.D. and **Fox, D.L.**, 2010. Stable isotopic evidence for terrestrial latitudinal climate gradients in the late Miocene of the Iberian Peninsula. *Palaeogeography, Palaeoclimatology, Palaeoecology* 287: 28-44.

Martin, R.A., Peláez-Campomanes, P., Honey, J.G., **Fox, D.L.**, Zakrzewski, R.J., Albright, L.B., Lindsay, E.H., Opdyke, N.D., and Goodwin, H.T., 2008. Rodent community change at the Pliocene–Pleistocene transition in southwestern Kansas and identification of the *Microtus* immigration event on the Central Great Plains. *Palaeogeography, Palaeoclimatology, Palaeoecology* 267: 196-207.

Fox, D.L., Fisher, D.C., Vartanyan, S., Tikhonov, A.N., Mol, D., and Buigues, B., 2007. Paleoclimatic implications of oxygen isotopic variation in late Pleistocene and Holocene tusks of *Mammuthus primigenius* from northern Eurasia. *Quaternary International* 169-170: 154-165.

Fox, D.L. and Koch, P.L., 2004. Carbon and oxygen isotopic variability in Neogene paleosol carbonates: constraints on the evolution of the C_4-dominated grasslands of the Great Plains, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 207: 305-329.

Badgley, C. and **Fox, D.L.**, 2000. Ecological biogeography of North American mammals: species density and ecological structure in relation to environmental gradients. *Journal of Biogeography* 27: 1437-1467.

(e) Synergistic Activities

Mentor for undergraduate NSF-REU summer interns: 2011 (Brad West, Whitman College), 2008 (Sam Miller, Amherst College; Lucy Chang, University of Chicago), 2006 (Keith Christianson, Carleton College), 2004 (Robert Dietz, Iowa State University), 2003 (Jenn Campbell, Williams College), 2002 (Neil Kelly, Oberlin College)

Service to the Society of Vertebrate Paleontology: Chair, Alfred S. Romer Prize (student presentation award), 2006-present; member, Program Committee, 2007-present

Editorial service: Treasurer, Editorial Board Member, *Palaeontologia Electronica*, 2003-present; Associate Editor, *Paleobiology*, 2009-present; Associate Editor, *PALAIOS*, 2011-present.

Organizer of theme session for 2011 GSA Annual Meeting (9-12 October, 201, Minneapolis, MN): T65. Paleoclimate, Terrestrial Ecosystems, and Human Evolution in Africa from the Pleistocene to the Present. Sponsored by the GSA Quaternary Geology and Geomorphology, Limnogeology, and Archaeological Geology Divisions.

Organizer of theme session for GSA Annual Meeting (18-21 October, 2009, Portland, OR): T88. The Present is the Key to the Past: Identifying and Characterizing Isotopic Pattern and Process in Modern Ecosystems. Sponsored by the Paleontological Society.

Anthony W. D'Amato

Associate Professor – Department of Forest Resources, University of Minnesota

1530 Cleveland Ave. North, St. Paul, MN 55108 – (612) 625-3733 – damato@umn.edu

Education and training

University of Maine	Forest Ecosystem Science	B.S., 2000
Oregon State University	Forest Science	M.S., 2002
University of Massachusetts	Forest Resources	Ph.D., 2006
University of Massachusetts	Forest Resources	Post-Doc, 2006-2007

Research and professional experience

2012 – present	Associate Professor	University of Minnesota, St. Paul, MN
2007 –2012	Assistant Professor	University of Minnesota, St. Paul, MN
2006 – 2007	Post-Doctoral Fellow	University of Massachusetts, Amherst, MA
2002 – 2006	Research Assistant	Harvard Forest, Harvard University/University of Massachusetts, Amherst, MA

Five publications related to proposed project:

1. Reinikainen, M.R., A.W. D'Amato, J. Bradford, and S. Fraver. *In press*. Influence of low-severity canopy disturbance and forest age, stocking, site quality, and composition on sub-boreal aspen mixedwood carbon stocks. Canadian Journal of Forest Research.

2. Russell, M., C. Woodall, S. Fraver, and A.W. D'Amato. 2013. Estimates of coarse woody debris decay class transitions for forests across the eastern United States. Ecological Modeling 22-31.

3. Bradford, J., and A.W. D'Amato. 2012. Quantifying tradeoffs in multi-objective land management. *Frontiers in Ecology and the Environment* 10: 210-217.

4. Bradford, J.B., S. Fraver, A. Milo, A.W. D'Amato, B. Palik, and D. Shinneman. 2012. Effects of multiple interacting disturbances and salvage logging on forest carbon stocks. Forest Ecology and Management 267: 209-214.

5. D’Amato, A.W., J. Bradford, B. Palik, and S. Fraver. 2011. Forest management for mitigation and adaptation to climate change mitigation: insights from long-term silviculture experiments. *Forest Ecology and Management* 262: 803-816.

Five other publications:

1. Silver, E.J., D’Amato, A.W., Fraver, S., Palik, B.J., Bradford, J.B., 2013. Structure and development of old-growth, unmanaged second-growth, and extended rotation *Pinus resinosa* forests in Minnesota, USA. Forest Ecology and Management 291: 110-118.

2. Aakala, T., S. Fraver, B. Palik, and A.W. D’Amato. 2012. Spatially random mortality in old-growth red pine forests in northern Minnesota. Canadian Journal of Forest Research 42: 899-907.

3. Reinikainen, M.R., A.W. D’Amato, and S. Fraver. 2012. Repeated insect outbreaks promote multi-cohort aspen mixedwood forests in Minnesota, USA. *Forest Ecology and Management* 266: 148-159

4. D’Amato, A.W., S. Fraver, J. Bradford, B. Palik, and L. Dunn. 2011. Interactive effects of blowdown, salvage logging, and wildfire on sub-boreal pine systems. *Forest Ecology and Management* 262: 2070-2078.

5. D’Amato, A.W., and D.A. Orwig. 2008. Stand and landscape-level disturbance dynamics in western Massachusetts. Ecological Monographs 78: 507-522.

Synergistic Activities:

1. Chair, Forest Ecology Working Group, Society of American Foresters
2. Session organizer. 7th and 8th North American Forest Ecology Workshops, 2009, 2011.
3. Chair, Education Development Committee, Minnesota Chapter of the Society of American Foresters
4. Subject-matter editor (forest ecology): *Ecology, Ecological Monographs,* and *Journal of Forestry*
5. Reviewer for several interdisciplinary scientific journals, including *Bioscience, Ecology, Ecological Applications, Ecological Monographs, Forest Science, Journal of Ecology, Journal of Forestry, Northern Journal of Applied Forestry, The Journal of the Torrey Botanical Society,* and *Western Journal of Applied Forestry*

Contributions to teaching and training: 3 PhD students, 9 MS students, 5 post-doctoral research associates. Recipient of 2011 Newman Art of Teaching Award and 2012 College of Food, Agricultural, and Natural Resources Sciences Distinguished Teaching Award. Serve as advisor for Forestry Club student group (2008- present).

IX. Dissemination and Use

A fact sheet that summarizes our findings will be distributed to LCCMR members and land managers at the state and federal level; this will also be made available on the Department of Fisheries, Wildlife, and Conservation Biology website. In addition, several manuscripts will be written and submitted for publication in peer-reviewed journals. Results will be presented at state and national wildlife and ecology conferences (e.g., the annual Minnesota Moose Meeting, The Wildlife Society [both state and national conferences], the Ecological Society of America, and the International Association of Landscape Ecology). All publications resulting from this project will be made available through the FWCB website or Open Access journal websites.

We also expect that there will be a large amount of informal dissemination because we will be working closely with researchers and managers from the Department of Natural Resources, The Nature Conservancy, the Grand Portage Band of the Lake Superior Chippewa, the National Park Service, and the US Forest Service. These researchers will take the results of our study into consideration as they make management decisions and will work with us to ensure that our data products and research papers reach a broad audience within their agencies.

Finally, we will continue to pursue public outreach through the Bell Museum of Natural History at UM, which brings University research to the public onsite within the BMNH and offsite through community venues, traveling exhibits, and film productions. We will continue to collaborate with them to develop a unique learning environment that integrates interactive media that presents our on-going research with the existing detail-rich and aesthetically compelling traditional diorama in the BMNH. The decline of moose in Minnesota is of significant public interest, and we expect the presentation of this research to improve public understanding of both the scientific process and the state of this iconic species.

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

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