**2014 Project Abstract**
For the Period Ending June 30, 2017

**PROJECT TITLE: Impacts of forest quality on declining Minnesota moose.**

**Project Manager:** James D Forester
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**Web Address:** [http://fwcb.cfans.umn.edu/forester/index.html](http://fwcb.cfans.umn.edu/forester/index.html)
**FUNDING SOURCE:** Environment and Natural Resources Trust Fund
**LEGAL CITATION:** M.L. 2014, Chp. 226, Sec. 2, Subd. 05l and Date of Work Plan Approval: June 4, 2014

**APPROPRIATION AMOUNT: $300,000**
**AMOUNT SPENT: $277,414**
**AMOUNT REMAINING: $22,586**

**Overall Project Outcome and Results**
We examined characteristics of land cover and forage quality that could be affecting the declining Minnesota moose population at multiple spatial and temporal scales. At a broad spatial scale, we found that the landscape of NE Minnesota has changed over 18 years, both in the composition (e.g., more coniferous and less mixed-wood forest) and arrangement (e.g., decreased fragmentation of coniferous forest and increased fragmentation of mixed-wood forest) of forested land-cover types. At the scale of the moose survey unit (2.8 x 5 miles), some of these changes appear to be related to moose population dynamics. Specifically, moose tended to have higher population growth rates in cooler areas and in survey units that had more young and mixed-wood forest, less coniferous and deciduous forests, and less fragmented forested wetlands. We found that, during summer, moose are in fact altering their behavior to seek out mixed-wood forest at the hottest times of the day, and because we found that forage availability differs both by cover type and by location in moose range, these decisions may be affecting diet. Further, because the diets of animals that died were different from those of live animals, we suspect that the availability of high-preference foods may be critical. Because several independent sources of data all point in a similar direction, we recommend a large-scale, long-term experiment to explicitly test how different combinations of land cover and food availability may be affecting moose habitat use and population dynamics. Specifically, we suggest working with forest managers to harvest blocks of forest stands to manipulate overstory and understory features that appear to be important to moose. Monitoring the success of these manipulations with collared animals and camera traps over a 5-10 year period could help determine how to best manage forest landscapes for a healthy moose population.

**Project Results Use and Dissemination**
This research has been presented 15 times at national or international research conferences or invited seminar series. The research team has worked with the Bell Museum to contribute information related to the moose diorama and also provided an extensive interview to the “Access Minnesota” radio show. Three scientific articles have been published so far, and the research team is working with MNDNR and tribal biologists to discuss the results and implications of this work. Finally, 12 undergraduate students, five graduate students, and three postdoctoral researchers received training as part of this project;

results from this research have been added into teaching materials in two required Fisheries, Wildlife, and Conservation Biology courses at UMN.

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

**Date of Report:** 31 August 2018

**Date of Next Status Update Report:** **Final Report**

**Date of Work Plan Approval:** 4 June 2014

**Project Completion Date:** 30 June 2017

**PROJECT TITLE: Impacts of forest quality on declining Minnesota moose.**


**Project Manager:** James D Forester

**Organization:** University of Minnesota

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**Location:** St. Louis, Lake, and Cook Counties (see Figure 1).

**Total ENRTF Project Budget:**

| | |
|---|---|
| **ENRTF Appropriation:** | **$300,000** |
| **Amount Spent:** | **$277,414** |
| **Balance:** | **$22,586** |

**Legal Citation:** M.L. 2014, Chp. 226, Sec. 2, Subd. 05l and Date of Work Plan Approval: June 4, 2014

**Appropriation Language:**
$300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota in cooperation with the Department of Natural Resources to link regional patterns of moose abundance through time to the distribution of food and cover and determine if this distribution affects the diet and survival of individual moose. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

**I. PROJECT TITLE: Impacts of forest quality on declining Minnesota moose.**

**II. PROJECT STATEMENT:**

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 2). 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.

Our <u>*broad aim*</u> 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 <u>*research goals*</u>:

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.

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.

This will be the first study to link the movement behavior and landscape context of individual moose (e.g., the distribution of food and cover within an animal's home range) to the animals' diet, body condition, and mortality risk. It will allow us to place the moose movement, mortality, and forage quality data already being generated by LCCMR funding into a detailed ecological and behavioral framework that will provide critical and timely insight into the causes of the moose population decline.

**III. PROJECT STATUS UPDATES:**

**Project Status as of 1 December 2014:**

We had a successful first field season – collecting several thousand plant samples at 140 sites distributed across moose range in northeastern Minnesota. We have also begun running stable isotopic analysis of hair previously collected from moose and the initial results confirm the large amounts of variability we saw in our pilot analysis conducted last year. Our graduate student has found other funds to support his stipend, so we are using the remaining funds initially set aside for his summer salary to support a postdoctoral researcher for 6 months next year. This person has already been working on moose in Ontario and will be able to do the critical initial organization of the moose movement data and begin to develop statistical models that link resource availability to diet composition.

Our work with the FIA data is also proceeding as planned. We have summarized annual estimates of land-cover compositions within each moose survey unit and have developed initial population models to understand if changing land cover is linked to dynamics in the moose population. We are now working with remote sensing labs to begin the process of developing a time series of Landsat images within our study area.

LCCMR approved the amendment to add the postdoctoral scholar to the personnel budget category -December 17, 2014.

**Amendment Request 30 April 2015:**

We would like to shift the GIS and Statistical consulting funding in Activity 1 “Professional/Technical Service contracts” to “Personnel” in Activity 1. We were originally planning on getting this done through an external contract but we decided that using UMN facilities would produce a more consistent product since they specialize in MN satellite analysis. We are requesting that we use $25,000 to pay 3.5 months of GIS analyst time (split between the Knight and Falkowski labs) to produce the satellite products we need for the next phase of this project. We have made no changes in the work plan as this is simply a shift in the budget that will yield the same product. *Approved by the LCCMR 5/1/2015*

**Project Status as of 31 May 2015:**
We hired a postdoc for this project to compile the moose movement data collected by many researchers in the state. He has finished cleaning these data and is well into his analysis of how moose change their selection of landscapes based on time of day and changes in daily temperature. We are preparing for another field season to collect additional vegetation data and control points to help with validating the land-cover classification we have commissioned from the Knight lab. Our initial results from the stable isotope analysis show that we can detect differences in isotopic ratios in different cover types and across a summer temperature gradient in the study area; we see similar patterns in the moose hair that we have analyzed. As we continue to collect more data, we will use this information to build models to estimate the diet of individual moose and relate this to body condition, behavior, and survival.

**Project Status as of 31 January 2016:**
Our second field season went very well. We focused on collecting aquatic vegetation during June and continued to collect data on forage abundance and composition throughout the study area for the rest of the summer. Although our progress has been slightly hampered by a malfunctioning mass spectrometer and having one of our remote-sensing colleagues move to another university, we are still making progress with the analysis. Our first manuscript was accepted for publication in Landscape Ecology, and in it we show that Minnesota moose strongly alter their selection of land-cover composition based on ambient temperature; this effect was not as strong in moose followed in Ontario where forest composition is more mixed (i.e., foraging opportunities are closer to thermal cover). We will use the results from this paper to help drive our analysis of landscape patterns at the individual and population levels.

**Project Status as of 31 May 2016:**
We conducted a winter field season to collect browse samples at our field sites. In the lab, we have been focusing on finishing our stable isotope analyses and our initial data set has shown that the moose in the state eat markedly different diets depending on where they live; these differences are even more dramatic when seasonal changes in diet are examined. Now that we have our improved land-cover classification, we have begun examining how forage composition and availability differs among cover types and by disturbance history. We are currently preparing for our final field season in which we will primarily collect plant samples and forage biomass data from forested wetlands.

**Project Status as of 1 May 2017:**

We received the historical land-cover data for moose range and are in the process of analyzing how the composition and arrangement of different land-cover classes change across moose survey units. Half of our stable isotope and metabolomics samples are still being analyzed by the labs; however, we expect the data to arrive in the next two weeks. Our spatially-explicit population estimation model has shown great improvement over previous versions and we continue to refine it using the newly received historical land-cover data. Our initial model to predict forage biomass across moose range using LiDAR has limited predictive power due to high variation in the observed field data; we are currently testing whether adding in additional data layers (land cover, topographic position, soils) will improve the model. Using data collected from recovered moose collars, we have developed an approach to estimate the amount of time an animal spends foraging at different times of the day; our initial results indicate that, during summer, moose actively forage the most during dawn and dusk. This suggests that the cover types preferred by the animals at these times will be the most important contributors to the overall summer diet of the moose. Because our data have been delayed due to processing issues in the labs we contracted with, we are slightly behind our initial schedule. We anticipate being able to complete the work on time if we are able to move some of the unspent budget to personnel.

**Amendment Request 1 May 2017:**

*Personnel (Wages and Benefits):* $47,815

Because so much of the contracted data (historical land-cover layers and plant chemical composition results) have been late to arrive, we need extra help on the analysis end. We request the unspent and unencumbered amounts in the other budget sections ($47,815) to be transferred to Personnel to fund additional work on the final analysis (two full time and one part-time graduate student, a postdoc, and one month of PI Forester's time). One graduate student worked for one month to develop models that allow us to identify moose behaviors in different areas of the landscape (i.e., proportion of time foraging in wetlands), another student is currently working full time on refining the moose diet composition models, and a third student is developing a program that will help us predict how moose distributions will change in response to different distributions of land-cover and other resources. The postdoc is refining forage availability maps for moose range and also developing the spatially-explicit population estimation model; Forester will continue to work on a population dynamics model that will further refine the spatially-explicit estimates. For the graduate students and postdoc, we are making this request retroactively because although we had discussed these changes with LCCMR staff and prepared our amendment request earlier in the year, the report was mistakenly not sent out before leaving for the field this winter.

*Professional/Technical/Service Contracts: -$2,084*

In 2013, we began running stable isotope analysis on plant and animal tissue at the stable isotope lab in the Department of Earth Sciences at the University of Minnesota; however, multiple stoppages due to a wide range of technical issues slowed progress for extended periods of time. In mid 2014, a new isotope lab in the Department of Soil Sciences was up and running, and to help minimize our dependence on the lab in Earth Sciences, we decided to run samples in this lab as well. Prior to sending new samples to this lab we decided to run a series of replicates to ensure that we would not experience any lab-specific bias. Unfortunately, this lab is tuned to running soil samples and the nitrogen values we received were well outside normal $\delta^{15}N$ values of plant and animal tissues. In mid 2015, the stable isotope laboratory in the Department of Earth Sciences at the University of Minnesota began to occasionally encounter severe column issues that resulted in unreliable nitrogen values, which is a critical part of our analysis, and by mid 2016, this lab decided to stop running samples until the issue had been completely resolved. At this point we were beginning to get too far behind schedule and began to look for other stable isotope labs to analyze our samples in case the UMN machine took too long to repair. Unfortunately, we could not find other labs in the state of Minnesota that run outside samples. After comparing prices at three different isotope laboratories (the University of California at Santa Cruz, University of Utah, and University of California at Davis), we found the lowest price at the University of California at Santa Cruz ($11.74/sample compared to $13.13/sample and $12.50/sample at the other labs — note that this price includes weighing out of the samples, a service not included in the

$9/sample charged at UMN, so this price is not substantially higher than our original in-house rate). The Santa Cruz lab is a national leader in stable isotope ecology and specializes in the analysis of a broad range of materials, including plant and animal tissues. In addition, they have an excellent reputation for working with large numbers of samples and with individuals from outside the University of California system. We contacted the University of California at Santa Cruz in July of 2016, and sent them approximately 50 replicate samples. Within two weeks we received these replicate data and they aligned extremely well with the same samples run in the Department of Earth Sciences at the University of Minnesota. We continued to wait for the UMN stable isotope lab to come back online; however, by the end of 2016 the machine was still down so we decided to send our remaining samples to Santa Cruz. We are asking for a retroactive approval for this switch because Forester did not realize that approval was needed before changing service providers. The Santa Cruz Stable Isotope Lab is currently processing our samples (2191 samples for $25,719) and should have the results to us in the next few weeks. To get more information on chemical composition of forage, we processed samples using liquid chromatography–high resolution mass spectrometry (LC–HRMS) in the UMN Metabolomics lab ($15,000). Finally, the Knight Lab in UMN preferred to charge us under a Professional Contract instead of us paying salary as originally planned ($5,000). We request the balance of this portion of the budget ($2,084) to be transferred to Personnel.

*Equipment/Tools/Supplies: -$385*
Because much of our sampling was moved to an external lab, we did not need to purchase as much lab equipment and supplies as expected. Of the difference, $5845 is being reallocated to pay for the non-capital GPS receiver; we request the balance ($385) to be transferred to Personnel.

*Capital Expenditures: -$5,845*
Because the GPS system included two different parts (a data recording tablet and a high-precision GPS receiver), they could not be listed as capital expenditures so $5845 was paid out of the Equipment budget. We request the budget for Capital Expenditures ($5,845) be transferred to Personnel.

*Travel expenses in Minnesota: -$39,500*
We were able to find much cheaper than expected accommodation for our field crew, and ended up requiring the vehicle for less time during the year. We also needed to hire the crew at a higher hourly rate to be competitive so we did not pay for meals over the entire period. As a result of these reductions, this budget line was not heavily used. We request the balance ($39,500) be transferred to Personnel.

**Project Status as of 31 June 2017:**
We are still waiting on the results from Santa Cruz. The UMN stable isotope lab realized they had not processed some of our samples they had on file, so they have sent them to Santa Cruz for processing. As a consequence, we moved $2,178 to that contract.

**<u>Overall Project Outcome and Results</u>**
We examined characteristics of land cover and forage quality that could be affecting the declining Minnesota moose population at multiple spatial and temporal scales. At a broad spatial scale, we found that the landscape of NE Minnesota has changed over 18 years, both in the composition (e.g., more coniferous and less mixed-wood forest) and arrangement (e.g., decreased fragmentation of coniferous forest and increased fragmentation of mixed-wood forest) of forested land-cover types. At the scale of the moose survey unit (2.8 x 5 miles), some of these changes appear to be related to moose population dynamics. Specifically, moose tended to have higher population growth rates in cooler areas and in survey units that had more young and mixed-wood forest, less coniferous and deciduous forests, and less fragmented forested wetlands. We found that, during summer, moose are in fact altering their behavior to seek out mixed-wood forest at the hottest times of the day, and because we found that forage availability differs both by cover type and by location in moose range, these decisions may be affecting diet. Further, because the diets of animals that died were different from those of live

animals, we suspect that the availability of high-preference foods may be critical. Because several independent sources of data all point in a similar direction, we recommend a large-scale, long-term experiment to explicitly test how different combinations of land cover and food availability may be affecting moose habitat use and population dynamics. Specifically, we suggest working with forest managers to harvest blocks of forest stands to manipulate overstory and understory features that appear to be important to moose. Monitoring the success of these manipulations with collared animals and camera traps over a 5-10 year period could help determine how to best manage forest landscapes for a healthy moose population.

**Project Results Use and Dissemination**

This research has been presented 15 times at national or international research conferences or invited seminar series. The research team has worked with the Bell Museum to contribute information related to the moose diorama and also provided an extensive interview to the "Access Minnesota" radio show. Three scientific articles have been published so far, and the research team is working with MNDNR and tribal biologists to discuss the results and implications of this work. Finally, 12 undergraduate students, five graduate students, and three postdoctoral researchers received training as part of this project; results from this research have been added into teaching materials in two required Fisheries, Wildlife, and Conservation Biology courses at UMN.

## IV. PROJECT ACTIVITIES AND OUTCOMES:

**ACTIVITY 1:** Linking moose abundance to broad-scale distributions of food and cover that change across space and through time.

**Description:** We hypothesize that broad-scale changes in the arrangement (rather than simply the abundance) of important cover types (e.g., young and mature forest, wetlands) measured at the level of four townships or larger will be linked to changes in moose abundance. Areas dominated by one cover type (e.g., young forest) will be avoided in preference for areas that contain a mixture of cover types that provide reduced distances between thermal cover and high quality forage. We will use a combination of USFS Forest Inventory and Analysis (FIA) data and 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 Minnesota range.

Our broad-scale analysis will use data from the 2012 FIA database in addition to time series of classified satellite images. The FIA data will be analyzed using geographic information system (GIS) techniques to examine differences in the amount and types of habitat available to the moose population in different survey zones. We will also create a new satellite classification for portions of the moose range in NE Minnesota. This classification (based on historic and current satellite images) will be specifically developed to focus on moose habitat and will subsequently be analyzed using Fragstats and texture statistics to describe how the amount and distribution of different land cover types change across space and through time. The results of these two analyses will then be compared with the relative abundance of moose on plots with differing habitat characteristics.

To understand the process that may lead to moose selecting one landscape over the other, we need to understand how forage availability changes across space. We will characterize the forest communities in 61 sites (Figure 1) that represent a range of cover types and known disturbance histories. Our sampling methodology is adapted from previous studies in Superior and Chippewa National Forests and will help us predict how forage resources change in response to land-surface attributes (e.g., soil type, aspect, land cover). These data will allow us to determine whether coarse distributions of food and cover are correlated to local estimates of moose abundance.

Finally, to quantify how the moose population is responding to changes in the landscape, we need to describe how the spatial distribution of the animals has changed through time. 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 will allow us to make relative estimates of local abundance over the last 8 years. Using these results we will determine if there is spatial variation in local moose population trends and whether this variation is linked to changes in landscape characteristics.

**Summary Budget Information for Activity 1:**

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|---|---|
| **ENRTF Budget:** | **$ 140,911** |
| **Amount Spent:** | **$ 118,328** |
| **Balance:** | **$ 22,583** |

**Activity Completion Date:** *September 2016*

| Outcome | Completion Date | Budget |
|---|---|---|
| 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 | $ 8,570 |
| 2. Produce a new classification of satellite data for NE MN to show how the distribution of high-quality moose habitat has changed in recent years. | September 2015 | $ 36,848 |
| 3. Identify how the species composition of moose forage changes among land-cover types and in response to stand age. | December 2015 | $ 69,448 |
| 4. Publish a spatially-explicit analysis of how moose population density changes in response to availability and arrangement of forage in the landscape. | September 2016 | $ 13,012 |

**Activity Status as of 1 December 2014:**
Data from 1,258 FIA plots has been compiled and summarized for each moose survey block. Existing land-cover data have also been summarized in those areas. We have completed an initial population analysis and will be summarizing our results in a manuscript we hope to submit early in 2015.

**Activity Status as of 31 May 2015:**
We have continued to analyze population data and have identified two labs at UMN to produce current and historic moose-specific land-cover data for this region. Joe Knight's lab will lead the 2013 update and Mike Falkowski's lab will produce historical satellite classifications so that we can compare previous populations to changes in cover type availability. We have updated the moose population data and FIA data and are continuing to develop a model that describes how the population responds to broad-scale change. Although still a preliminary analysis, we see that the areas with larger amounts of forest that also include mixtures of young birch and aspen tend to host larger local moose populations; however, broad-scale changes in landscape composition did not account for the majority of the region-wide decline. Once we have satellite classifications through time, we will be able to determine if annual changes in the structure and arrangement of the landscape is important. Our postdoc, Garrett Street, has been compiling moose location data from the DNR, Voyageurs National Park, and the Grand Portage Band to examine if changes in daily temperature during the summer affect how the animals select habitat. We are planning to compare these data to moose movement data collected in Ontario in the mid 1990s to see if there are differences in behavior across a broader range of habitats and ambient temperatures.

**Activity Status as of 31 January 2016:**
The production of our landcover maps is still in progress in part because Mike Falkowski left UMN for a job at Colorado State; his lab is continuing to work on the product and expect to deliver in early summer. Our 2013 map was also delayed but is nearly finished and we expect a draft in March. Despite this setback, we have been progressing well with the analysis of how moose use the landscape. The postdoc on this project, Garrett Street, has finished compiling moose movement data from a variety of sources in Minnesota and Ontario (the population in Ontario is not experiencing a decline and thus provides a useful comparison). Using a much coarser land-cover classification, we analyzed how the animals alter their habitat selection through the day and

as temperatures change during summer. We found that habitat selection patterns of moose in Minnesota were more dynamic than those in Ontario and indicated time- and temperature-dependent trade-offs between use of foraging habitat and thermal cover. Specifically, we found that during the hottest part of the day, Minnesota moose tended to choose landscapes with large amounts of treed wetlands and coniferous forest – both cover types that provide fewer and lower-quality foraging opportunities. Ontario moose tended to spend more time in mixedwood forests where thermal cover and foraging opportunities are in close proximity; this cover type is more abundant and evenly distributed in Ontario compared to Minnesota. These results suggest that differences in landscape structure may drive moose to select sub-optimal habitat when temperatures rise in the summer; this selection behavior may have long-term consequences if animals must repeatedly forgo foraging opportunities and more frequently travel between foraging habitat and thermal cover. Our next steps will be to more closely examine how variation in movement behavior is explained by broad-scale habitat characteristics.

**Activity Status as of 31 May 2016:**
We have received the updated classification of moose-specific cover types for NE Minnesota; production of the historical land-cover dataset is in progress and we expect to receive those classifications by August. We are now working on the analysis of how forage diversity and abundance change among cover types and disturbance histories; this analysis will be completed by the end of summer. In March, we collected winter browse across our study area and are preparing those samples for analysis. We are also preparing for our final field season in which we will focus primarily on collecting data in forested wetlands.

**Activity Status as of 1 May 2017:**
We have developed an improved spatially-explicit population estimation model that accounts for sightability of moose. Upon receiving the historical land-cover data on 28 April, we began calculating landscape metrics for all of the moose survey units (for time periods starting in 1999 to present). We are now starting to include metrics of land-cover arrangement and composition to see if they have an effect on local populations of moose. Our initial findings, that include only Forest Inventory and Analysis data and three years of Landsat cover-type composition data, suggest that moose populations decline slower in areas that have lower summer and winter temperatures and where there are mixtures of mature forest and young deciduous forest. We are attempting to use maps of land-cover type, LiDAR estimates of vegetation complexity, and topographic position to model forage biomass availability across moose range. This model will be important to provide context to the moose diet estimates we are developing for Activity 2 (i.e., it will allow us to determine if there is diet selection in the different areas); however, our field data show that biomass is highly variable even within cover types, so we are looking to add additional information (e.g., soils data) to improve our predictive power. To predict the proportion of time moose are travelling, foraging, and resting at different times of the day and when they are in different land-cover types, we have developed models (using observations of captive moose) to use activity data to predict behavior (our preliminary analysis is only on three animals, but these activity data are available for all animals for which we have recovered GPS collars). This analysis shows that in the summer, moose forage the most during dawn and dusk, and spend > 75% of their time resting during the middle of the day. Our next step is to link these behavioral patterns to the habitat use and diet composition of specific animals.

**Final Report Summary:**

I. Landscape analysis (Outcomes 1.1, 1.2)

Two separate products were created for this portion of the project. First, the Knight lab at UMN reclassified the northeastern portion of the state using the same approach they used to produce their most recent state-wide classification but with the added goal of identifying key moose habitat types. Our field plots provided additional ground-truth data for this object-based product in which land cover was classified into moose-centric cover types. This product was used for all analysis of diet and movement patterns of moose because it uses many sources of current data (e.g., LiDAR, current ground-truth points). Because all of the supplementary data sources are not available before 2011, we needed a second approach to produce historical land-cover maps. This second product was a time series of classified imagery produced by the Falkowski lab. These data relied on historical Landsat imagery and yielded biennial land-cover maps for the study region from 1999 to 2016. This time series allowed us to identify changes in forest composition through time for the population analysis (Outcome 1.4). Both of these datasets will be made publically available on UMN DRUM in fall of 2019.

To determine how the forested landscape of northeastern Minnesota has changed in recent years, we analyzed two sources of land-cover data: the US Forest Service's Forest Inventory and Analysis (FIA) data (based on repeated surveys of forest stands from 2005 to 2015) and an 18-year, biennial time series of classified satellite data (from the Landsat satellite). We found that there has been a surprising increase in the amount of conifer forest (12% of the average moose survey unit in 1999 compared to 20% in 2015, Figure 1.1), with a decrease in mixed forest (i.e., a fine-scale mixture of deciduous and coniferous trees; 30% in 1999, 26% in 2015) and forested wetland (18% in 1999, 11% in 2015). Although the proportion of deciduous forest has stayed relatively stable since 2005 (at about 16%), the FIA data show that the composition of those stands is changing, in part due to declines in aspen, birch, and willow (key food sources for moose).

In addition to changes in the proportions of the dominant forest cover types, from 1999 to 2015 the overall landscape has become more fragmented: current landscapes have a greater edge density due to patches of different land-cover types having more complex edges (mean Edge Density increased from 8453 in 1999 to 9428 in 2015). This increase in fragmentation is subtle, but appears to be driven by decreases in the aggregation of forested wetlands and mixed forest, and increases in the edge-to-area ratios of patches of those cover types (Figure 1.2). Despite the overall increase in fragmentation, as coniferous forest has become more dominant in the region, this cover type has become more aggregated with lower edge-to-area ratios (i.e., less fragmented).

The implications of these changes on moose populations are that the landscapes in which they live are being altered in ways that may be suboptimal for their needs. While all land-cover types are used by moose in some fashion, the relative amounts of these cover types, their distribution in the landscape, and the plant composition of their understory (i.e., the quality and abundance of moose food) will affect where moose go and how well they are able to survive and reproduce when they get there.

## II. Forage availability (Outcome 1.3)

### *a) Forage availability by cover type*

We estimated forage availability at 70 sites distributed within three broad areas of moose range (Figure 1.3). These areas were distinguished by their summer temperatures (Figure 1.4) and are referred to as Cold (NE portion of moose range near Grand Marais), Moderate (SE portion of moose range near Isabella), and Warm (NW portion of moose range near Ely). We classified potential food plants into four different groups based on previous studies of moose dietary preference: aquatics, high, medium, and low. The species that we categorized into each group are as follows:

- aquatics – all aquatics collected from the warm and cold regions
- high – paper birch, trembling aspen, and all willows.
- medium – all cherries and maples, as well as mountain ash
- low – all species of service berry, dogwood, and alder, in addition to balsam fir, beaked hazel, and any other species that are not included in the original preference study but might be encountered and sampled on an occasional basis (e.g., green and black ash, red pine, and white pine)

Using standardized methods developed by the UMN Department of Forest Research, we recorded the species composition and biomass of each of the forage preference groups. We found that all forest types had greater amounts of high-preference forage in the Cold region, while the Warm and Moderate region forests had more low-preference forage (Figure 1.5).

Collectively, our results suggest that cover type plays an important role in dictating the availability of forage for moose, with mixed and coniferous forest types offering more forage than any other cover type (Table 1.1). When compared to the amount of forage available in conifer habitat, grasslands and regenerating forest had substantially less food available to moose. Although we also found statistical evidence that deciduous and wetland habitat offer less forage for moose, the support for this relationship was not as strong (Table 1.1). We were initially surprised that regenerating forests tended to have much lower forage availability than other cover types; however, the reason for this is that regenerating forests are highly variable in biomass and species composition depending on the age of the regeneration (e.g., one year after a severe fire would have different forage availability than 10 years after a fire).

Overall, our results emphasize the importance of mixed-wood forest, which tended to have as much or more forage biomass than coniferous stands. It is also important to point out that while forage from different preference groups also varied among cover types, these differences were strongest for low and medium-preference forage (Table 1.2). Evidence for differences in the availability of high-preference forage among cover types was marginal.

**Table 1.1** Results of generalized linear model testing the influence of cover type on overall forage availability. We used coniferous forest as our reference category.

| cover type | estimate | standard error | t-value | p-value |
|---|---|---|---|---|
| deciduous forest | -0.3780 | 0.1868 | -2.023 | 0.0472* |
| wetland | -0.3779 | 0.1678 | -2.252 | 0.0278* |
| grassland | -0.6894 | 0.1647 | -4.185 | 0.0001* |
| mixed forest | 0.1745 | 0.1715 | 1.018 | 0.3126 |
| regenerating forest | -0.6147 | 0.1596 | -3.851 | 0.0003* |

*Indicates a statistically significant difference ($\alpha = 0.05$) when compared to our reference group (coniferous forest).

**Table 1.2** Results of one-way ANOVAs assessing how forage from different preference groups varies among cover types. For all tests we used coniferous forest as our reference cover type.

| preference group | cover type | estimate | standard error | t-value | p-value |
|---|---|---|---|---|---|
| low | | | | | |
| | deciduous forest | -0.20543 | 0.07876 | -2.608 | 0.0113* |
| | wetland | -0.11318 | 0.07075 | -1.600 | 0.1146 |
| | grassland | -0.35465 | 0.06944 | -5.107 | < 0.0001* |
| | mixed forest | 0.11146 | 0.07227 | 1.542 | 0.1279 |
| | regenerating forest | -0.29696 | 0.06728 | -4.414 | < 0.0001* |
| medium | | | | | |
| | deciduous forest | -0.03562 | 0.03582 | -0.994 | 0.3238 |
| | wetland | -0.10010 | 0.03218 | -3.111 | 0.0029* |
| | grassland | -0.10826 | 0.03158 | -3.428 | 0.0011* |
| | mixed forest | -0.03089 | 0.03287 | -0.940 | 0.3508 |
| | regenerating forest | -0.10483 | 0.03060 | -3.426 | 0.0011* |
| high | | | | | |
| | deciduous forest | -0.13694 | 0.12419 | -1.103 | 0.2743 |
| | wetland | -0.16466 | 0.11157 | -1.476 | 0.1449 |
| | grassland | -0.22644 | 0.10950 | -2.068 | 0.0427* |

| | | | | |
|---|---|---|---|---|
| mixed forest | 0.09395 | 0.11397 | 0.824 | 0.4128 |
| regenerating forest | -0.21289 | 0.10610 | -2.007 | 0.0490* |

*Indicates a statistically significant difference ($\alpha$ = 0.05) when compared to our reference group (coniferous forest).

*b) Forage availability by stand age*

The 70 semi-permanent plots that we sampled represented disturbed stands from three different time periods (2002, 2006, and 2011) in addition to areas that have not experienced any known disturbance in the recent past (≥ 25 years). For each of the stand ages, we calculated the mean biomass (kg/m$^2$) of each forage preference group across different stand ages (≥ 25 years, 13 years, 9 years, and 4 years) to estimate how biomass availability changes with disturbance in each temperature region (Figure 1.6). There was no significant difference with respect to disturbance age for any class except the medium-preference forage (there was slightly more of this food source in the 13-year old stands); however, the warm and moderate regions had consistently lower biomass in all preference groups and stand ages, compared to the cold region (Figure 1.6).

We used generalized linear models to determine if the overall availability of forage varies as a function of stand age and multivariate analysis of variance (MANOVA) to determine if the availability of forage from different preference groups varies as a function of stand age. For MANOVA tests that had a significant effect, we performed one-way ANOVA's to determine the most important relationships.

The influence of stand age on forage availability varied among age categories (Table 1.3). Specifically, overall availability of forage in 9-year old stands is significantly lower from that available in control plots (stand age ≥ 25 years), whereas there was no difference between control plots and stands that were either 4-years old or 13-years old. However, despite this lack of significance, the disturbed stands typically had less biomass than the control plots (Table 1.3). The relative proportions of different forage preference groups was highly variable, but the moderate and warm regions were more similar in their distributions than the cold region (Figure 1.5).

**Table 1.3** Results of generalized linear model testing the influence of stand age on overall forage availability. We used forest stands with an age of 25 years or more as our reference category.

| Stand Age | estimate | standard error | t-value | p-value |
|---|---|---|---|---|
| 4 years | -0.3587 | 0.2129 | -1.934 | 0.0575 |
| 9 years | -0.4587 | 0.2150 | -2.134 | 0.0367* |
| 13 years | -0.4117 | 0.2092 | -1.714 | 0.0912 |

*Indicates a statistically significant difference ($\alpha$ = 0.05) when compared to our reference category.

III. Moose Population Density (Outcome 1.4)

We examined how moose were distributed across the region by quantifying, 1) what landscape and environmental factors affect moose movement and habitat selection decisions, and 2) how broad-scale characteristics of the landscape (e.g., the composition of forest cover types within each moose survey unit) affect the local population growth of moose. To describe the individual-scale patterns of moose habitat use, we examined how moose in Minnesota changed their movement patterns in response to available habitat and ambient temperature. We then compared these patterns to those from moose in Ontario, Canada. We estimated summer resource selection models for 134 adult female moose in Minnesota and 64 in Ontario. We found that while the moose in Ontario did not show strong patterns of resource selection (and very little response to ambient temperature), the Minnesota moose had strong patterns in selection that changed both throughout the day and in response to temperature (Figure 1.7). In particular, MN moose selected for mixed forests and treed wetland during the middle of the day and whenever the temperature was above their thermal optimum (i.e., 14° C). In the evening hours, or during lower temperature periods, the moose tended to favor open uplands. Overall, moose used the mixed forest type much more than expected based on availability throughout the day. This suggests that it is a critical habitat for moose, likely because of the large amount and diversity of forage available (see II above) and because of the fine-scale mixture of coniferous and deciduous trees that allows for thermal cover during the hottest parts of the day. The contrast with moose from Ontario was marked; however, this difference is likely because the mixed forest type dominates the Ontario landscape, so moose have an abundance of thermal cover and food and thus do not need to alter their foraging or movement patterns in response to temperature. These results were published in *Landscape Ecology*: Street et al. 2016, and an advance in statistical methodology that stemmed from this research was published in *Ecography:* Fieberg et al. 2017.

To determine what factors might be linked to changes in moose population density across the range, we developed a spatially explicit population model that used raw data from the DNR moose survey to estimate differences in population growth rate. After using moose resource selection patterns during the survey period to calibrate sightability, we found that moose populations were greater in areas with more mixed and young forest but less deciduous forest and open water (Figure 1.8). Populations were also greater in areas with larger patches of regenerating forest, smaller patches of coniferous forest, and less fragmented forested wetlands. Finally, moose populations did worse in areas and years where there were higher than usual summer temperatures (i.e., the heat stress index was greater). Clear patterns of high and low populations emerge across moose range, but they also change through time (Figure 1.9). When the predicted number of moose per survey unit was summed, the range-wide population estimate of this model is very similar to that produced for the region by the MN DNR (Figure 1.10). The advantage of our spatially explicit model is that it allows researchers and managers to more closely examine areas that are either doing well or declining in numbers and then use what is learned there to develop targeted interventions.

This model explains how spatial and temporal variability in temperature and land cover can directly affect moose populations; however, despite the influential patterns we have discovered, it is important to note that there was a large, unexplained annual effect that was not directly linked to the factors we measured. Further, some factors may have important interactions with each other, may only be correlated with true drivers of population dynamics, or have effects that operate on a time lag greater than one year. For example, temperature alone (here included as summer Heat Stress Index, or the cumulative number of degrees that exceed 14°C during the summer) cannot explain the decline of the moose population by itself. This index was actually higher for more years in the late 1980s (Figure 1.11), and while there are no reliable moose population estimates from that time period, anecdotal evidence does not support a previous decline in this region. This model should be used to develop large-scale experimental manipulations in moose range to determine how altering the pattern of forest patches can affect usage by moose (and subsequent effects on the local population size). Future work with this model will involve collaborations with researchers currently monitoring moose habitat restoration areas and land managers of state, federal, private, and tribal land. The goal will be to initiate long-scale manipulations that will be monitored for long time periods (10-20 years).

Figures (Activity 1)

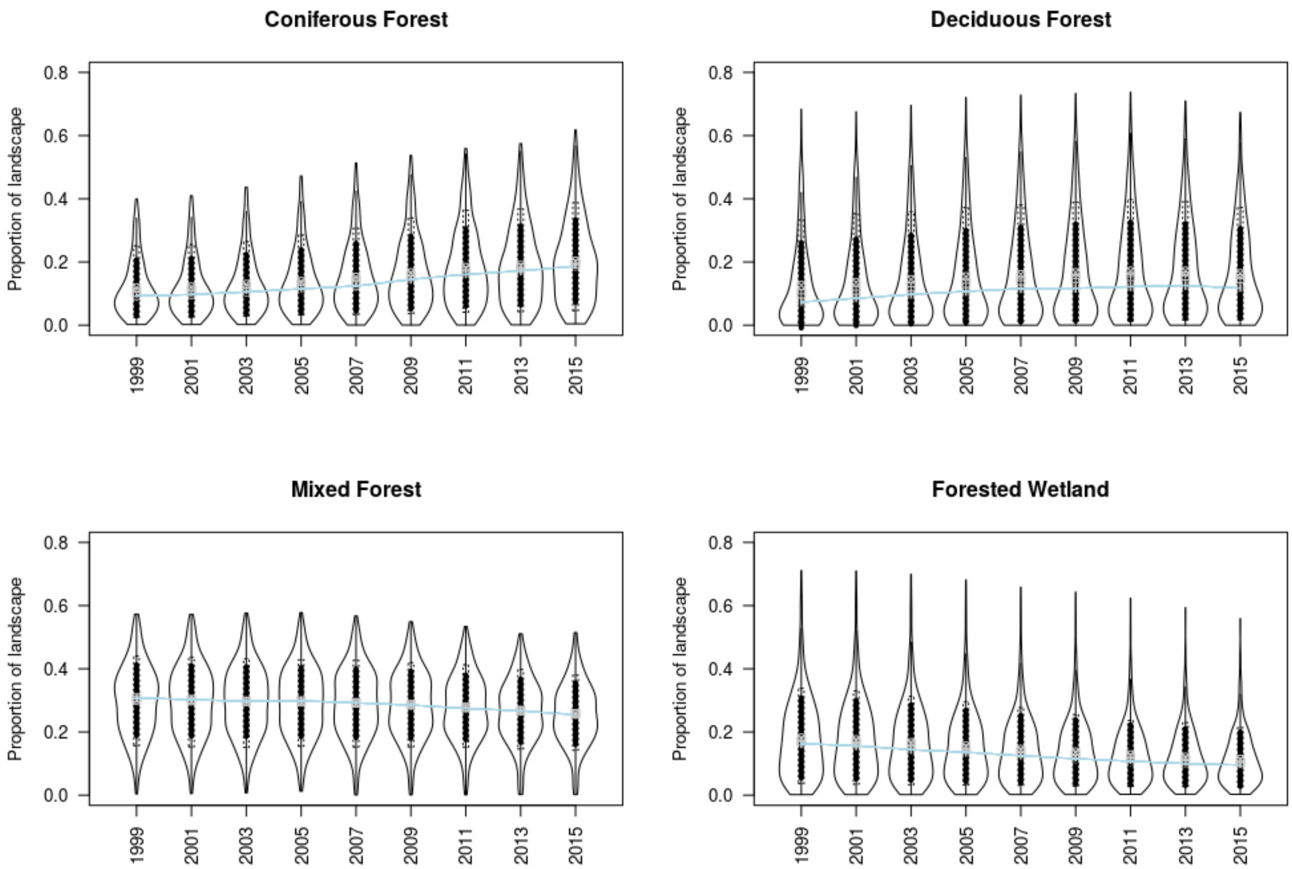



**Figure 1.1** *Violin plots of the proportion of dominant forest types in moose survey units from 1999 to 2015.*

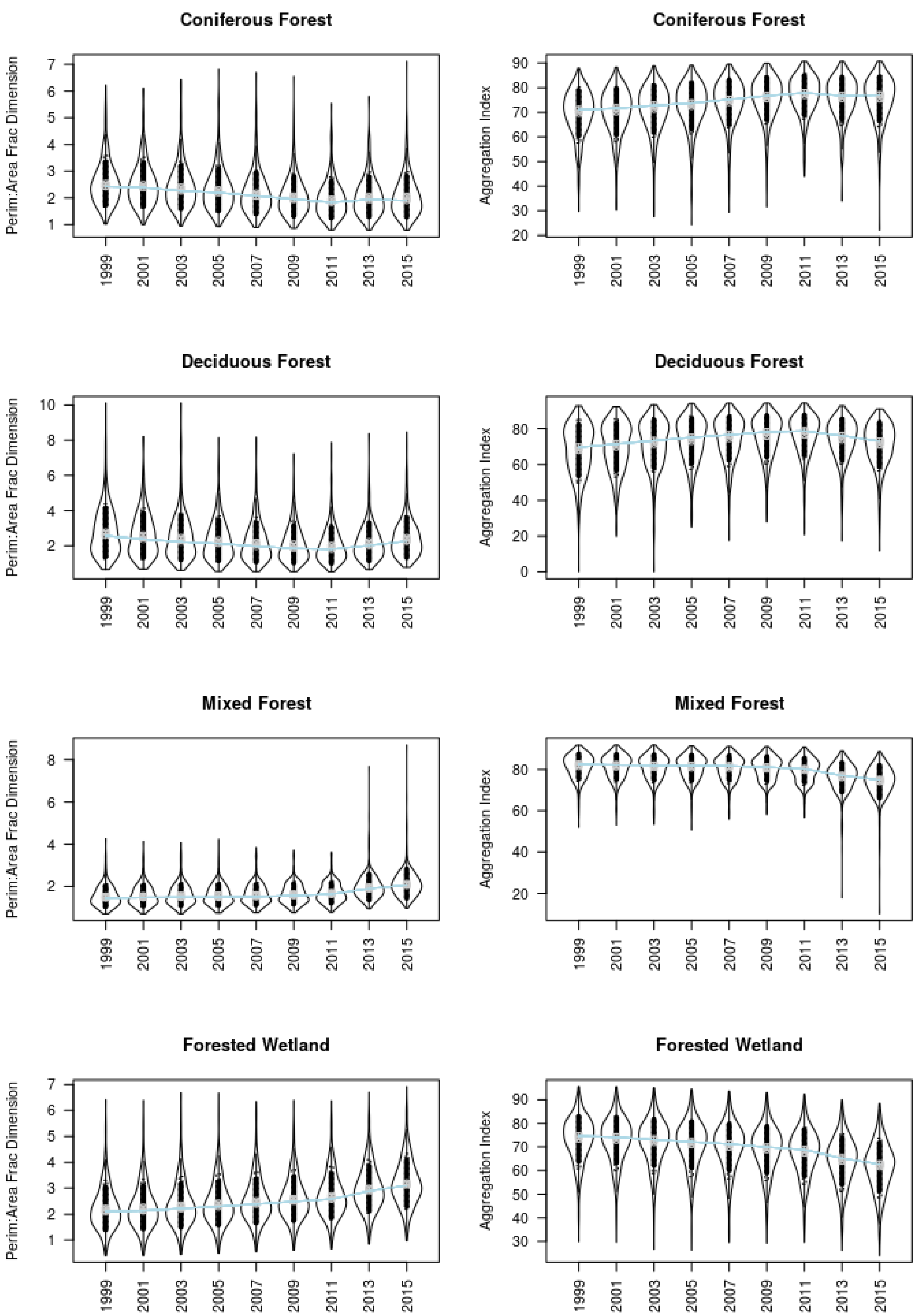



**Figure 1.2** *Two measures of fragmentation calculated for the major forested cover types. Larger values of the Perimeter:Area Fractal Dimension metric indicate that patches of that cover type tended to have more complex edges (the smallest possible value of 1 would indicate a square patch). Larger values of the Aggregation Index indicate that the cover type in question tends to be in fewer numbers of tightly packed patches in the landscape. Collectively, these figures show that Conifer forests have become less fragmented while the other cover types, especially Forested Wetlands and Mixed Forest, have become more fragmented.*

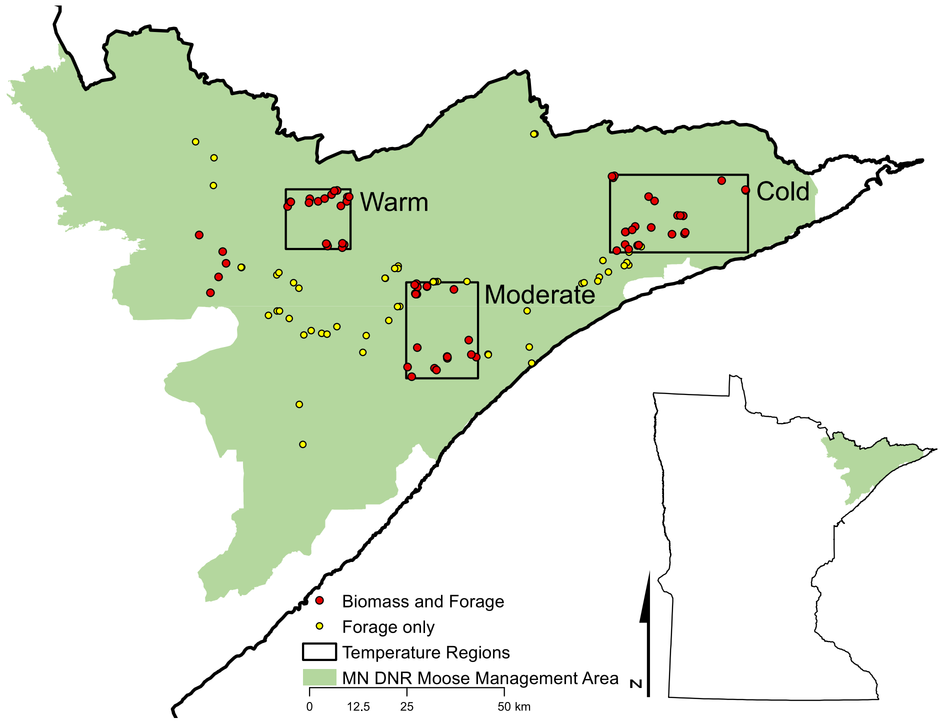



**Figure 1.3** *Distribution of biomass plots, forage sampling plots, and designated temperature regions across northeastern Minnesota. Biomass data and forage samples for stable isotope analysis were collected at those locations identified as "Biomass and Forage." Sites identified as "Forage only" were visited for the sole purpose of collecting forage samples.*

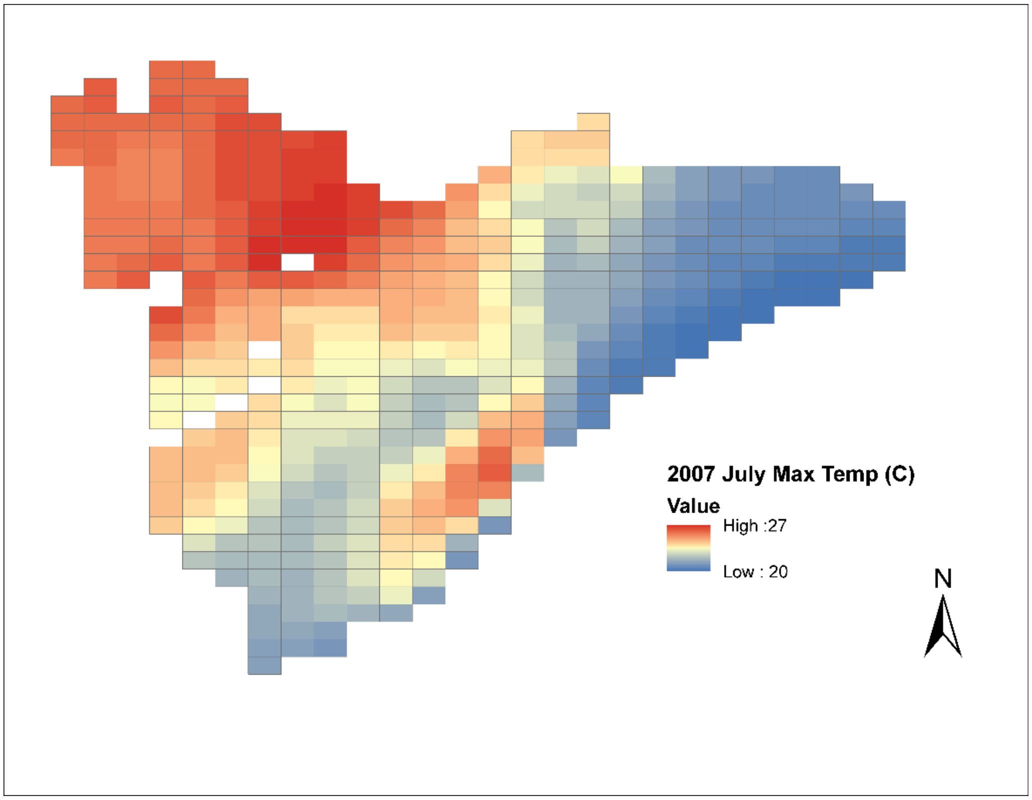



**Figure 1.4** *Mean maximum July temperatures in survey blocks across moose range in 2007. Temperature data are from the PRISM data set.*

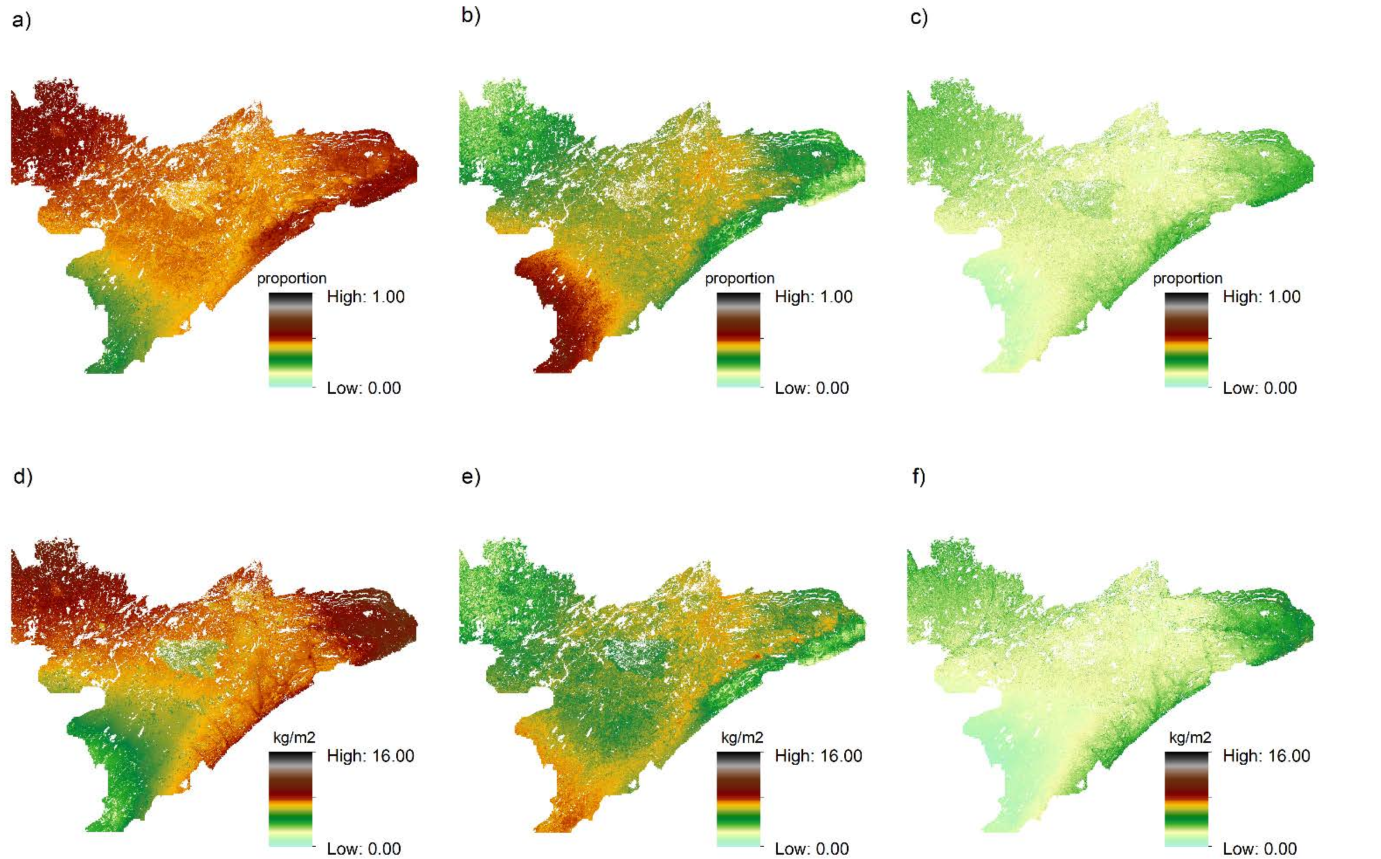



**Figure 1.5** *Maps of the relative abundance (a, b, c) and estimated biomass (d, e, f) of the three preference groups of terrestrial forage: Low (a, d), Medium (b, e), and High (c, f). Low-preference forage is present and abundant throughout the study area, but High-preference forage is much more prevalent in the northeastern portion of moose range.*

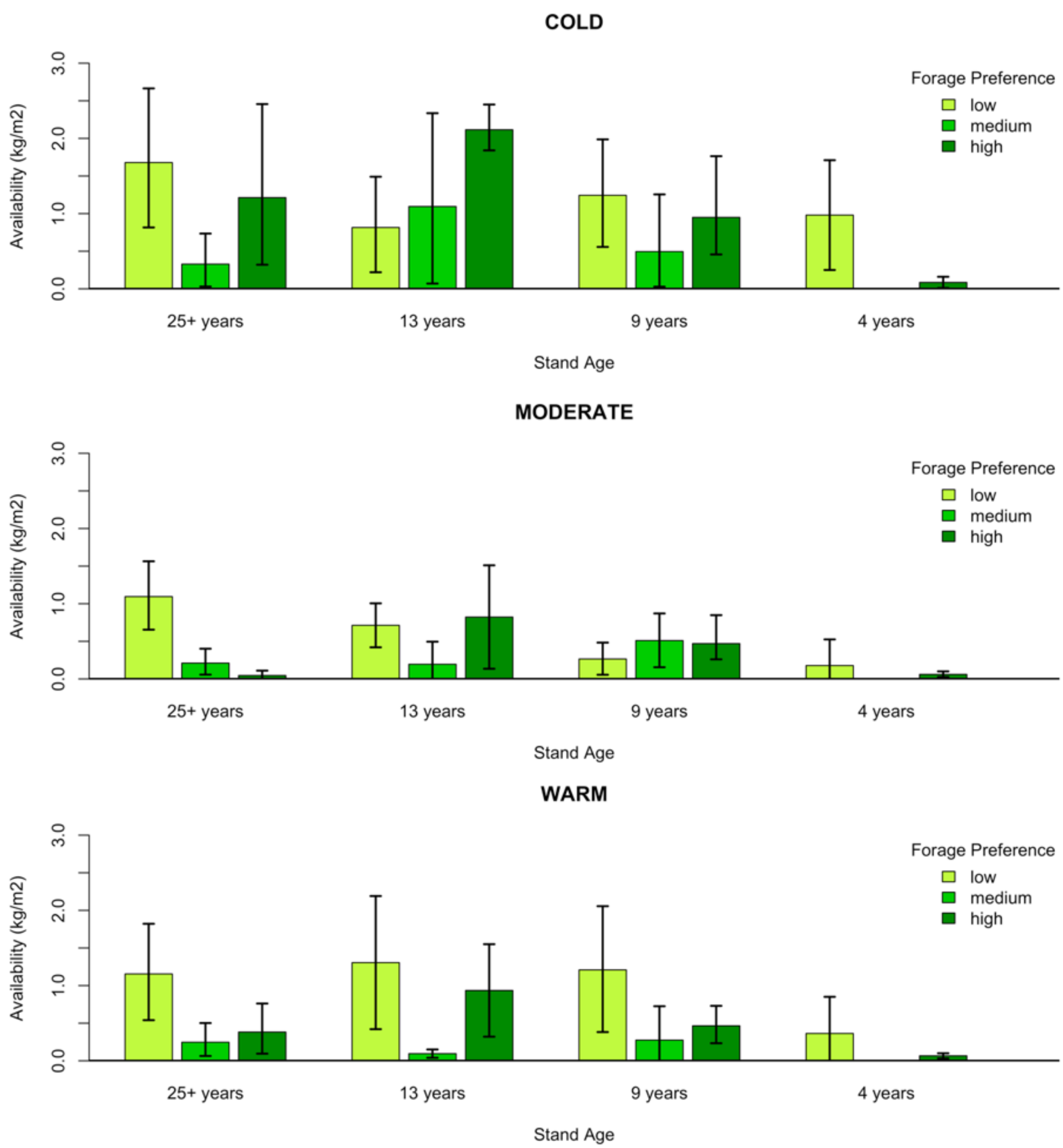



**Figure 1.6** Availability of different forage preference groups (low, medium, high) within each temperature region, as a function of stand age. Lines represent 95% bootstrapped confidence intervals.

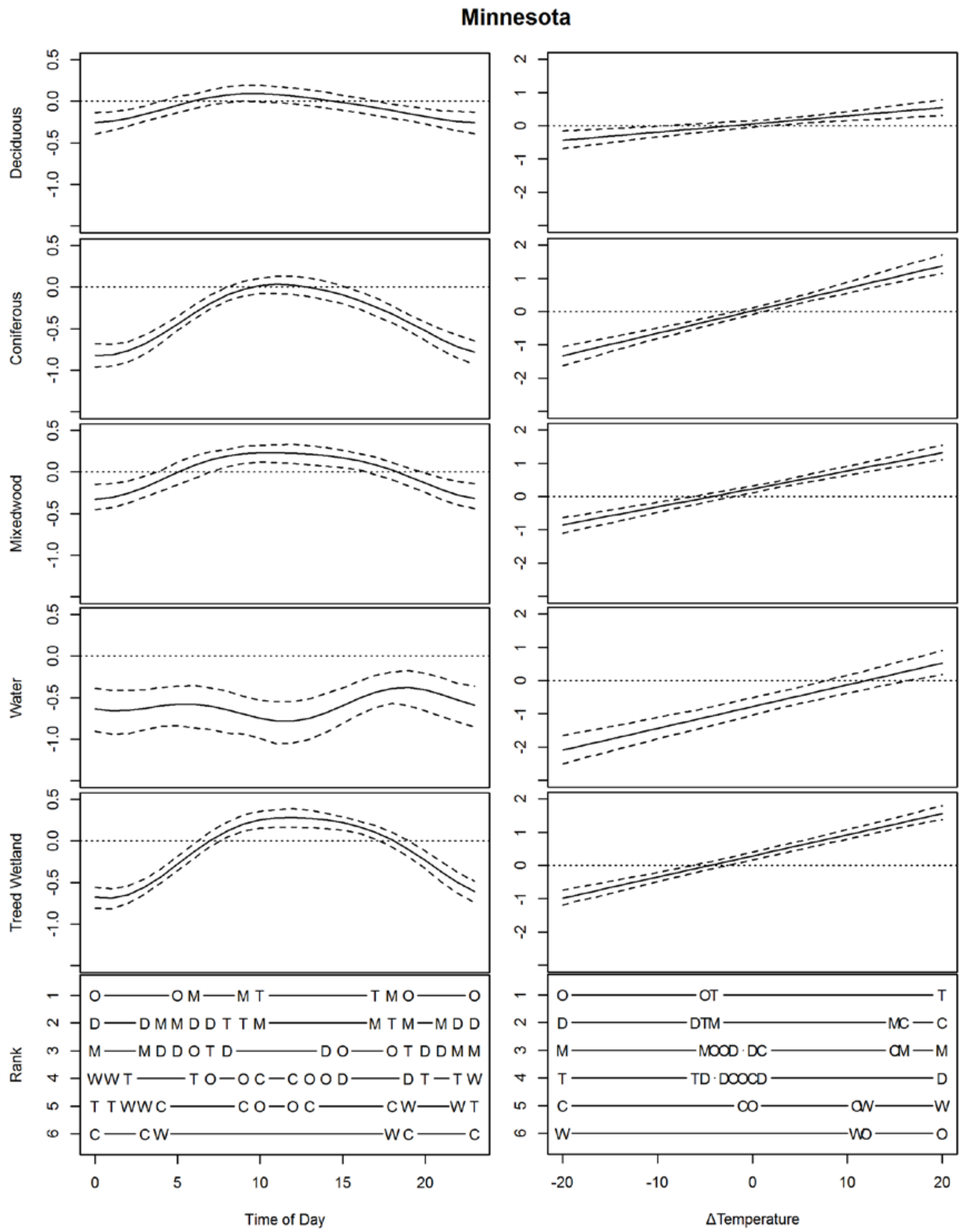



**Figure 1.7** *Predicted selection strength (log relative risk, solid lines) by moose with 95 % Confidence Intervals dashed lines) for 100 % cover by land cover classifications during summer (June 1–September 30) in Minnesota across both time of day (left column) and temperature (C) scaled to moose upper thermal optima (right column). Temperature is held constant at the moose upper thermal optimum (i.e., Δ Temperature = 0° C) in time of day plots, and time is held constant at noon in Δ Temperature plots. Bottom panels indicate relative rank of selection strength for each land cover class (D deciduous; C*

*coniferous; M mixed forest; W water; T treed wetland; O other) across the diurnal cycle and temperature gradient. Figure from Street et al. (2016).*

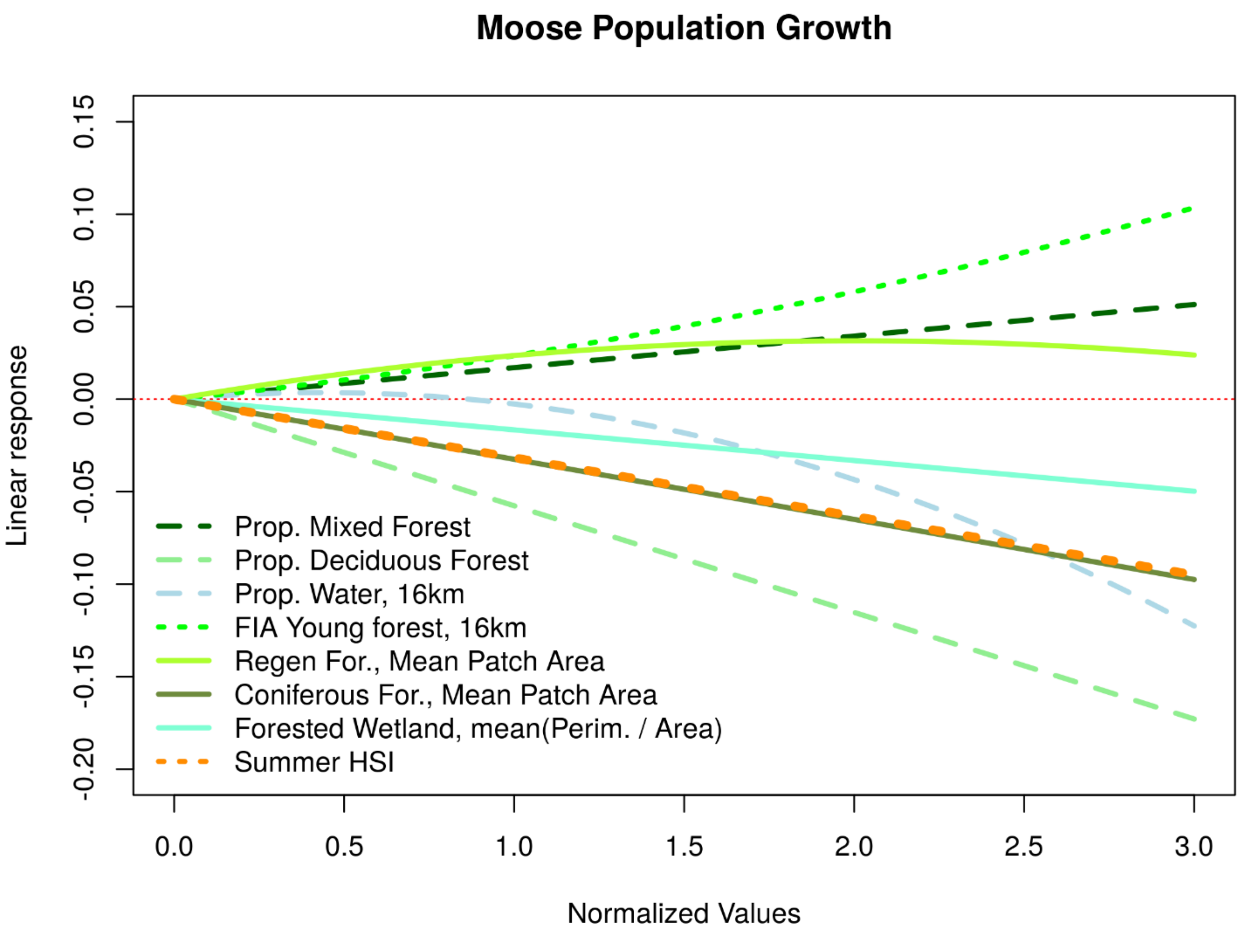



**Figure 1.7** *The effect of different factors, calculated at the level of moose survey units, on the population growth rate of moose. All factors are normalized to allow for direct comparison of their effects.*

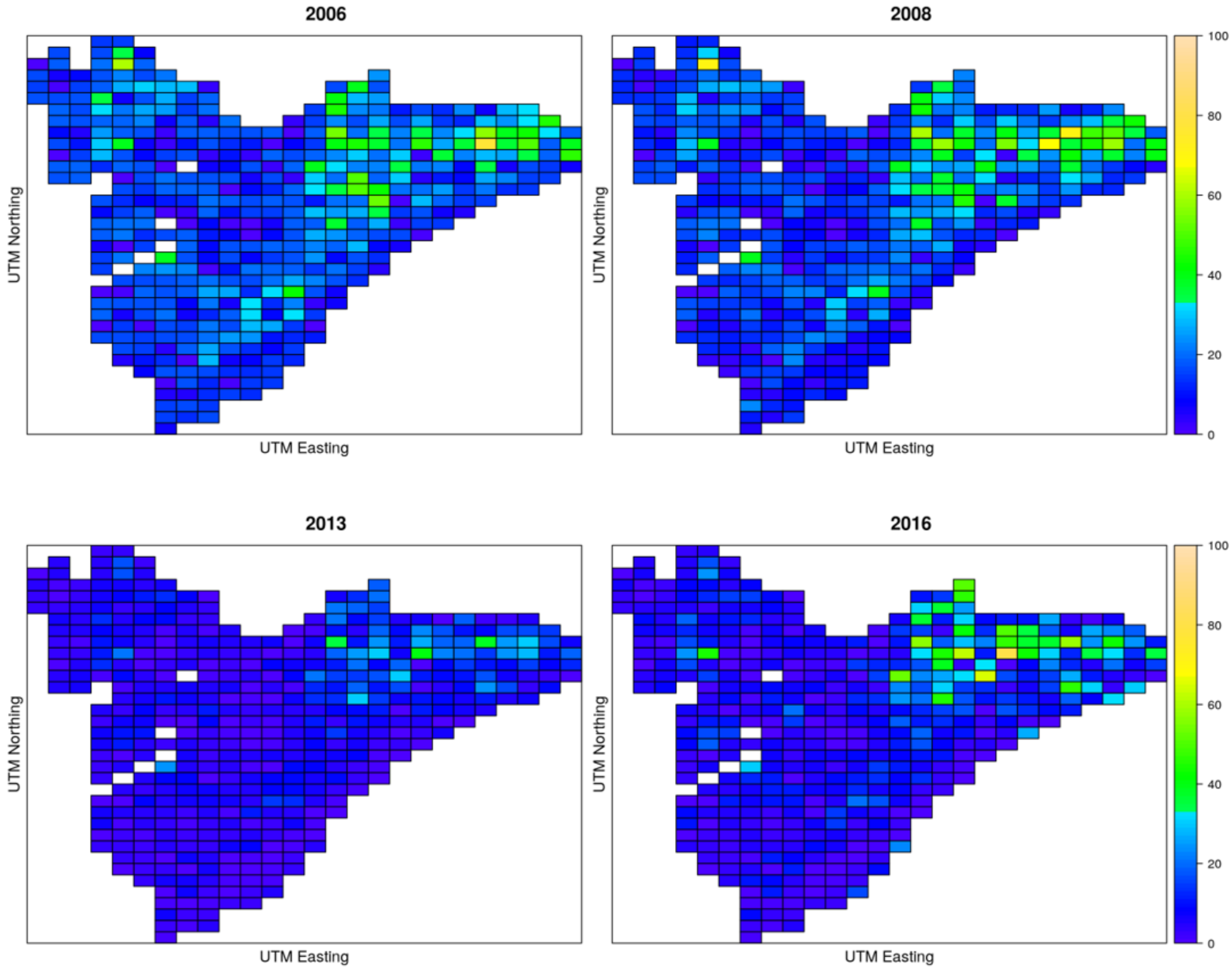



**Figure 1.9** *Spatially explicit estimates of the Minnesota moose population through time. Rectangles are moose survey units established by MN DNR.*

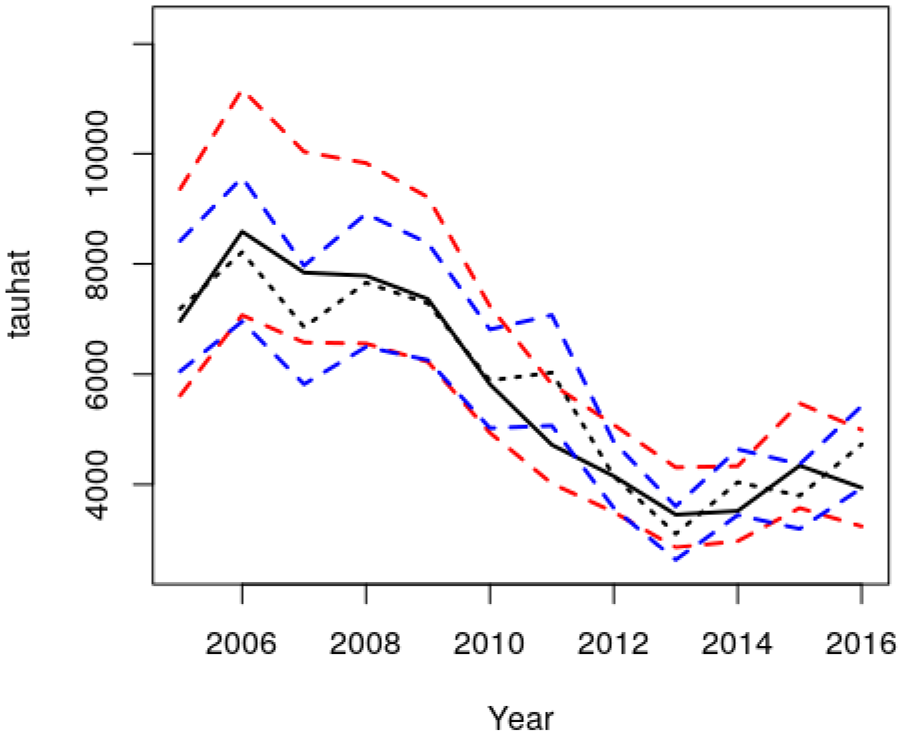
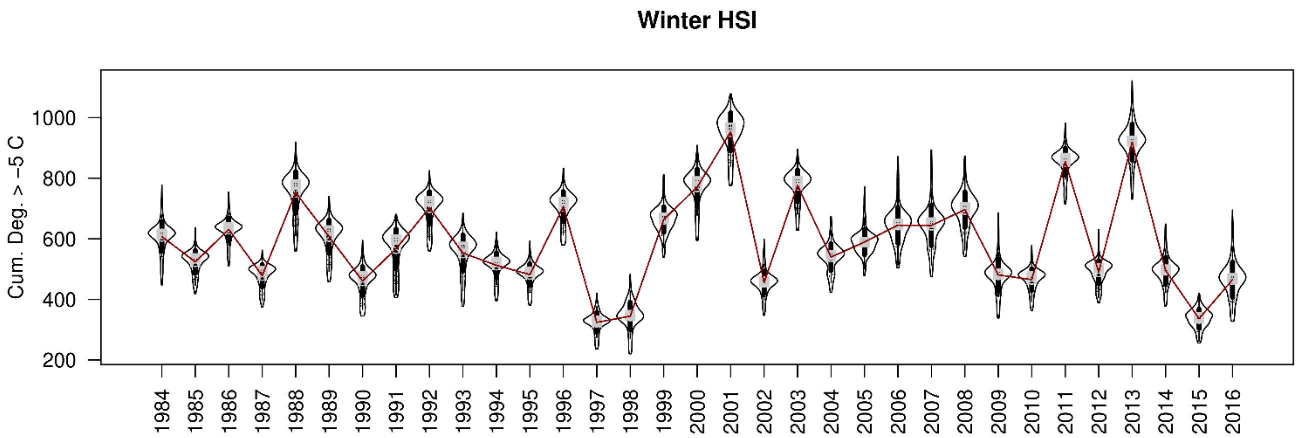



***Figure 1.10*** *Region-wide population estimations through time. The solid black line is the MN DNR estimate based on an established sightability model (red lines are 90% prediction intervals). The dotted black line is the population trajectory estimated from the spatially explicit model developed here (blue lines are 90 % prediction intervals).*



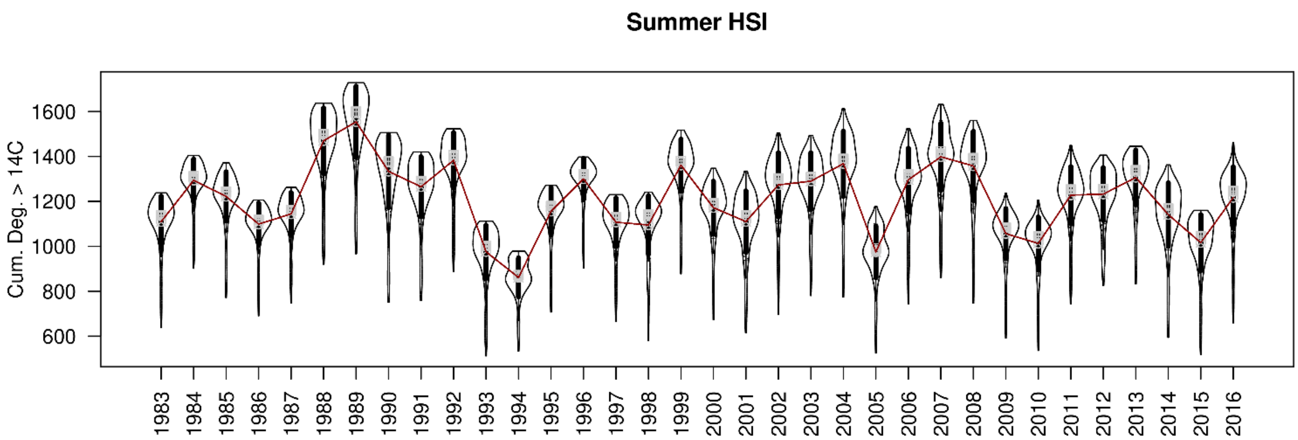




**Figure 1.11** *Violin plots of Heat Stress Index for Summer (top) and Winter using data collected within moose survey units from 1984 to 2016.*

**ACTIVITY 2:** Linking the distribution and quality of food and cover to moose diet, body condition and mortality risk.
**Description:** We will use stable isotope analysis to determine how the distribution of food and cover affects diet and whether individual movement behavior allows some individuals to have higher quality diets in landscapes with lower quality habitat. We hypothesize that diets of individual animals will reflect the forage available to them within their home range area and that 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. 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. 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.

During Years 1 and 2, we plan four field sessions of unequal duration each utilizing two field teams: (1) in an early spring session we will sample leaves and wood of common forage in one replicate plot of each land-cover type; (2) in a late spring session, we will revisit the same sites to describe early phenological changes in vegetation quality and isotopic composition; (3) in a longer summer session, we will focus on the entire range and sample leaves, wood, and fruiting bodies in three replicates of each land-cover type; (4) a winter session will focus on woody forage in 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. This sampling scheme will control for seasonal and inter-annual variation in forage composition over the course of the project. In Years 2 and 3 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 Years 2 and 3, we will backtrack moose paths known from collar data to sample consumed vegetation and collect snow urine. Given the number of plots and samples planned, flexibility in sampling during Years 2 and 3 is possible and will allow us to concentrate on known home ranges without sacrificing the comprehensiveness of sampling. Year 3 will also include revisits of a subset of sites and marked plants (this year will also include substantial ground truthing efforts for the satellite classifications).

The stable isotopic composition of vegetation sampled in the field will be related to that of moose tissues we collected at capture. To develop robust estimates of diet, we need to analyze a large number (7368) of individual plant and animal tissue samples. For the moose, we will primarily focus on hair and hoof keratin, although we will opportunistically sample feces, bone, and tooth enamel from dead animals. 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, we can assess individual moose diet and habitat use on timescales from days to months to years.

We will use statistical 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, 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. The results from this analysis will allow us to make specific management recommendations related to the distribution and abundance of different land-cover types that will increase the probability of stabilizing the moose population.

**Summary Budget Information for Activity 2:** **ENRTF Budget: $ 159,089**
**Amount Spent: $ 81,606**
**Balance: $ 77,483**

**Activity Completion Date:** *June 2017*

| Outcome | Completion Date | Budget |
|---|---|---|
| 1. Assess the nutrient quality and stable isotopic concentration of forage available in each collared animal's home range. | November 2015 | $118,413 |
| 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 | $15,736 |
| 3. Assess whether forage availability or diet affect the rates of survival. | December 2016 | $33,172 |
| 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 | $4,801 |

**Status as of 2 December 2014:**
During summer of 2014 we sampled vegetation at roughly 140 sites across northeastern Minnesota, and collected more than 2500 plant samples across 8 different species, ranging from low to high preference for moose. At each of these sites, we also estimated browse diversity and are currently working on estimating forage availability throughout the geographic range of moose in northeast Minnesota.

To date, we have logged all plant samples with a unique identification number and are currently preparing to strategically analyze forage samples for stable isotopes of carbon and nitrogen. Currently we have roughly 100 plant samples that are ready for stable isotope analysis. By mid December, we will have an additional 40+ aquatic vegetation samples prepared for stable isotope analysis. In the past month, we have run stable isotope analysis on more than 250 moose hair samples.

**Activity Status as of 31 May 2015:**
The mass spectrometer that we use has been unavailable for the early part of this year; however, we are beginning to run samples again as of 1 May. Using the data we have thus far, we began an exploratory analysis focused on determining whether there is a strong spatial pattern in the stable isotope composition of a key forage species (paper birch) across moose range. This is critical to understand because our goal is to compare the isotopic composition of forage plants to that of moose hair and thus estimate the likely diet of individual animals. Working with an undergraduate UROP student at UMN, we have found that the isotope values of paper birch do vary in a predictable manner based on disturbance history and region. Although our estimates of crude protein (one measure of forage quality) present in the samples were constant across the study region, we found that the carbon and nitrogen isotope ratios of paper birch both increased in stands recently disturbed by wildfire or timber harvest. Further, the carbon ratios and nitrogen ratios increased and decreased respectively in the northwestern portion of the study area (compared to the northeast). Despite this broad-scale effect, there does not seem to be a strong fine-scale pattern to account for other than the impact of disturbance history; we will conduct similar tests with other forage species as the data come in from the mass spectrometer. When examining isotope ratios of moose hair, we see similar patterns: the nitrogen isotope ratios increase from North to South, while the carbon isotope ratios increase from East to West. These trends may be a function of regional changes in the isotopic composition of forage (as observed in paper birch), but they may also result from differences in what is available and palatable to the animals. Our next steps will be to attempt to tease apart these effects.

Our study region includes areas that experience very different summer temperatures (a difference in mean summer temperature of approximately a +6 degrees Celsius from Grand Portage to Ely). Temperature may affect the secondary compounds produced by plants to reduce palatability and digestibility of the plant tissue by herbivores (i.e., an overall reduction in effective forage quality). To understand how this may affect moose forage, we sampled trees grown in the B4Warmed study to experimentally test whether warmer temperatures during the growing season lead to different chemical compositions of paper birch and balsam fir. We will be collecting field samples of these species at our study plots this summer to see if we can detect region-wide and land-cover specific differences in the impact of summer temperature on forage quality.

**Activity Status as of 31 January 2016:**

The mass spectrometer malfunctioned over the summer and has been out of commission for a number of months. We are only now starting to get samples run; however, at this point we have first priority in the queue and expect to have our samples completed by November 2016. Although this is somewhat later than expected, we do not have other options and are still making progress on the project. We are currently revising a manuscript (reviewed in the Journal of Ecology) about how ambient temperature affects the chemical composition of moose forage species (specifically paper birch and balsam fir). We found several important results in an experimental setting. As temperatures increased: 1) the diversity and relative abundance of secondary compounds changed for both species; 2) balsam fir reduced the total number of compounds produced and paper birch reduced variance in their abundance; and 3) the concentrations of two representative compounds, catechin and diterpene resin acid, both declined. These results suggest that we may see changes in the relative palatability of different forage species across the landscape; in the coming months we will be testing samples collected from our study sites to see if the trends we observed in the experimental plots hold up in the field. As we get more stable isotope data from our plant samples, we will be able to develop diet models for individual animals to see if the moose are eating different plants across the region (and if this is linked to changes in the abundance).

**Activity Status as of 31 May 2016:**

We conducted a brief winter field season to collect winter forage from many of our sites across NE MN. These samples will be used to answer the question of how winter forage quality changes (if at all) across moose range. Our stable isotope data continue to come in, but we have been developing a workflow for analysis so that once all of the plant tissue samples are analyzed we can finalize our statistical results quickly. Using the data we have collected thus far, our preliminary results suggest that the composition of moose diets change both across space and through time. For example, in the central part of the range, moose diets consist of roughly 9% paper birch (a high-preference food) during spring; whereas in the fall, the composition of paper birch in the diet increases to about 30%. Similarly, diets in the western part of the range are comprised of about 21% paper birch in the spring, and about 43% in the fall. However, the use of balsam fir (a low-preference food) remains relatively constant across the geographic range of moose in Minnesota, regardless of season, making up roughly 2% to 5% of the diet. Moose diets in the eastern-most part of the range do not appear to change with season. We have also begun to analyze hair collected postmortem from collared moose. This will allow us to determine if diets of individual moose change dramatically year to year, and whether knowing the animals' movement patterns help us to better predict their diet.

**Activity Status as of 1 May 2017:**

The mass spectrometer in the Fox lab again malfunctioned during summer 2016 and has been out of commission since. Starting in January 2017, we began sending forage samples to another lab for analysis of stable isotope composition. To date, we have analyzed more than 900 forage samples analyzed from 11 different species and 147 individual moose for stable isotopes of carbon and nitrogen, with plans to analyze another 2000 plant samples by the end of May. Preliminary analyses suggest that early summer diet varies throughout the geographic range of moose in Minnesota, and this variation is correlated with mean summer temperature. In the coldest parts of their summer range (close to Grand Portage), more than 80% of ingested forage during early summer consists of only two species – willow (44%) and maple (42%), while in the warmest parts of their summer range (close to Ely), 80% of ingested forage during early summer consisted of five different species – willow (19%), beaked hazel (17%), trembling aspen (16%), paper birch (14%), and juneberry (11%). These results suggest moose in the coldest part of their range have much lower dietary diversity than moose in the warmest parts of their range. Moreover, these changes do not appear to be associated with differences in the availability of different forage species, suggesting that moose in the coldest parts of their range are more selective feeders than moose in the warmest parts of their range. We are starting to analyze data collected from 100 temperature loggers that have been intermittently recording temperature at two-hour intervals since 2012 throughout the geographic range of moose in northeastern Minnesota. Preliminary analysis of these data suggests that during our study, 2013 was both the coldest and hottest year for moose in Minnesota. During summer 2013, some recorded temperatures exceeded 100°F and during winter of that same year, temperatures dropped to as low as -42°F. By the end of May, we will have data that will allow us to determine if ambient temperature and/ or land cover are influencing the chemical composition of forage in a way that alters palatability of different forage species, thereby influencing the diet composition estimates noted above.

**Final Report Summary:**

IV. Forage Quality and Forage Isotopes (Outcome 2.1)

*a) Quality of Forage Plants*
We collected plant samples at 131 sites (Figure 1.3) and found that plant species considered to be highly preferred by moose were indeed of higher quality, based on Carbon:Nitrogen ratios (C:N; lower is better) and %Nitrogen (%N; higher is better). The quality of forage varied spatially across moose range, with the area currently supporting the highest populations of moose (i.e., NW of Grand Marais) having the best combinations of C:N and %N (Figures 2.1 & 2.2); it is important to note that this area also has the highest forage biomass of all regions (Figure 1.5).

Because of the strong gradient of ambient temperature seen across moose range (Figure 1.4), we also tested whether plant chemistry changed in response to temperature. Specifically, we examined how ambient temperature and canopy cover affected the production of plant secondary metabolites (PSMs), which include chemical defenses produced by plants (i.e., chemicals that could cause a moose to avoid an otherwise high-quality plant). We compared common high and low quality forage plants in the B4Warmed experimental plots and also collected plant material from across the study area to explore how landscape-scale variation of abiotic conditions could impact the PSM profile of important forage plants.

Plant secondary metabolites are a key mechanism by which plants defend themselves against potential threats, and changes in the abiotic environment can alter the diversity and abundance of PSMs. While the number of studies investigating the effects of abiotic factors on PSM production is growing, we currently have a limited understanding of how combinations of factors may influence PSM production. The objective of this portion of our study was to determine how ambient temperature influences PSM production and how the addition of other factors may modulate this effect. We used untargeted metabolomics to evaluate how PSM production in five different woody plant species in northern Minnesota are influenced by varying combinations of temperature, moisture, and light in both experimental and natural conditions. We used perMANOVA to compare PSM profiles and phytochemical turnover across treatments and NMDS to visualize treatment-specific changes in PSM profiles. Finally, we used linear mixed-effects models to examine changes in phytochemical richness.

Under closed-canopy, experimental warming led to distinct PSM profiles and induced phytochemical turnover in paper birch but not balsam fir (Figure 2.3). In open-canopy sites, warming had no influence on PSM production (Figure 2.4). In samples collected across northeastern Minnesota, regional temperature differences had no influence on PSM profiles or phytochemical richness but did induce phytochemical turnover in two important moose foods: paper birch and trembling aspen (Figure 2.5); however, warmer temperatures combined with open canopy resulted in distinct PSM profiles for all species and induced phytochemical turnover in all but beaked hazel. Our results demonstrate that woody plants do alter the chemicals they produce in response to abiotic factors; however, different species respond in different ways. Importantly, it seems that canopy cover can modulate the impact of temperature on PSM production—this could have implications on moose diet given the changing patterns of land cover observed in Activity 1. Because the impact of changing PSM profiles on moose is not known, future research that investigates the chemistry of browsed vs. non-browsed plants in different parts of moose range will be important and will help to explain the differences in diet that we have observed in this project (Outcome 2.2). The results from this research were published in *Frontiers in Plant Science* (Berini et al. 2018, in press).

*b) Stable isotopic composition of forage plants*

After combining our forage species into preference groups (low, medium, high), we were able to reliably separate them using stable isotope compositions measured as $\delta^{15}N$ and $\delta^{13}C$ (i.e., the composition of nitrogen and carbon isotopes; Figure 2.6); all pair-wise comparisons are significantly different for $\delta^{13}C$ (Table 2.1) and $\delta^{15}N$ (Table 2.2). Statistically significant differences in $\delta^{13}C$ and $\delta^{15}N$ between forage preference groups indicate that these groups can be used to reliably estimate diet composition (Outcome 2.2).

To determine how isotopic composition of forage plants changed across the region, we collected data on 10 landscape variables at all biomass and forage collection points (Figure 1.3) using the geographic information system (GIS) software ArcGIS 10.3. The variables we considered in these analyses are mean maximum summer temperature (1981-2010; PRISM Climate Group), elevation (U.S. Geological Survey), aspect, slope, disturbance type, percent canopy cover, canopy height, bedrock geology, and water table depth. To evaluate how stable isotope composition of different forage preference groups vary over the landscape, we created linear mixed-effects models in Program R using the lmer command from the lme4 package. We created a null model for both $\delta^{13}C$ and $\delta^{15}N$, with easting and northing as our fixed effects and land cover, disturbance type, and bedrock type as our random effects. The fit of our model characterizing landscape-level variation in $\delta^{13}C$ was significantly improved by the inclusion of slope, water table depth, elevation, and mean-maximum summer temperature. The fit of our model characterizing landscape variation in $\delta^{15}N$ was significantly improved by the inclusion of water table depth, slope, and elevation. After fitting these models to our data, we created landscape-level predictions using regression kriging to illustrate how the isotope values vary across northeastern Minnesota (Figure 2.7).

**Table 2.1** Results of Tukey's HSD test for $\delta^{13}C$ of forage preference groups based on Peek (1976). "Difference" refers to the difference between the observed means, whereas "lower" and "upper" refer to the endpoints of the interval. P-values were adjusted for multiple comparisons.

| group comparison | difference | lower | upper | p-value |
|---|---|---|---|---|
| high-aquatics | -1.643 | -2.060 | -1.226 | < 0.0001 |
| low-aquatics | -2.675 | -3.082 | -2.268 | < 0.0001 |
| mid-aquatics | -2.006 | -2.431 | -1.580 | < 0.0001 |
| low-high | -1.032 | -1.212 | -0.852 | < 0.0001 |

| | | | | |
|---|---|---|---|---|
| mid-high | -0.363 | -0.581 | -0.145 | 0.0001 |
| mid-low | 0.670 | 0.472 | 0.867 | < 0.0001 |

**Table 2.2** Results of Tukey's HSD test for $\delta^{15}N$ of forage preference groups based on Peek (1976). "Difference" refers to the difference between the observed means, whereas "lower" and "upper" refer to the endpoints of the interval. P-values were adjusted for multiple comparisons.

| group comparison | difference | lower | upper | p-value |
|---|---|---|---|---|
| high-aquatics | -2.589 | -3.168 | -2.011 | < 0.0001 |
| low-aquatics | -3.707 | -4.272 | -3.143 | < 0.0001 |
| mid-aquatics | -4.392 | -4.982 | -3.803 | < 0.0001 |
| low-high | -1.118 | -1.368 | -0.868 | < 0.0001 |
| mid-high | -1.803 | -2.105 | -1.501 | < 0.0001 |
| mid-low | -0.685 | -0.959 | -1.411 | < 0.0001 |

V. Moose diet (Outcome 2.2)

To determine how moose diet changes through the growing season and across moose range, we analyzed the stable isotope data from samples of forage plants and moose hair. The plant samples were collected from throughout northeast Minnesota for five consecutive summers (2012-2016; Outcome 2.1) and the moose hair was collected by the Minnesota Department of Natural Resources at radio collaring events from 2013-2014 and at necropsies. Moose shed their winter coat as new hair growth begins in mid to late May and hair growth ends in late August to early September. Because of this seasonal renewal and growth pattern, stable isotopes in hair reflect that of the forage consumed during the summer period—the most important time of food consumption for moose. Thus, hairs collected from fall through early spring allow us to estimate the diet of individual moose during the previous summer. We segmented each hair sample into early summer (the tips of the hair) and late summer (the base of the hair) segments and used stable isotope data from these different segments to estimate seasonal differences in diet.

To estimate diet, we created Bayesian mixings models in Program R using the package MixSIAR, which allowed us to estimate the diet for each individual. We found that early summer diets in the cold region were dominated by medium preference forage, while diets in the moderate and warm regions were dominated by low preference forage and aquatic forage, respectively (Figure 2.8 a). Late summer diets showed that moose in the cold region still focused more on medium preference forage, while the moderate and warm regions had progressively more aquatic forage in their diet (Figure 2.8 b). To test whether diet reflected habitat use we tested whether proportion of aquatic forage in the diet was influenced by the amount of time a given animal spent in wetland habitat. We found a significant, positive relationship, with animals in the warm region tending to have both higher use of wetland habitats and more aquatic plants in their diet (Figure 2.9). In general, animals in the warm region showed stronger selection for aquatic habitats (i.e., they were using them proportionally more than expected, based on wetland availability in their home ranges; Figure 2.10).

VI. Impacts of moose diet on survival (Outcome 2.3)

To determine if summer diet composition was related to the survival of individual moose, we used logistic regression to examine how the summer diet of animals that lived through the following year (n=124) compared to the diets of animals that died before the next summer (n=34). Because of the small number of mortalities, we could not draw robust conclusions; however, our initial analyses indicate that animals that died tended to eat more low-quality forage early in the summer, but less high-quality and more aquatic forage later in the summer (e.g., Figure 2.11). Although these results are tentative, we feel that they may help drive future research into whether changes in diet can lead to mortality, or whether those changes are indicative of health complications that cause the animals to die in the following season.

## VII. Management recommendations (Outcome 2.4)

Based on the findings of this study, we suggest that wildlife researchers at state, federal, and tribal agencies work with foresters in the public and private sectors to identify large blocks of moose range that can be experimentally manipulated or opportunistically monitored. Specifically, there should be paired blocks (treatment / control) that have similar initial conditions in which moose density will be monitored for 1-2 years prior to treatment. If additional radio collars cannot be added to animals in these blocks, the research area can be restricted to locations with existing data on moose space use; in this case, future moose density estimates would have to be conducted by a combination of aerial surveys, pellet counts, browsing surveys, and possibly camera trap grids.

The main cover types to manipulate in treatment plots would be large deciduous and coniferous forest stands. Managing these stands to increase the conversion to a more heterogeneous mixture of tree species will involve selective cutting and possibly planting of trees. While conversion to a true mixed-wood stand will take decades, opening the canopy of some of these stands should increase the density of high-quality forage species (especially aspen and birch) in the understory. Food quantity and quality should be monitored along with the browsing intensity of these plots. Because some moose habitat plots have already been created by researchers in the state, we suggest that those plots be included as reference plots for this research. Other research plots should be created in areas with higher moose populations (e.g., NE portion of moose range) as well as historically moderate densities (e.g., around Isabella, NW of Ely; Figure 1.9). The goal of this management should be twofold: 1) can manipulations create fine-scale increases in habitat use by moose, and 2) at a broad scale, can these manipulations increase the moose population or make it more resilient to changes in predator densities, deer densities, or climate. Clearly it will be difficult to create such a long-term monitoring plan; however, if the timber harvesting can fit within existing forestry goals, then the monitoring of moose densities and forage could be managed on a marginal budget and also provide training for wildlife and forestry students at MN Universities.

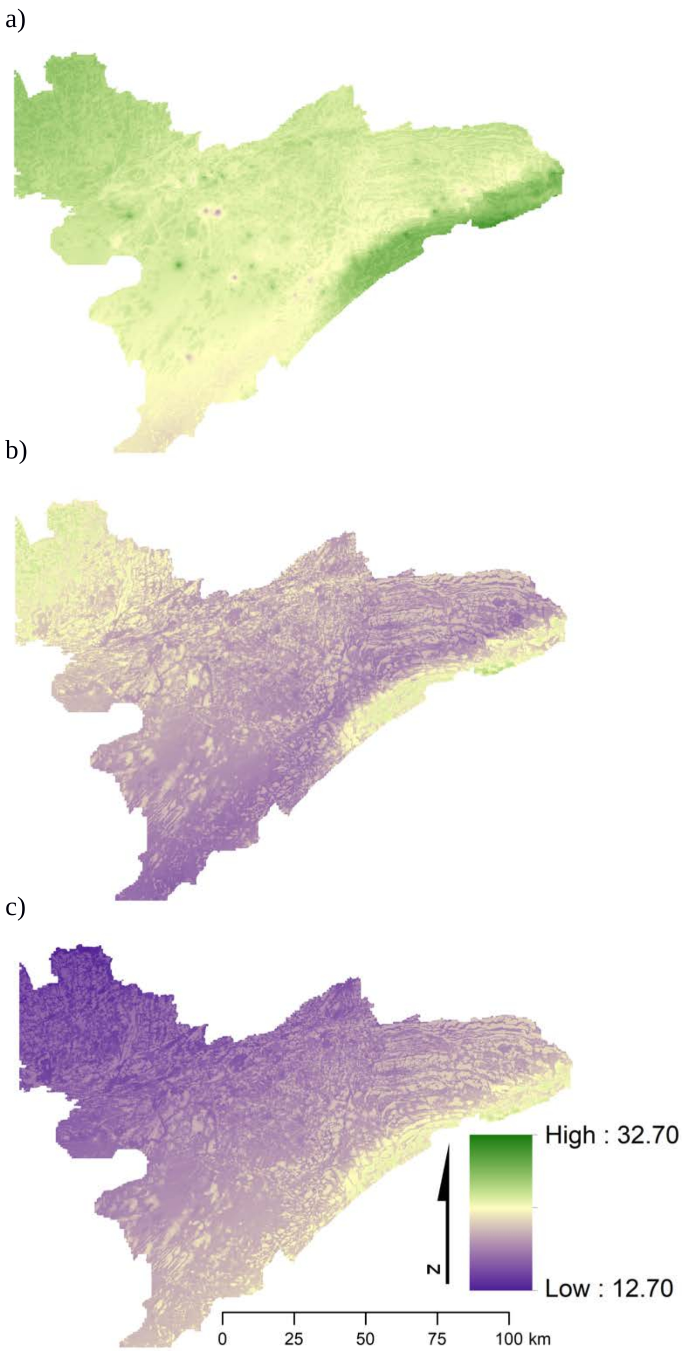



**Figure 2.1.** Variation in C:N across northeast Minnesota for low (a), medium (b), and high preference (c) forage. Landscape-level predictions were derived via regression kriging using linear mixed effects models. The C:N decrease from low to high preference, indicating an increase in nutrient quality.

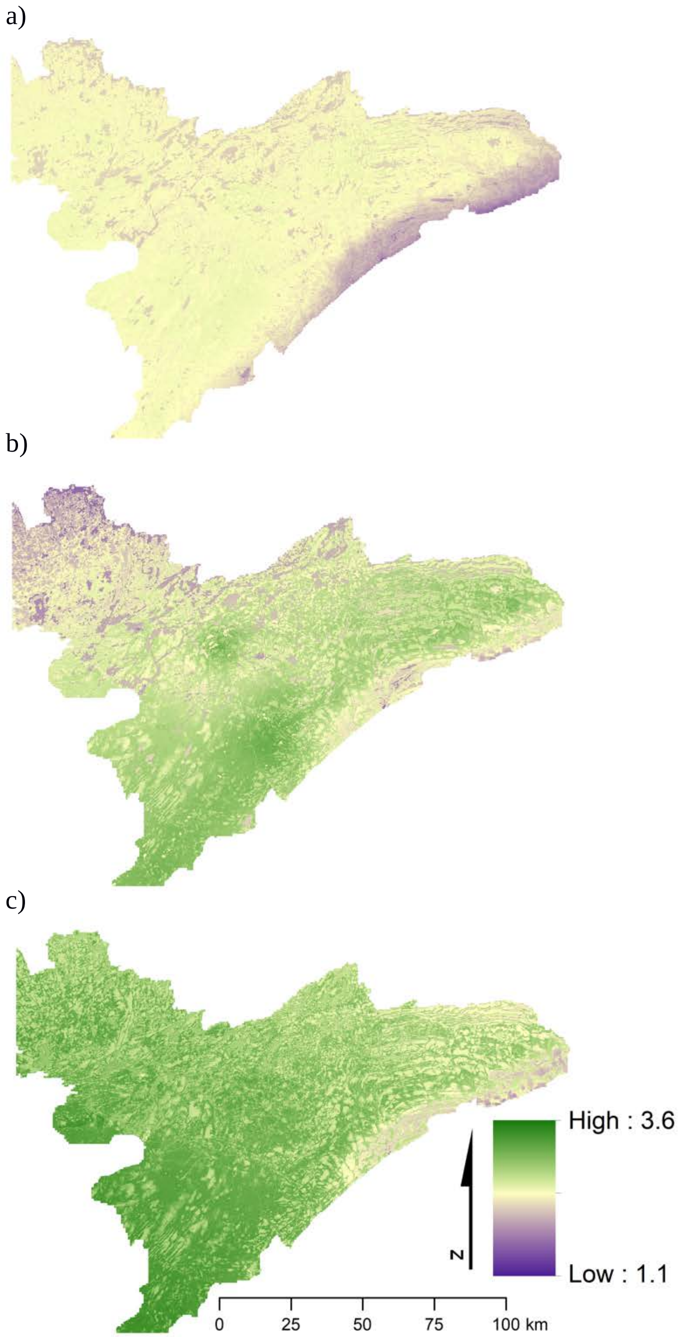



**Figure 2.2.** Variation in %N across northeast Minnesota for low (a), medium (b), and high preference (c) forage. Landscape-level predictions were derived via regression kriging using linear mixed effects models. The %N values increase from low to high preference, indicating an increase in nutrient quality.

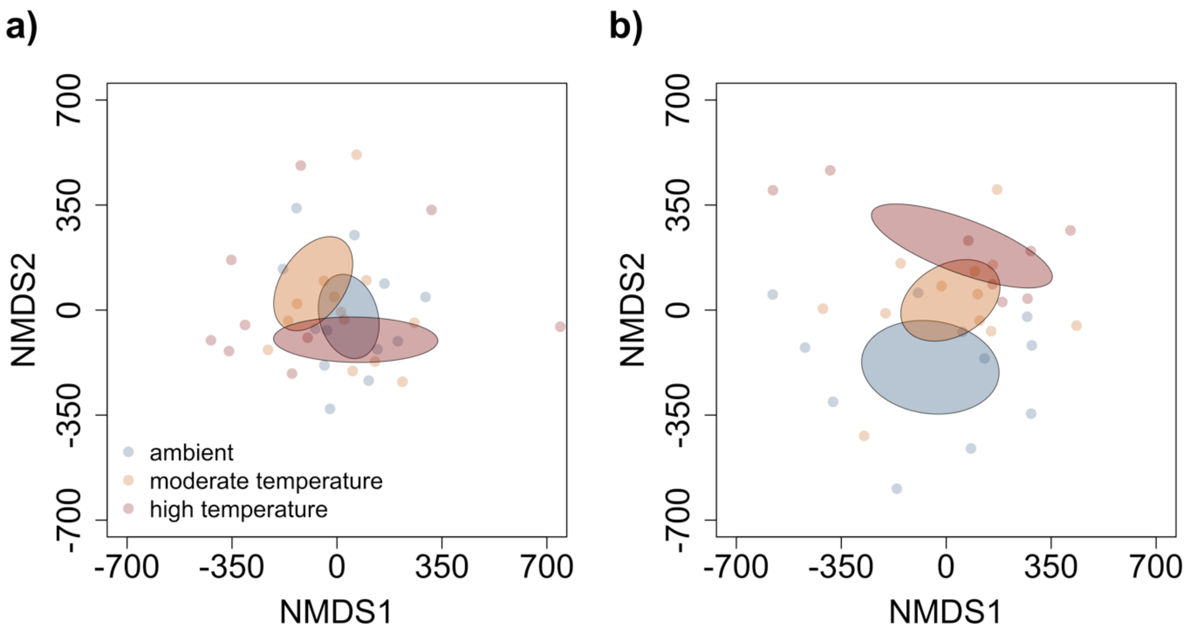



**Figure 2.3** Non-Metric Multidimensional Scaling (NMDS) plots detailing the influence of moderate and high-temperature stress on PSM profiles of balsam fir (a) and paper birch (b) in closed overstory. Ellipses represent 95% confidence intervals, based on standard error. In balsam fir (a), both warming treatments exhibit less overlap with each other than with ambient. In paper birch (b), different temperature conditions lead to distinct profiles when compared to each other and ambient.

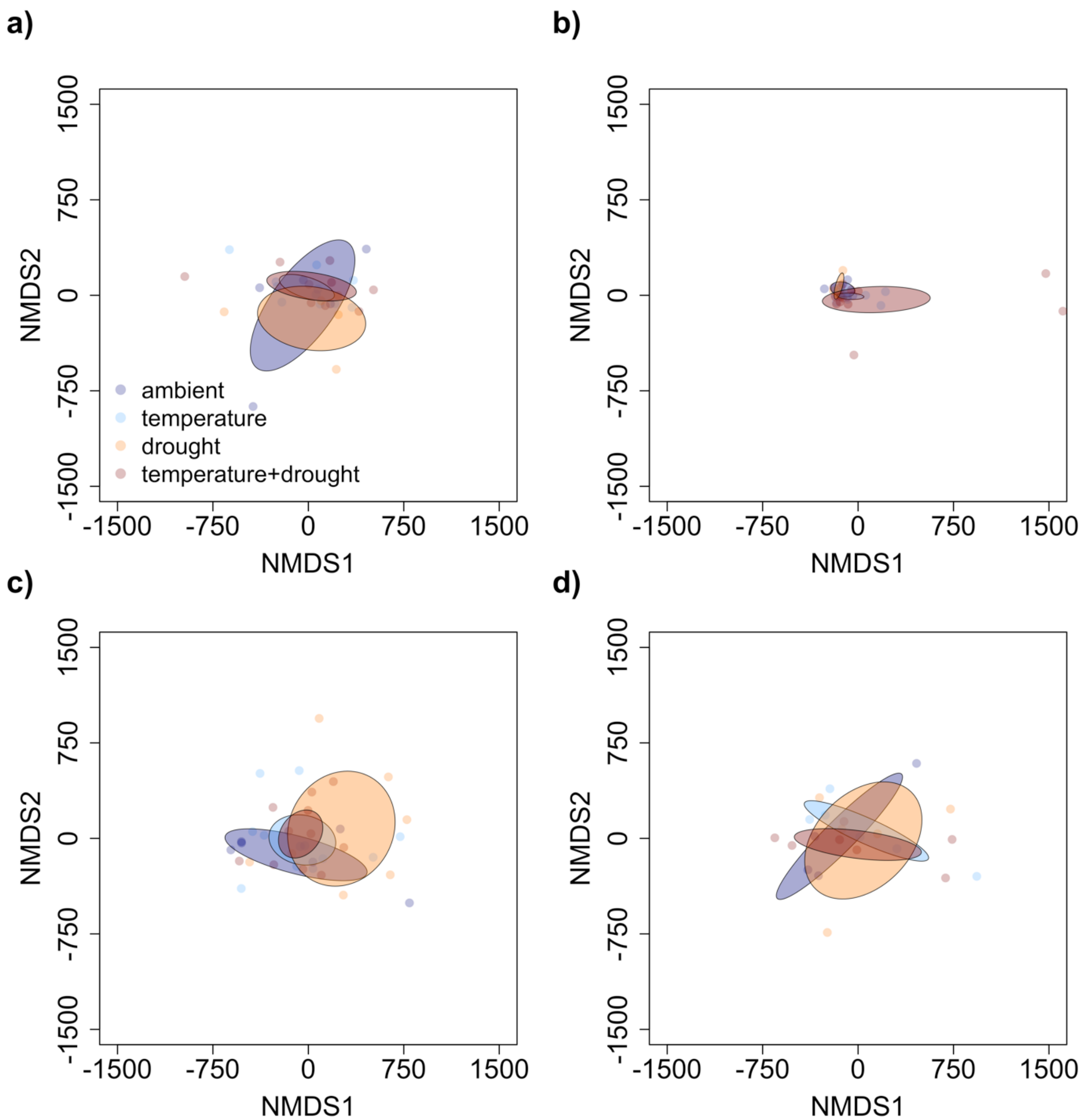



**Figure 2.4** Non-Metric Multidimensional Scaling (NMDS) plots detailing the influence of temperature and drought on PSM profiles of balsam fir (a), red maple (b), paper birch (c), and trembling aspen (d) in open overstory. Ellipses represent 95% confidence intervals, based on standard error. There appears to be no discernible pattern between stress conditions and PSM profiles, regardless of species.

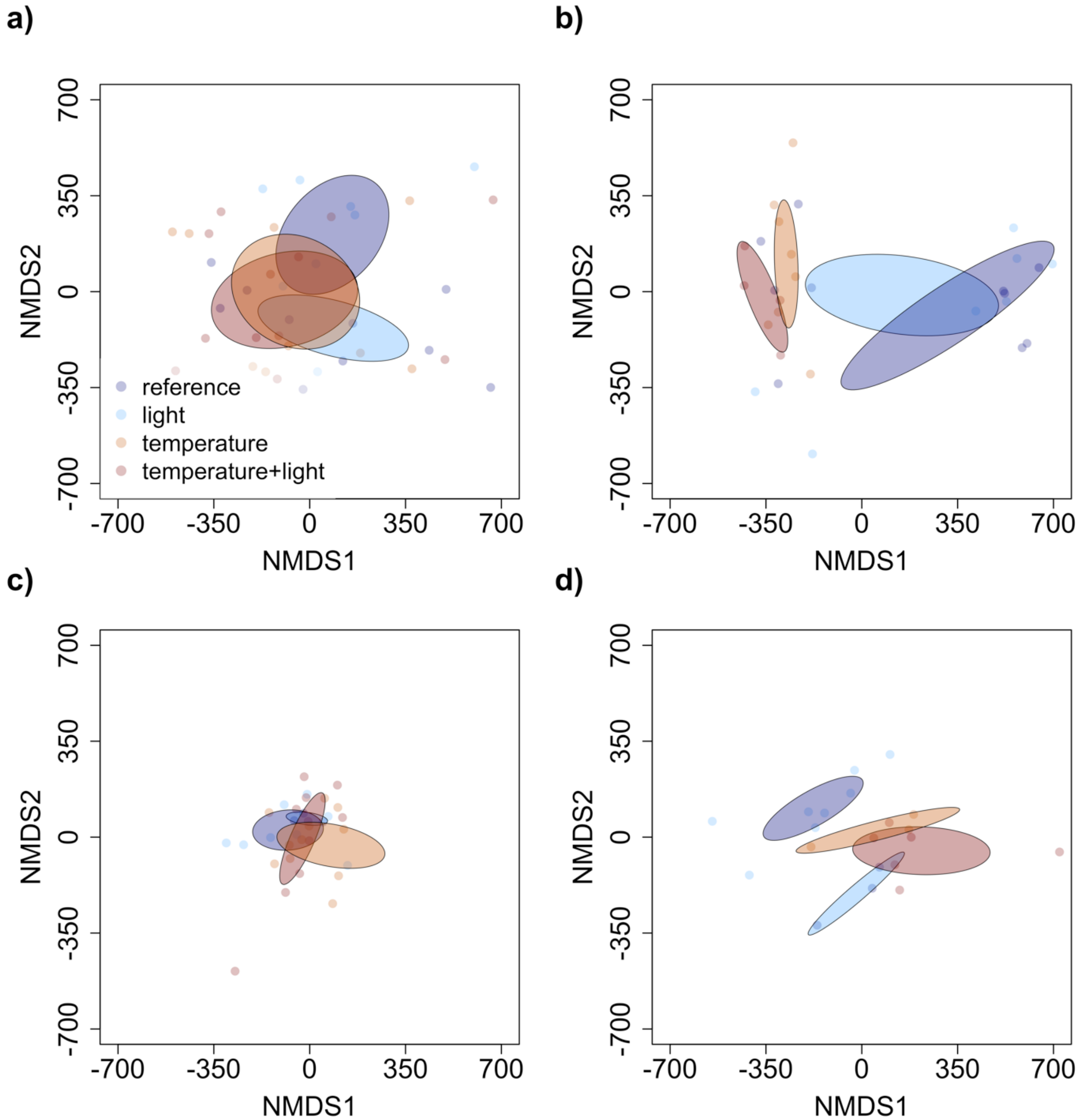



**Figure 2.5** Non-Metric Multidimensional Scaling (NMDS) plots detailing the influence of light and temperature stress on PSM profiles of balsam fir (a), paper birch (b), beaked hazel (c), and trembling aspen (d). Ellipses represent 95% confidence intervals, based on standard error. Each species appears to respond to different abiotic conditions in a unique manner. Balsam fir (a) appears to create unique PSM profiles as a function of high light when compared to our reference group (low-light, low-temperature), while paper birch (b) and trembling aspen(d) appear to have distinct PSM profiles for each condition. Beaked hazel (c) exhibits no discernible pattern.

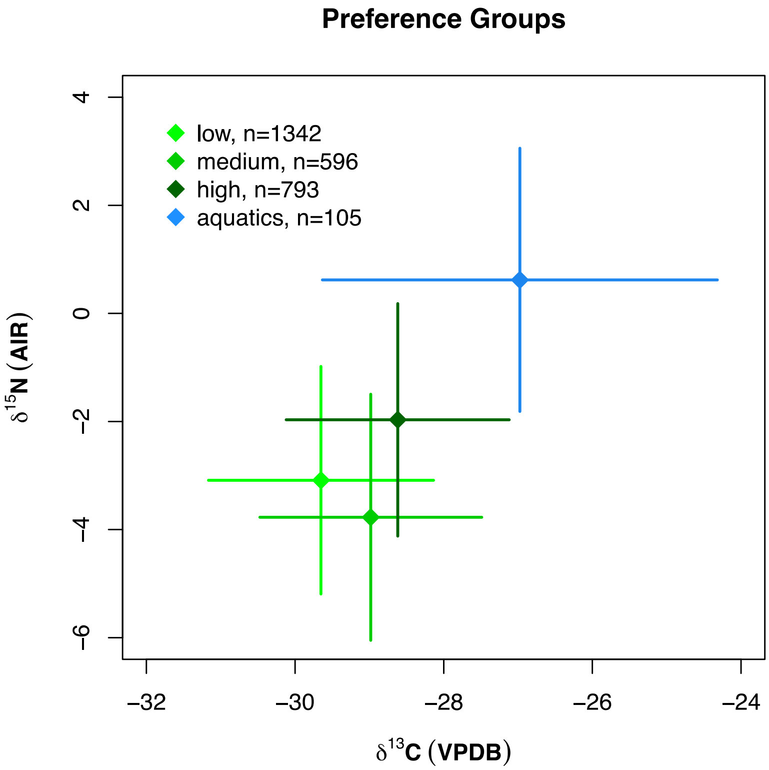



**Figure 2.6** Bi-plot representing the mean (points) and standard deviation (lines) of $\delta^{13}C$ and $\delta^{15}N$ for each forage-preference group. Sample sizes are presented in the legend. Standards used for verifying machine accuracy were air for $\delta^{15}N$ and Vienne Pee Dee Belemnite (VPDB) for $\delta^{13}C$.

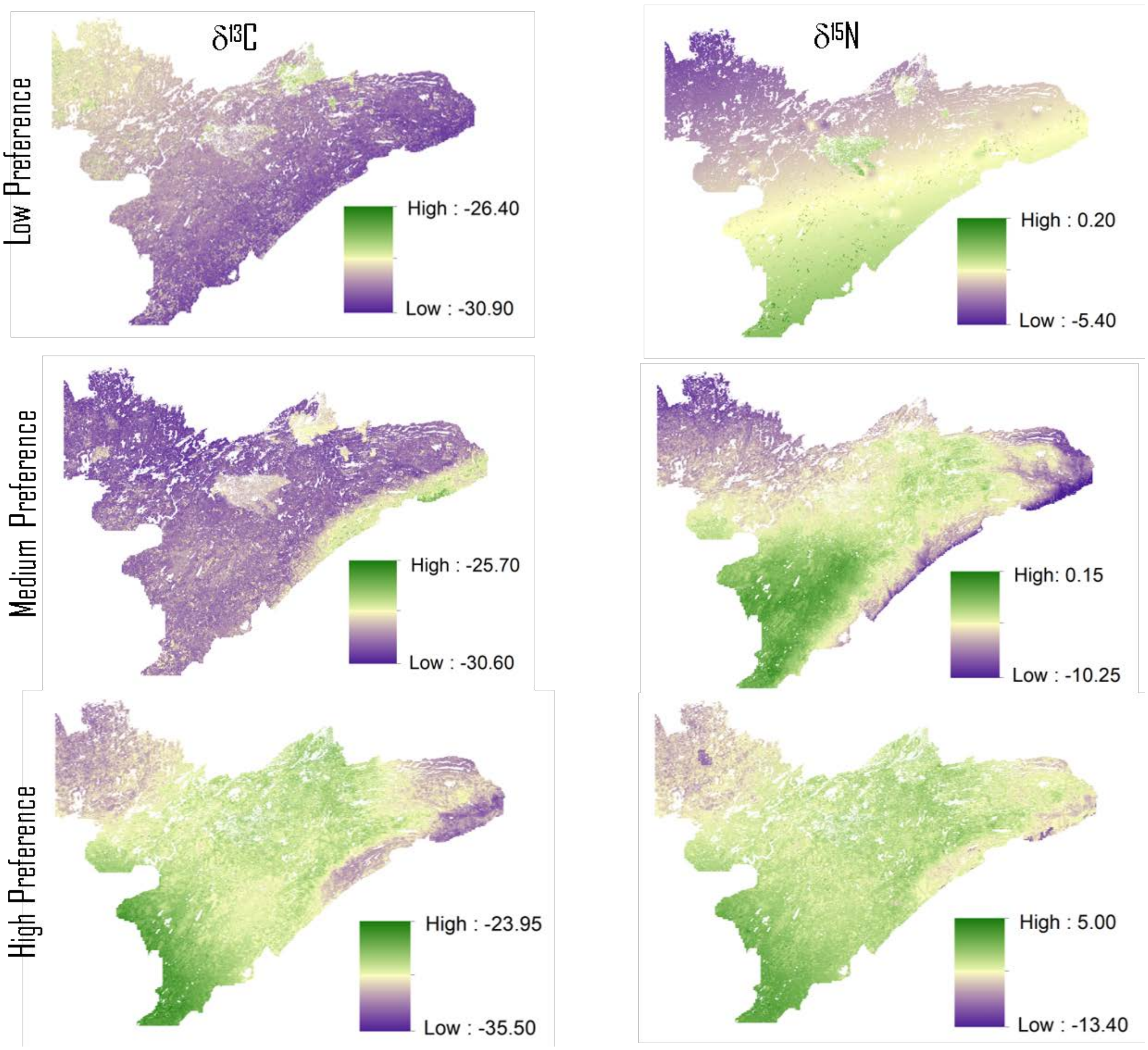



**Figure 2.7** Distribution of $\delta^{13}C$ and $\delta^{15}N$ across NE Minnesota for all three moose forage preference groups. Landscape-level predictions were derived via regression kriging using linear mixed effects models.

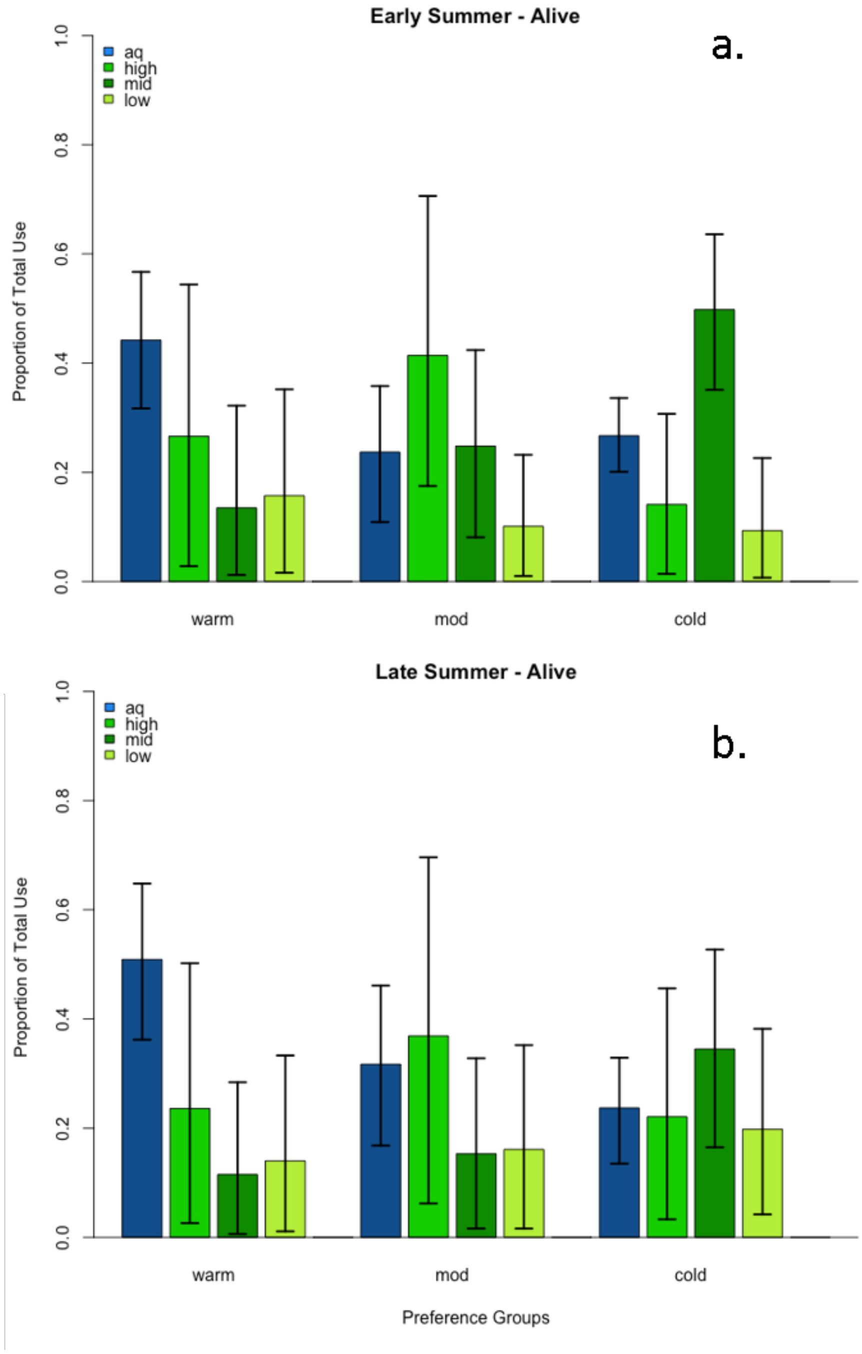



**Figure 2.8** Early (a) and late summer (b) diet compositions of moose that survived or died in the following winter. Diets derived from the terminal (early summer) and basal (late summer) portions of hair collected at capture or after mortality.

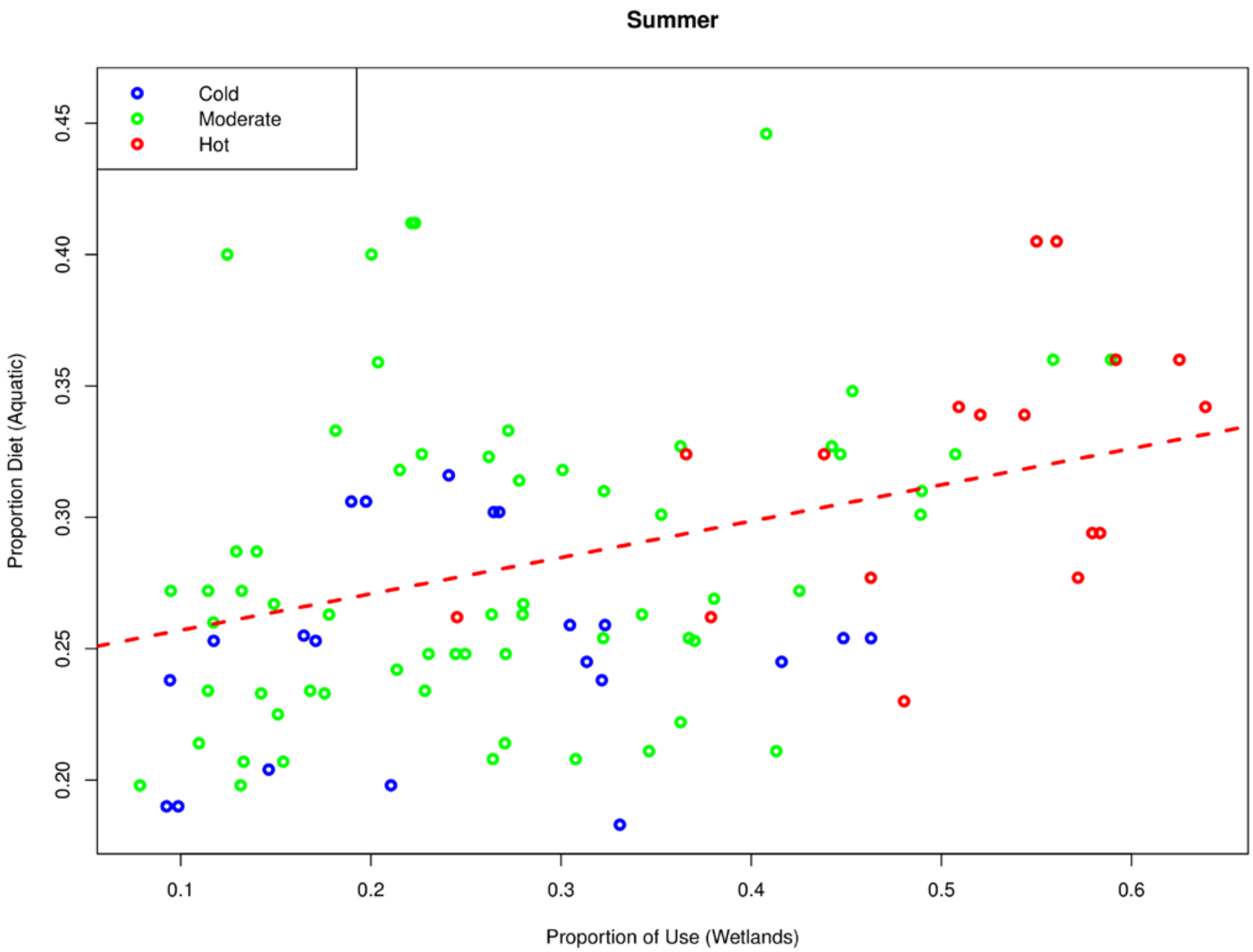



**Figure 2.9** Scatterplot and regression of how the summer use of wetlands by moose in each of the three temperature regions is related to the estimated proportion of aquatic forage in the animals' early-summer diet.

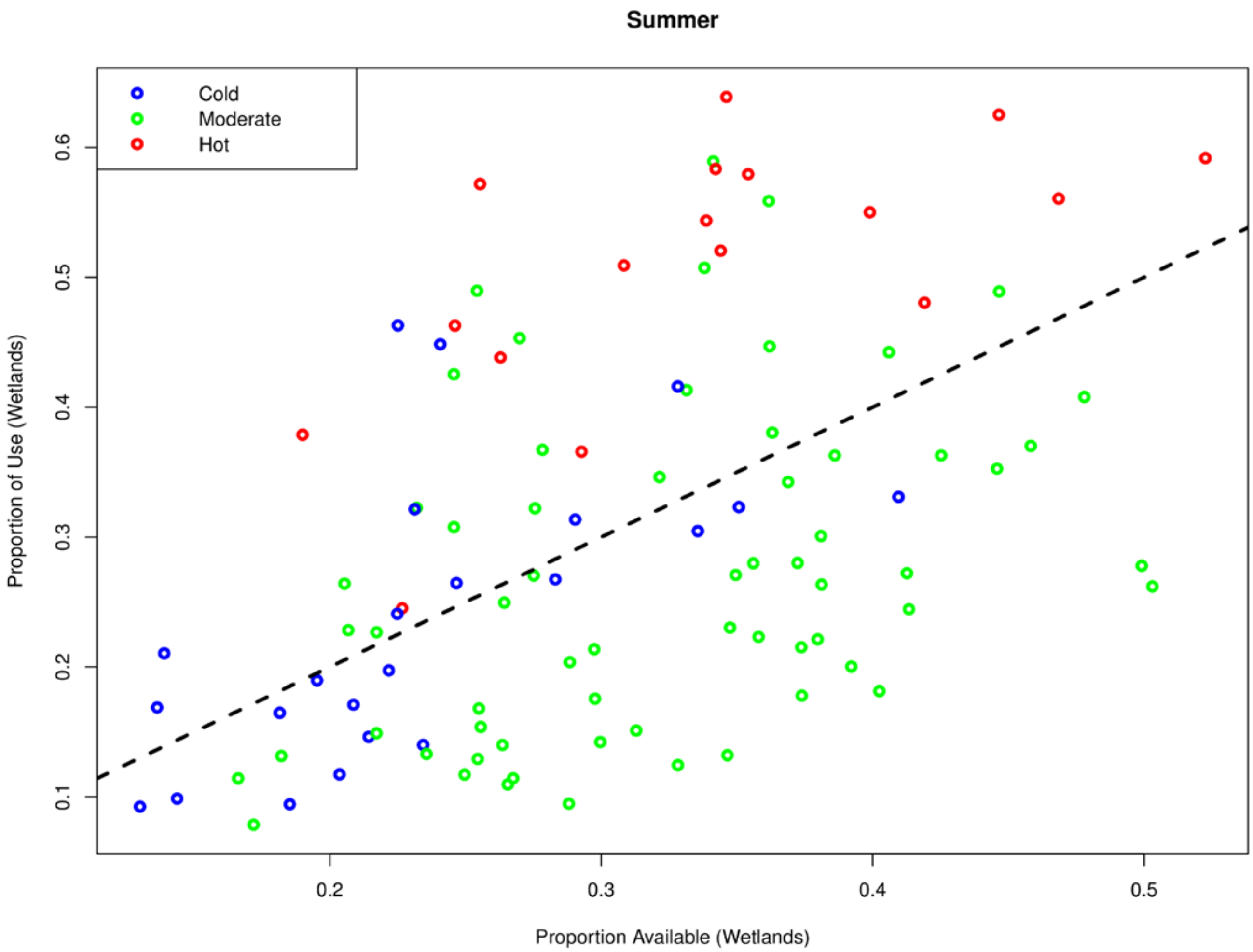
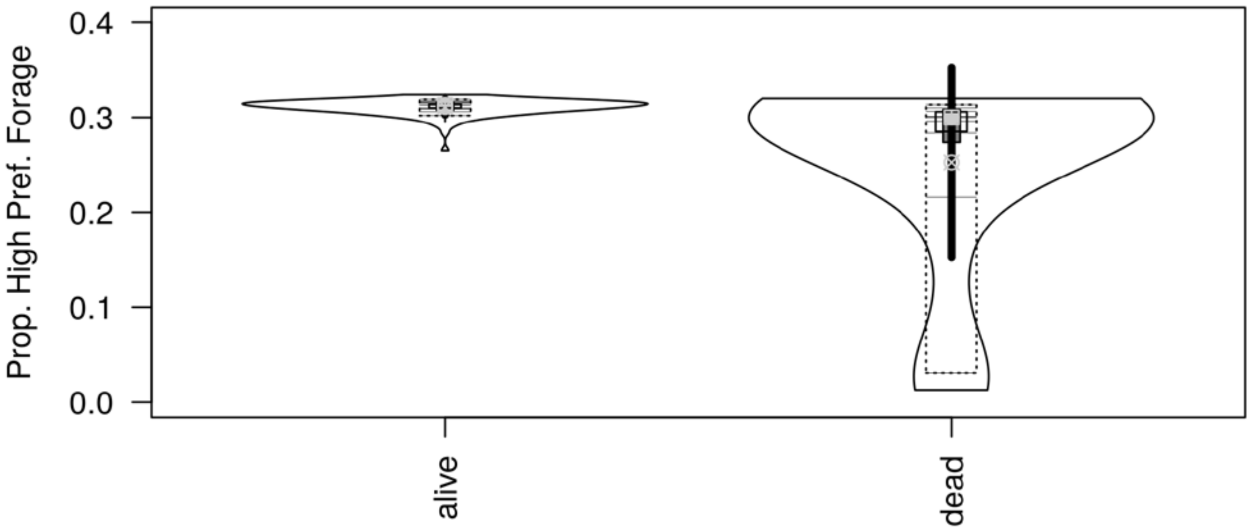



**Figure 2.10** Scatterplot of how use of wetlands during summer by moose in the three temperature regions is related to the availability of wetlands within their home ranges. Moose in the warm region tended to select for wetlands (i.e., they used them in a higher proportion than they were available). The dotted line is the 1:1 line; points above that line represent animals that are using wetlands in a greater proportion than available.

**Figure 2.11.** Violin plots of late summer, high-preference food in the diet of moose that lived through the winter (n=124) compared to those that died (n=34). The dead animals tended have less high-preference forage in their late-summer diets. More research is needed because of the small sample size of dead animals.




**V. DISSEMINATION:**

**Description:** 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 UMN 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 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.

**Status as of 2 December 2014:**
Forester has given two seminars on the moose population analysis (one to students visiting from Norway, and another to prospective UMN students). Another public seminar is planned for mid December. Forester also gave an extended interview about the moose population to the "Access Minnesota" radio show produced by the Minnesota Broadcasters Association (mid July air date).

**Status as of 31 May 2015:**
Forester presented at the Annual North American Moose Conference in Granby, CO and gave one public seminar in the Conservation Biology seminar series at the University of Minnesota. Graduate student John Berini presented at a UMN research symposium. Forester continues to work closely with researchers from the MNDNR and Grand Portage Band. Three manuscripts are in the initial stages of drafting. Forester worked with a UROP student at UMN to examine the spatial variation of stable isotope values in paper birch (an important moose food species).

**Status as of 31 January 2016:**
Berini, Street, and Forester all presented at the Annual Conference of The Wildlife Society in Winnipeg , MB Canada. Forester also gave an invited seminar to the American Association of University Women in Minneapolis, MN. One manuscript is in press, another was submitted for publication and is currently under revision, and a third is in the final stages of drafting.

Street, G. M., J. Fieberg, A. R. Rodgers, M. Carstensen, R. Moen, S. A. Moore, S. K. Windels, and J. D. Forester. 2016. Habitat functional response mitigates reduced foraging opportunity: implications for animal fitness and space use. Landscape Ecology – In Press.

**Status as of 31 May 2016:**
Forester presented the preliminary results from this research at "A Sip of Science" in Minneapolis. A UMN RAP student we work with presented the results of her study (how moose diet changes across NE MN) at the 2016 UMN Undergraduate Research Symposium. John Berini gave a guest lecture on this material for the Principles of Conservation Biology class at UMN and also presented at the Conservation Biology Research Spotlight. We plan to resubmit our manuscript on secondary compounds in moose forage species within the next few weeks and will submit a manuscript on spatially-explicit changes to the moose population by mid summer.

**Status as of 1 May 2017:**
Forester presented results to a visiting group of students and scholars from Norway in September 2016. He also presented at the International Association of Landscape Ecology conference in Baltimore, MD (April 2017) and will be presenting at the International Congress for Conservation Biology in Cartagena, Colombia in July 2017. Two manuscripts are in revision for submission to journals.

**Final Report Summary:**

Forester contributed to a multimedia display associated with the moose diorama in the Bell Museum (https://z.umn.edu/BellMoose); an excerpt of this interview was featured in the recent PBS special, "Windows to Nature" (https://z.umn.edu/Windows2Nature). Forester also gave an extensive interview on the moose population for "Access Minnesota" (https://z.umn.edu/mooseradio), presented seven invited talks (UMN Conservation Biology Seminar Series, 2014 & 2017; Minnesota Moose Symposium, 2015; American Association of University of Minnesota Women, 2015; A Sip of Science, 2016; Boise State University, 2017; Universidade Federal de Mato Grosso do Sul, Brazil 2018), contributed talks to five national or international scientific conferences (North American Moose Conference, Colorado 2015; The Wildlife Society, Winnepeg 2015; US-IALE, Baltimore 2017 & Chicago 2018; International Convention for Conservation Biology, Colombia 2017). John Berini (Ph.D. student) contributed talks to one national (American Society of Mammalogists, Minneapolis 2016) and one international scientific conference (The Wildlife Society, Winnepeg 2015), as well as at two UMN research symposia. Both Forester and Berini included aspects of this research into teaching materials that were delivered to undergraduate students in Wildlife and Conservation Biology courses. Garrett Street also presented at one conference (TWS Winnepeg 2015). Throughout the course of this project, we provided mentorship and training in field, laboratory, and quantitative methods to 12 undergraduate students, five graduate students, and three postdoctoral scholars. Three manuscripts have been published as part of this project:

Street, G. M., J. Fieberg, A. R. Rodgers, M. Carstensen, R. Moen, S. A. Moore, S. K. Windels, and J. D. Forester. 2016. Habitat functional response mitigates reduced foraging opportunity: implications for animal fitness and space use. Landscape Ecology 31:1939-1953 doi:10.1007/s10980-016-0372-z.

Fieberg, J. R., J. D. Forester, G. M. Street, D. H. Johnson, A. A. ArchMiller, and J. Matthiopoulos. 2017. Used-habitat calibration plots: A new procedure for validating species distribution, resource selection, and step-selection models. Ecography (in press) doi:10.1111/ecog.03123.

Berini, J. L., S. Brockman, A. Hegeman, R. Muthukrishnan, P. B. Reich, R. Montgomery, J. D. Forester. Combinations of abiotic factors differentially alter production of PSMs in woody plants along the boreal-temperate ecotone. Frontiers in Plant Science (*in press*).

**VI. PROJECT BUDGET SUMMARY:**

**A. ENRTF Budget Overview:**

| Budget Category | $ Amount | Explanation |
|---|---|---|
| Personnel: | $ 150,969 | 1 project manager at 8%FTE for 3y; 1 field manager at 38% FTE for 3y; 1 lab manager at 4% FTE for 3 y;1 lab technician at 8% FTE for 3 y; 1 research associate at 6% FTE for 1 y; 2 undergraduate research assistants at 19%FTE for 3y; 1 PhD student at 14% FTE for 3y. |
| Professional/Technical/Service Contracts: | $ 83,944 | 1 contract for laboratory analysis of plant and tissue samples; 2 contracts for satellite imagery analysis. |
| Equipment/Tools/Supplies: | $ 9,980 | Lab supplies for stable isotope analysis; field equipment (tapes, sample bags, etc) |
| Capital Expenditures over $5,000: | $ 5,845 | High precision GPS for relocating sites and individual plants for resampling. |
| Fee Title Acquisition: | $ 0 | |
| Easement Acquisition: | $ 0 | |
| Easement – Long-term Monitoring, Management, and Enforcement | $ 0 | |
| Professional Services for Fee Title and | $ 0 | |

| | | |
|---|---|---|
| Easement Acquisition: | | |
| Printing: | $ 0 | |
| Travel Expenses in MN: | $ 49,262 | Travel to study area by staff and technicians (1 fleet truck for 4mo/y over 3y); lodging and meals for 2-6 crew members for 4mo/y over 3y. |
| Other: | $ | |
| **TOTAL ENRTF BUDGET:** | **$ 300,000** | |

**Explanation of Use of Classified Staff:**

**Explanation of Capital Expenditures Greater Than $5,000:** One Trimble GeoExplorerXT will be purchased for high-resolution field sampling and ground-truthing of satellite classifications. The instrument will continue to be used for similar projects and purposes by the Forester Lab at UMN for the life of the instrument. If the instrument is sold prior to its useful life, proceeds from the sale will be paid back to the Environment and Natural Resources Trust Fund.

**Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 2.98 FTEs**

**Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.5 FTEs**

**B. Other Funds:**

| Source of Funds | $ Amount Proposed | $ Amount Spent | Use of Other Funds |
|---|---|---|---|
| **Non-state** | | | |
| | $ 0 | $ 0 | |
| **State** | | | |
| Purchase and maintenance of 15 moose GPS collars (Forester startup) | $89,463 | $ 50,000 | Data from these collars will provide the critical data for this project. We will be able to link where animals spend their time to what they are eating and subsequently their body condition. |
| Graduate Lab Manager (Fox Stable Isotope Lab, 1mo summer salary + 23.1% health and FICA) | $2,400 | $ 0 | This lab manager will help with the analysis of our samples |
| Computer equipment dedicated to data analysis and simulation for this project (Forester startup) | $5,558 | $ 5,558 | These computers will provide the computational power to fit the statistical models we will develop in this project. |
| Foregone ICR funding (52% MTDC, excluding graduate fringe) | $153,770 | $ 0 | |
| In-kind Services During Project Period: Salaries for Forester (1% match), D'Amato (1% match) | $6,550 | $ 0 | The PIs will be spending substantial time organizing the crews, analyzing data and writing up manuscripts and reports. |
| **TOTAL OTHER FUNDS:** | **$ 257,741** | **$ 50,000** | |

**VII. PROJECT STRATEGY:**

**A. Project Partners:**

The research team will be led by scientists at the University of Minnesota Departments of Fisheries, Wildlife and Conservation Biology (Dr. James Forester), Earth Sciences (Dr. David Fox), and Forest Resources (Dr. Anthony D'Amato).

Partners include the UMN (Dr. Alan Ek), MNDNR (Dr. Michelle Carstensen, Dr. Glenn DelGiudice), TNC (Mark White), and the Grand Portage Band of Lake Superior Chippewa (Dr. Seth Moore).

**B. Project Impact and Long-term Strategy:**

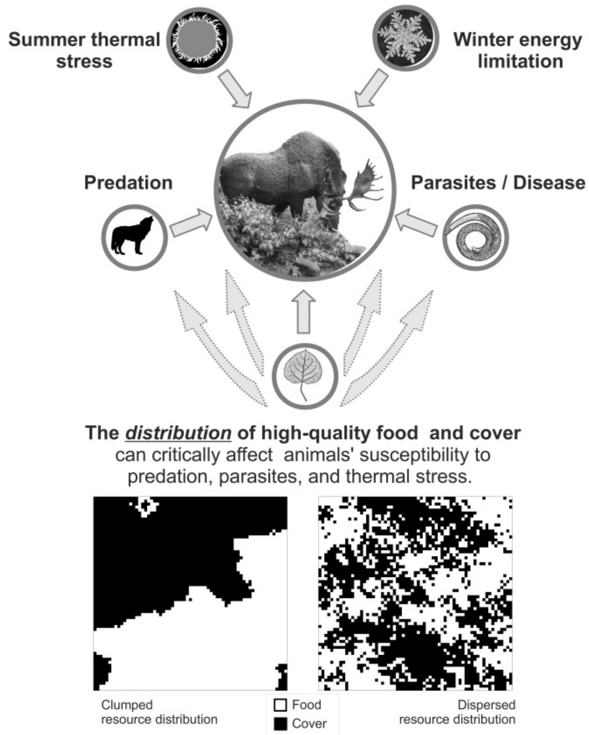
Opportunities to gain insight into the spatial structure of population demographic rates are rare. The proposed work builds on moose research by the MNDNR to examine how this species (of local economic and cultural importance) is responding to changing landscapes. This study will directly address questions of management concern and will also advance managers' understanding of (1) how animals behaviorally mitigate environmental stress; (2) how behavior and landscape context affect diet, survival, and fecundity; and (3) how broad-scale landscape structure can affect the space use and demographic rates of the moose population. Our ongoing collaborations with state, tribal, and federal agencies will ensure that the research results are broadly disseminated. Likewise, our interaction with the Bell Museum will expose the public to our ongoing efforts to manage and conserve moose in Minnesota.

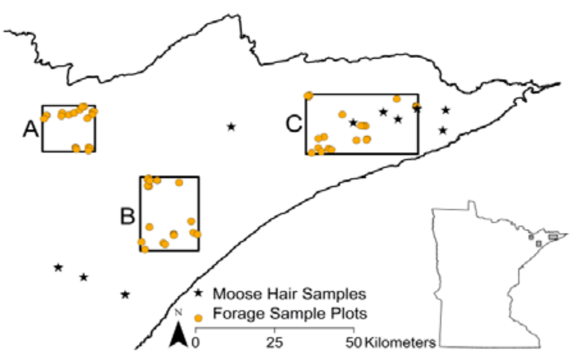
**C. Spending History:**

| Funding Source | M.L. 2008 or FY09 | M.L. 2009 or FY10 | M.L. 2010 or FY11 | M.L. 2011 or FY12-13 | M.L. 2013 or FY14 |
|---|---|---|---|---|---|
| Forester startup funds | | | 52,500 | 3,058 | |
| | | | | | |
| | | | | | |
| | | | | | |

**VIII. ACQUISITION/RESTORATION LIST: N/A**

**IX. VISUAL ELEMENT or MAP(S):**




**X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A**

**XI. RESEARCH ADDENDUM:**

See attached Research Addendum

**XII. REPORTING REQUIREMENTS:**
**Periodic work plan status update reports will be submitted no later than 2 December 2014, 31 May 2015, 31 January 2016, 31 May 2016, 31 January 2017, and 30 June 2017. A final report and associated products will be submitted between June 30 and August 15, 2017.**

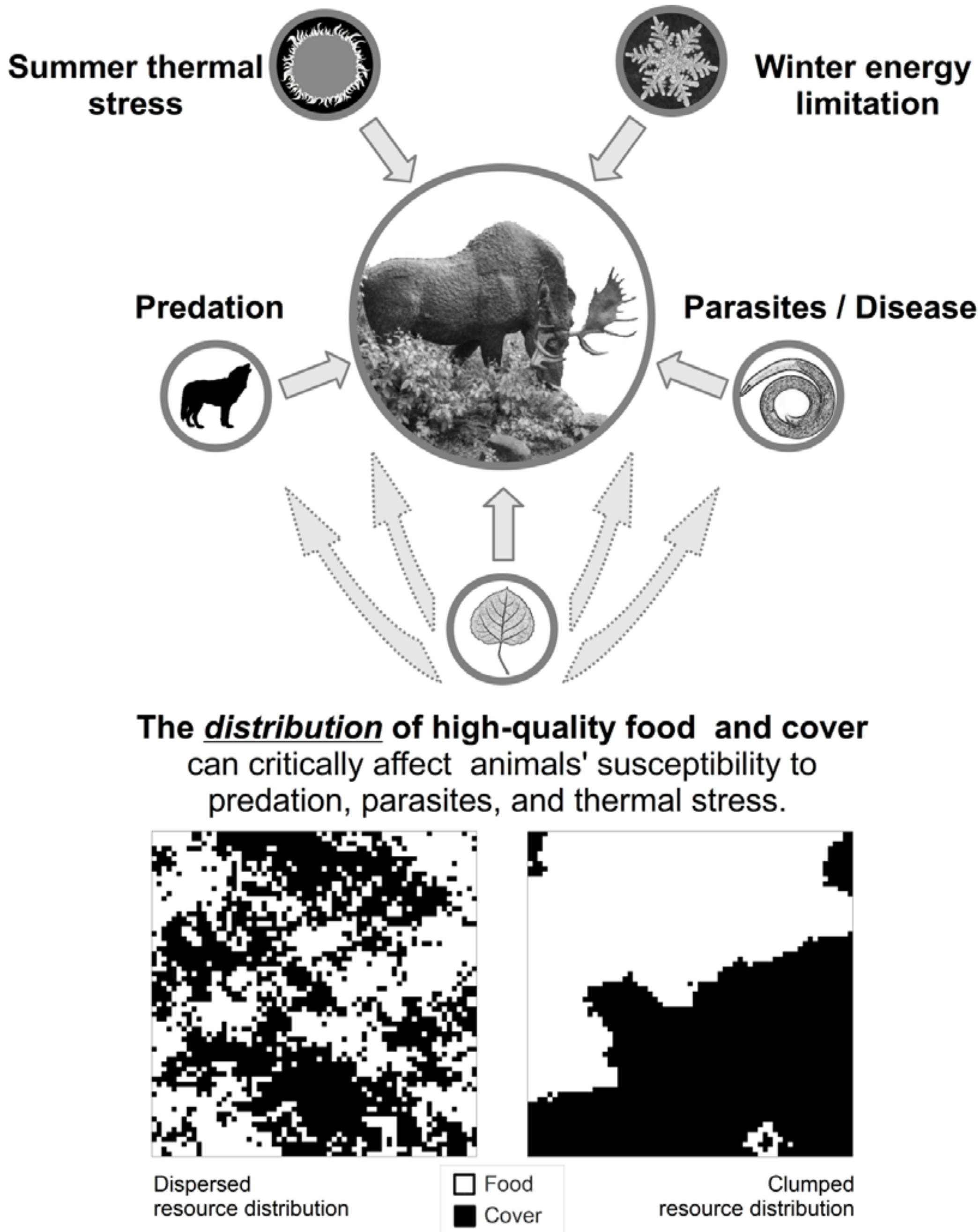



Figure 1. Moose can suffer in the summer heat, run out of food in the winter, fall prey to wolves, or succumb to parasites or disease. The distribution of high-quality food and cover can affect how susceptible animals are to these threats. **We found that: 1) the landscape composition of moose range has changed over 18 years, with mature coniferous forest becoming more dominant, 2) local moose populations had higher growth rates in cooler areas that had large amounts of mixedwood and young forests, and 3) although diets of moose varied across the range, animals that died tended to have eaten less high-quality forage in the previous summer. We suggest that these results be experimentally tested by observing moose behavior and population dynamics in large-scale forest manipulations where the amount of mixedwood and young aspen/birch stands are controlled and the quality and composition of forage species in the understory is monitored.**

**Environment and Natural Resources Trust Fund**

**M.L. 2014 Project Budget**

**Project Title:** Impacts of forest quality on declining Minnesota moose.

**Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 05l and Date of Work Plan Approval: June 4, 2014**

**Project Manager:** James Forester

**Organization: University of Minnesota**

**M.L. 2014 ENRTF Appropriation: $** 300,000

**Project Length and Completion Date:** 3 years, 30 June 2017

**Date of Report:** 2018-08-31

| **ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET** | **Revised Activity 1 Budget 5/01/2017** | **Amount Spent** | **Activity 1 Balance** | **Revised Activity 2 Budget 5/01/2017** | **Amount Spent** | **Activity 2 Balance** | **TOTAL BUDGET** | **TOTAL BALANCE** |
|---|---|---|---|---|---|---|---|---|
| **BUDGET ITEM** | ***Linking moose abundance to broad-scale distributions of food and cover that change across space and through time.*** | | | ***Linking the distribution and quality of food and cover to moose diet, body condition and mortality risk.*** | | | | |
| **Personnel (Wages and Benefits)** | $134,056 | $111,473 | $22,583 | $89,728 | $89,728 | $0 | $223,784 | $22,583 |
| Field manager - $23,242 (79% salary, 21% benefits); 38% FTE for two years; will lead vegetation sampling effort. | | | | | | | | |
| Faculty (Forester) - $40,287 (66.2% salary, 33.8% fringe); 8% FTE for four years; will manage project, and lead analysis of moose movement data. | | | | | | | | |
| Faculty (Fox) - $15,664 (84% salary, 16% benefits); 4% FTE for three years; will supervise the stable isotope analyses | | | | | | | | |
| Lab technician - $13,076 (73% salary, 27% benefits); 8% FTE for three years; will maintain stable isotope lab equipment and assist with analyses. | | | | | | | | |
| Research Associate (David Wilson) - $3,769 (73% salary, 27% benefits); 6% FTE for one year; will take lead on collecting and analyzing the FIA data for the moose range. | | | | | | | | |
| Undergraduate research assistants - $24,340 (100% salary); 2 x 19% FTE over 3 yr; will aid graduate student, field manager, and lab technician with data collection and entry. | | | | | | | | |
| Postdoctoral scholar (Garrett Street) 31,231 (81% salary, 19% fringe) 100% FTE over second 6 months, will compile moose movement data and begin initial habitat-use anlaysis. | | | | | | | | |
| Postdoctoral scholar (Althea ArchMiller) 18,721(81% salary, 19% fringe) 100% FTE over last 3 months, will analyze habitat data and develop population model | | | | | | | | |
| GIS Technicians (in Falkowski lab, UMN Forest Resources, $15,00) will classify historic and current satellite imagery. | | | | | | | | |
| PhD student (John Berini) $19,124 (86% salary, 14% benefits); 14% FTE over first year, 50% FTE over last six months; 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. | | | | | | | | |
| PhD student (Andrew Herberg) $2,340.18 (49% salary, 51% tuition and benefits); 50% FTE for one month; will analyze activity data of moose to predict how foraging behavior changes in different landscapes. | | | | | | | | |
| MS student (Amrit Shandilya) $16,989 (49% salary, 51% tuition and benefits); 50% FTE last six months; will develop computer program to predict locations of moose under changing landscapes. | | | | | | | | |
| **Professional/Technical/Service Contracts** | | | | | | | | |
| Isotope analysis (University of Minnesota Stable Isotope Lab) - $8,963; 956 samples of moose and plant tissue at $9/sample | | | | $8,963 | $8,963 | $0 | $8,963 | $0 |
| Isotope analysis (Santa Cruz Stable Isotope Lab) - $27,894; 2376 samples of plant tissue at $11.74/sample | | | | $27,894 | $27,894 | $0 | $27,894 | $0 |
| Chemical composition analysis of plant samples (UMN Metabolomics Lab $15,000) | | | | $15,000 | $15,000 | $0 | $15,000 | $0 |
| Development of a 2014 moose-specific habitat classification by combining LiDAR and LANDSAT data (Knight lab $5000) | $5,000 | $5,000 | $0 | | $0 | $0 | $5,000 | $0 |
| **Equipment/Tools/Supplies** | | | | | | | | |
| Lab supplies (reagents, weigh tins, gas canisters, and other consumable supplies used for stable isotope analysis) - $2,769 | | | | $2,769 | $2,769 | $0 | $2,769 | $0 |
| field equipment (measuring tapes, compasses, flagging tape, sample bags, stakes, etc) - $980 | $600 | $600 | $0 | $380 | $380 | $0 | $980 | $0 |
| Map-grade GPS unit for precise location of field samples and accurate ground truthing of satellite imagery $5,845 | | | | $5,845 | $5,845 | $0 | $5,845 | $0 |
| **Travel expenses in Minnesota** | | | | | | | | |
| Travel to study area by project management staff and technicians 4 months/yr for 3 years (1 fleet truck @$779/month, $0.37/mi, 7000 miles/ yr) - $17,040 | $255 | $255 | $0 | $6,923 | $6,923 | $0 | $7,178 | $0 |
| Room and board for field crew (3 yr of summer and winter field sessions, 4 months/yr, 2-6 crew members at a time, lodging @ $1,500/mo, meals @ $1,185/mo) - $32,222 | $1,000 | $1,000 | $0 | $1,584 | $1,584 | $0 | $2,584 | $0 |
| **COLUMN TOTAL** | **$140,911** | **$118,328** | **$22,583** | **$159,086** | **$159,086** | **$0** | **$299,997** | **$22,583** |