

Browse Selection and Constraints for Moose (*Alces alces*) in the Adirondack Park, New York, USA

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Abstract

Current estimates of moose density in the Adirondack Park of New York are surprisingly low compared to the surrounding region. Yet, much of the Adirondacks are designated as “Forever Wild” forest, covered by late-seral forests that provide little browse biomass for moose. Moose have high nutritional demands and require a large amount of forage daily. Here, I explored the extent to which moose are nutritionally limited within the Adirondacks to test this hypothesis by determining the diet and browsing characteristics of moose in the region, then determining quantity and quality of available forage. I determined that summer protein availability is the most limiting nutritional resource for this population, and regenerating forests are capable of supporting 150% more moose than late-seral stage forests. Additionally, I identified red maple as a critical browse species in both summer and winter, and a decrease in browsing intensity with increasing understory dominance of American beech.

Key Words: *Alces alces*, allometry, biomass availability, foraging ecology, moose, New York, nutritional carrying capacity,

INTRODUCTION

The Adirondack Park of New York is one of the most well-known natural areas in the eastern United States. This 5.8 million acre park is a patchwork of public and private lands, supporting a variety of ecosystems from boreal bogs to alpine meadows as well as human settlements and industrial activities. The Adirondack Forest Preserve represents the 2.6 million acres of state land included in the Park, on which constitutional protections prohibit removal of timber, the so-called “forever wild” provision. The intrinsic values of wilderness and wildlife, as well as a sustainable forest industry, are important for the continued economic and cultural success of this region (Dawson 2009, Porter 2009). As moose recolonize this area, they present a potential economic boost by attracting wildlife viewers, but also could negatively impact forestry operations.

The eastern moose (*Alces alces americana*) has been an important cultural component across North America for hundreds of years, seen by many as a symbol of wild places (Reeves and McCabe 1997). This animal, however, does not always exist in remote areas, but often interacts with humans on a regular basis, specifically through conflicts with foresters trying to regenerate tree species of economic value for future harvest (Hornberg 2001, Mathisen et al. 2013). Thus, striking a balance between cultural value and sustainable forestry is an important balancing act for wildlife and forests of the Adirondacks as elsewhere in moose range.

Moose were extirpated from the Adirondack Park in the late 1800's due to unregulated hunting and forest clearing. Forest protection enabled forests to rebound, and game laws helped forest wildlife recover. The recovery of beaver (*Castor canadensis*) purportedly enhanced moose habitat by restoring wetlands, and moose began to naturally recolonize the Park in the 1980's. This pioneering population perplexingly has not reached the same densities, nor achieved

the high growth rates, observed in other recolonized areas of the northeastern US. This lack of growth could be attributed to concerns with disease transmission from white-tailed deer (*Odocoileus hemionus*), specifically pertaining to brainworm (*Parelaphostrongylus tenuis*). But an additional explanation for the low moose numbers seen in the Adirondacks may be that suitable foraging habitat is not widely available. With the Forest Preserve dominated by late-seral deciduous and conifer forests, and given decades of overbrowsing by deer, the Adirondacks may provide insufficient food to support a robust moose population. .

This research focuses explores the hypothesis that moose in the Adirondack Park may be resource limited. I approached this issue by first working to understand moose diets in the region, specifically which tree and shrub species make up the bulk of the diet for moose in winter and summer. This work was conducted primarily by tracking GPS collared moose to observe their feeding habits. Next, I predicted the availability of principal browse species in different cover types across the Park, using a series of Monte Carlo simulations to scale up the availability of food from individual plants to cover types while accounting for error propagation. To understand the extent to which moose might be nutritionally limited in the Adirondacks, I incorporated information on the composition, availability, and nutritional content of browse with metabolic requirements of moose to estimate the nutritional carrying capacity of the Adirondack range.

The results of this research outline the importance of protein availability and high quality summer range to northern ungulate populations, as well as indicating that timber harvest or, potentially natural forest disturbance, within this system is necessary to substantively increase browse availability and by extension moose numbers if that is determined to be a management goal. This information is important as wildlife and forest managers move forward in establishing

and maintaining a sustainable moose population in the area, one that can coexist with local forestry operations and remain robust in the face of potential climate-related environmental change.

Each chapter of this thesis is formatted to the specifications of the Journal of Wildlife Management.

CHAPTER 1: BROWSE SELECTION BY MOOSE ALONG THEIR SOUTHERN RANGE LIMIT IN THE ADIRONDACK PARK, NEW YORK, USA

ABSTRACT

Moose (*Alces alces americana*), a large-bodied and cold-adapted forest herbivore, may be vulnerable to climate-induced environmental change especially along their southern range margin in the northeastern United States. Better understanding of moose foraging patterns and resource constraints in this region, which moose recolonized over the past several decades, is needed to guide management actions to ensure moose persistence into the future. I backtracked GPS-collared female moose (N = 23) within the Adirondack Park, NY to quantify moose diets related to their browse selection and intensity, nutritional quality of forage and potentially interfering vegetation. Moose demonstrated a generalist feeding strategy in summer, but in winter selected browse species largely in order of digestible dry matter. Red maple (*Acer rubrum*) was the most heavily used species in both seasons. Foraging areas having a high proportion of beech (*Fagus grandifolia*), which in this region regenerates in dense thickets following the aftermath of beech bark disease, led to reduced browsing intensity by moose in both seasons. As climate change continues to alter plant species composition and new factors affecting forest composition manifest, managers should consider the bottom-up forces structuring herbivore populations.

INTRODUCTION

Prior to European settlement, the geographic range of moose (*Alces alces americana*) in the northeastern United States extended south into northern Pennsylvania. During the 18th and 19th centuries, moose range receded northward as populations were decimated from unregulated

harvests and given broad-scale conversion of forests to agricultural lands (Alexander 1993, Foster et al. 2002). Successful resource protection ultimately restored forest habitat for moose and recovered populations of native species such as beaver (*Castor canadensis*), whose maintenance of wetlands enhances habitat conditions for moose. By the mid-1980s, moose recolonized their eastern range as far south as northernmost Connecticut and the Adirondack Park in New York State (Hicks, 1986). Yet, with a population of about 400 moose today (J. Frair, unpub. data), the 5.8 million acre Adirondack Park & Forest Preserve supports by far the lowest density of moose across comparable latitudes in their contemporary range in the Northeast (Adirondack Park Agency 2018, Wattles and DeStefano 2011). Following recolonization, New Hampshire and Vermont documented rapid growth in moose numbers through the 1990s, with population stabilization observed through the mid-2000's, and, more recently, declines in some areas. In contrast, the Adirondack moose population appears to have maintained itself at a low density since recolonization (Wattles and DeStefano 2011). Of the potentially limiting factors for moose within NY State, the most influential are likely to include parasites (i.e., *Parelaphostrongylus tenuis* and *Fascioloides magna*) and poor quality habitat in terms of food availability. Although winter tick (*Dermacentor albipictus*) have been observed on moose in NY, the high levels of ticks and tick-induced mortalities observed in neighboring states (and subsequent population declines observed in those states) has not yet been an issue likely owing to low moose density. However, numerical size is a key determinant in the viability of a population over time (Amos and Balmford, 2001), and the small Adirondack moose population is likely to be less resilient to changing environmental conditions than the larger populations recorded in neighboring states.

Within the contiguous United States, climate warming is predicted to be most rapid within the northeastern states (Karmalkar & Bradley 2017) and the Adirondack region is expected to experience climatic conditions similar to West Virginia by the year 2100 – shifting to a warmer, drier, and more oak-dominated forest (Jenkins 2010). Broad-scale changes in canopy dominance have occurred with some frequency in Adirondack forests due to invasive agents causing chestnut blight (early 1900s), Dutch elm disease (1920-1940s), and beech bark disease (1960s; Giencke et al. 2014). Shifts in canopy dominance precipitate knock-on changes in the understory plant communities that, in turn, affect the herbivore community. Although moose successfully exploit non-traditional habitats in the Northeast, such as oak-dominated forests in Massachusetts (Wattles & DeStefano 2013), their behavioral plasticity to changing environmental conditions may be out-paced by that of white-tailed deer (Post and Stenseth 1999). A high degree of behavioral plasticity in white-tailed deer has been evidenced by their expansion into human-dominated landscapes (VerCauteren 2003) as well as northward expansion into the little disturbed boreal forests long considered primary moose habitat (Latham et al. 2010). Broad-scale overlap between moose and deer poses concern for moose persistence owing to increased disease transmission and competition for resources.

Given differences in body size, morphology and energetic requirements, moose and deer have adopted differing foraging strategies (Irwin 1975, Ludewig and Bowyer 1985). With their smaller body size deer have lower energy requirements than moose. Moreover, given their smaller muzzles, deer can be selective for high energy and nutrient-rich plant parts. In contrast, moose are bulk feeders that require large bite sizes to meet their energetic needs, a feeding strategy that requires dense concentrations of browse and that may reduce spatial overlap between moose and deer to some degree. Across the northeastern states, the highest

concentrations of browse, and by extension the highest densities of moose, have been observed on regenerating forests following timber harvest (Ball 2009), areas that are uncommon within the largely “Forever Wild” Adirondack forests compared to elsewhere in moose range. Where moose are concentrated within the Adirondack Park now and into the future, how many moose can be supported by the landscape, and the degree to which moose and white-tailed deer overlap will be driven in large part by the structure and composition of suitable foraging habitat.

Herein, I investigated the seasonal composition of browse used by moose along their southern range boundary in the Adirondack Park, quantified diet selection relative to plant nutritional quality, and modeled local browsing intensity as a function of the availability of both desirable and potentially interfering woody species. I focused solely on browse because tree and shrub species compose up to 90% of moose diets (Belovsky 1978, Van Dyne et al. 1980, Dungan and Wright 2005). I further focused on beech (*Fagus grandifolia*) as a potentially interfering species because following the aftermath of a beech bark disease epidemic that hit the Adirondack region around 1970 (Houston 1994) beech persists in a ‘thicket’ like growth form that has been shown to suppress seedling survival by sugar maple (Hane 2003) and reduce floral species diversity (Cale et al. 2013). Because beech is both widespread and locally common, it may be a major factor influencing available forage for moose. Moreover, beech thickets form visually dense pockets of foliage potentially perceived wrongly by moose as suitable foraging habitat and costing them valuable foraging time. I evaluated how much time moose spend browsing in foraging patches given the local abundance of both principal browse species and beech. By outlining key forage considerations for moose, this work provides insights to habitat management for moose and establishes a baseline against which future forests might be compared to understand shifts in habitat availability for moose under climate change.

STUDY AREA

Established by the New York State Legislature in 1885, the Adirondack Park (43°57'08.9"N 74°16'57.5"W) encompasses ~5.8 million acres in northern New York consisting of both publicly (44.6%) and privately-managed land (49.4%; Figure 1.1; Adirondack Park Agency 2018). The majority of public land is protected by Article XIV of the New York State Constitution as “wild forest”, which precludes resource extraction or development of any kind. In contrast, the majority of private land is designated for resource management and owned by timber companies that focus on harvest of white ash (*Fraxinus americana*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), red oak (*Quercus rubra*), black cherry (*Prunus serotina*), and white pine (*Pinus strobus*; NYS DEC 2016). The forest community of the Adirondacks is a patchwork of the northern boreal ecosystem interspersed with temperate deciduous forests and large peatland complexes. Lower elevations with fertile soils support a diverse array of tree species dominated by American beech, yellow birch (*Betula allegheniensis*), paper birch (*B. papyrifera*), sugar maple and red maple. Higher elevations are typically more coniferous, dominated by species such as red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), white pine and eastern hemlock (*Tsuga canadensis*; Jenkins and Keal 2004). Elevation in the park ranges from 30 m on the shores of Lake Champlain to over 1600 m at the highest summit (Mount Marcy). Much of the park consists of large glacial valleys that gradually rise in elevation to the High Peaks region in the east-central part of the park. Average monthly winter temperatures range from -12°C to -6°C, whereas summer monthly temperatures typically range from 20°C to 26°C. Monthly precipitation averages 8-10 cm year round (Jenkins and Keal 2004). From aerial surveys, the 2016 abundance of white-tailed deer and moose were estimated at 11,562 (SE=2117.0) and 394 (SE=54.9; R. Wheat, SUNY ESF, unpub. data). The region also supports

sustainably harvested populations of two potential moose predators, black bear (*Ursus americanus*) and coyote (*Canis latrans*).

METHODS

My objectives were to 1) identify the principal species browsed by moose in summer and winter, 2) compare metrics of diet selection with species-specific energy and digestible protein in each season, and 3) investigate how moose browsing pressure, or intensity, might vary with browse availability and potentially interfering species.

Sampling moose browse

I back-tracked GPS collared moose to quantify browsing patterns using procedures similar to Dungan (2010), Seaton (2002) and Wilson (1971). Adult female moose (N=23) were captured Jan 2015-17, fitted with a GPS collar (BASIC Iridium Track M 3D, Lotek Wireless, Newmarket, ON or TGW-4670-3, Telonics, Mesa, AZ) and released on site (SUNY ESF IACUC protocol 140901). Collars were programmed to attempt a GPS fix every 2 hours for 2 years, and achieved a mean fix rate of $98.7 \pm 1.1\%$. Summer sampling took place 15 Jun – 15 Jul 2016 and 2017, and winter sampling took place over the intervening Dec-Jan period (Figure 1). I concentrated search efforts on clusters of consecutive locations (~10-15 GPS locations/ha) established by a given moose over the previous 10-day window, and field visited clusters the animal had moved >500m away from. Two-three person field crews searched the vicinity of each GPS location cluster in the field to record evidence of moose and deer sign. To avoid confusing browse by moose and deer, areas were not sampled for moose browse if deer scat or tracks were observed within 15m of any portion of the subplots described below.

Where browse was evident and sign of deer absent, I defined the perimeter of the browsed patch following Bailey et al. (1996) by walking from a central point in the GPS location cluster towards each cardinal direction until no browsed stems were observed on 5 consecutive

individual trees or shrubs. Within that patch boundary, I established one transect having 3, 2- × 4-m sub-plots spaced 10 m apart (Figure 1.2). I defined browseable twigs as those <8 mm diameter, that extended >15 cm from a given branch point to terminal bud, and that occurred within a 0.5-3 m height stratum (Crete and Jordan, 1982; Raymond et al. 1996). I tallied the total number of browsed and unbrowsed twigs by species within each subplot. For each individual plant, I measured basal diameter (10 cm above ground) or quantified volume (tallest height × longest width × perpendicular width) so as to predict the total browseable biomass on that individual using allometric equations (see Chapter 2). I recorded the cover type of each transect as deciduous/mixed forest, conifer forest, open wetland, or wooded wetland based on classes derived from The Nature Conservancy’s Terrestrial Habitat Map for the Northeastern US and Atlantic Canada (Ferree and Anderson 2013) or, in forest management patches, as harvested stands ranging in cut age from 9-11 years (J. Santamour, LandVest, unpub. data).

Browse Selectivity

I first calculated the proportional representation of each species, Pr_i , in the collective moose diet as:

$$Pr_i = \frac{T_i}{\sum_{i=1}^n T_i} \quad (1)$$

where T is the number of browsed twigs for each species i . In each season I rank ordered species by Pr_i , summed them cumulatively across species, and considered the top 95% to represent principal browse species. In the case where a principal browse species was geographically restricted (as described later), I substituted additional browse species until the 95% threshold was met to represent park-wide availability of principal browse for moose. The number of browsed and unbrowsed twigs on each transect were summed to represent browse availability for species

i , with two indices of selection calculated by species at the transect level. Ivlev's electivity index (Manly et al. 2002, Cook et al. 2016) ranges -1 to $+1$ and was calculated as:

$$I_{ij} = \frac{\% \text{ Twigs Browsed} - \% \text{ Twigs Available}}{\% \text{ Twigs Browsed} + \% \text{ Twigs Available}} \quad (2)$$

for species i along transect j . Given that Ivlev's index is symmetric about 0, one can readily interpret moose selection or avoidance of species i . In contrast, Chesson's index is bounded by 0 and 1, interpreted as the probability that the next bite will be of species i , and calculated as:

$$C_{ij} = \frac{\left(\frac{\text{Proportion twigs browsed}_i}{\text{Proportion twigs available}_i} \right)}{\left(\sum_{i=1}^n \frac{\text{Proportion twigs browsed}_i}{\text{Proportion twigs available}_i} \right)} \quad (3)$$

Nutritional Analysis

To quantify browse quality, I collected 73 summer samples (Jul-Aug 2016, N=1-8 per species, 29 locations) and 131 winter samples (Jan-Feb 2017, N=1-18 per species, 37 locations; Figure 1) from principal browse species, selecting individuals to represent the size distribution as observed during park-wide vegetation surveys (Chapter 2). From a sampled individual, 5 browseable twigs (as previously defined) were clipped from various heights within the browse stratum. Fresh clippings were stored in plastic bags, kept on ice in the field, and later frozen. Samples from different individuals were composited by size class and geographic region prior to nutritional analysis. Composites pooled samples across different size classes, with mass from a given size class proportional to the abundance of that size class across the landscape. Further, composite samples were organized to assess for potential variation in plant quality among central, northeastern, and southwestern portions of the park (Figure 1.1). Replicate composites were analyzed to quantify variation within a species and region (although not all species were sampled in all regions). Frozen samples were sent to the Washington State University Wildlife Habitat and Nutrition Laboratory to determine crude protein (% CP), gross energy (cal/g, GE), neutral

detergent fiber (% , NDF), acid detergent fiber (% , ADF), acid detergent lignin (% , ADL), acid insoluble ash (% , AIA) and bovine serum albumin protein precipitate (mg ppt./mg feed, BSA; Goering and Van Soest 1970, Martin and Martin 1982, Robbins et al. 1987a), the latter used to account for reductions in digestibility due to the tannin content of forage. Duplicates of NDF, ADF, ADL and AIA were determined for each composite sample, with values averaged across duplicates. Dry matter digestibility (% , DMD) and digestible protein (g/100g feed, DP) were calculated following Robbins et al. (1987a,b). Digestible energy (kcal/g, DE) was determined as the product of GE and DMD for a given species. For species in which samples from multiple regions were available, I used a one-way ANOVA test to compare the mean values of DMD, DE, DP, CP and BSA among regions. I calculated Pearson's correlation coefficients between each of the diet metrics (U_i , Pr_i , I_{ij} and C_{ij}), averaged across transects, and nutritional values (DE, DP, DMD, CP, NDF, ADF and BSA).

Modeling Browse Intensity

I used the number of stems browsed in plot k as a measure of local browse intensity. I expected browse intensity at the feeding station (i.e. plot) level to be influenced fundamentally by the amount of available browse available at that level, which I quantified as the total browseable biomass of all principal species on plot k (Bailey et al. 1996). Available browse biomass was predicted at the individual stem (plant) level using allometric equations (see chapter 2), then summed across individuals along the transect to provide a patch-level estimate of available browse biomass. I anticipated a peak in browse intensity with intermediate levels of browseable biomass (Wilmhurst and Fryxell, 1995), and further expected browse intensity to decline with increasing coverage of potentially interfering vegetation. Whereas beech was anticipated to attract moose visually but be avoided when moose chose bites, dense conifer may visually

obscure or physically obstruct access to otherwise suitable browse in a plot. Thus, I considered both beech and conifer species to potentially interfere with moose browsing patterns at the feeding station level (Bailey et al. 1996).

I modeled local browse intensity using standard and zero-inflated Poisson and negative binomial models using the R package *glmmADMB* (Bolker et al., 2012). The global model in each season included fixed effects for available browse biomass (linear and quadratic fits tested), proportion beech, proportion conifer, and two-way interactions among these three covariates. Models also included random intercepts for individual transect and moose. Covariates were centered and standardized prior to analysis (Schielzeth 2010; Dormann et al. 2012). Alternative models were compared using Akaike's Information Criterion with a bias adjustment for small sample size (AIC_c ; Burnham and Anderson 2002).

RESULTS

Principal Browse Species

I identified 13 and 12 principal browse species in summer and winter, respectively (Table 1.1, Appendix 1). Although mountain holly (*Ilex mucronata*) made up 6.4% of the summer moose browse, this species was not observed within broad-scale biomass surveys across the Park (see Chapter 2) and was thus judged to be rare and excluded from the list of principal browse species available to moose park-wide. Red maple constituted the largest portion of the diet in both seasons at 20.6 and 38.5% of the browse biomass consumed in summer and winter. Yellow birch comprised 19.0% of the summer diet and 10.0% of the winter diet. In contrast, gray birch and paper birch made up 8.3% and 6.6% of the summer diet, respectively, but accounted for <1% each of the winter diet. In contrast, Balsam fir accounted for 16.5% of the winter diet, but was not detected in the summer diet.

Selection Indices

For principal browse species, *C* ranged 0.04-0.39 with yellow birch and grey birch scoring the first and second highest *C* scores in summer (their scores dropping precipitously in winter; Table 1.1). Red maple ranked third according to *C* in summer but first in winter. According to values of *I*, in summer moose selected for striped maple, avoided sugar maple and hobblebush, and used the other species in proportion to their availability (Table 1.1). In contrast, in winter moose selected for red maple, avoided balsam fir, sugar maple, yellow birch, and black cherry, and used the other species in proportion to their availability. Among the non-principal browse species winterberry (*Ilex verticillata*) was selected for in summer and willow (*Salix spp.*) was selected in winter.

Nutritional Analysis

Northern wild raisin (*Viburnum nudum* L. var. *cassinoides*) and big-tooth aspen (*Populus grandidentata*) exhibited two of the highest DE values in summer at 2.85 kcal/g and 2.76 kcal/g, respectively, concurrent with the two lowest DP values at 1.58 and 0.77 g/100g feed, respectively. Low DP values are caused by relatively low CP content and, in the case of big-tooth aspen, compounded by a high reduction in digestion due to tannins (0.08 mg ppt./mg forage). Red maple, the largest component of moose diets in both seasons, exhibited moderate values for all nutrients measured. Perhaps the most nutritious forage in summer was pin cherry (*Prunus pensylvanica*), exhibiting the highest DP (6.20 g/100g forage), and second highest DE (2.76 kcal/g) and DMD (55.24%; Table 1.1, Figure 1.3). Quaking aspen (*Populus tremuloides*; DE=2.63 kcal/g, DP = 3.78 g/100g feed, DMD = 50.85%, BSA = 0.00) and balsam fir (DE=2.68 kcal/g, DP = 2.80 g/100g forage, DMD = 49.60%, BSA = 0.06 mg ppt/mg forage) were among the highest quality browse species in winter (Table 1.1, Figure 1.3). For species collected in both seasons, DE, DP and DMD were 18.65%, 23.12% and 19.31% lower on average across species,

respectively, in winter compared to summer values. No regional differences in DMD, DE, DP, CP or BSA were detected for any individual species (Summer $p = 0.08-0.96$; winter $p = 0.15-0.98$).

As expected, American beech exhibited relatively low values for DE (1.77 kcal/g), DMD (36.4%) and CP (7.40%) in summer, however there was no observed reduction in digestibility due to tannins (BSA = 0.00) for this species resulting in a relatively large DP (3.00 g/100g feed; Figure 1.5). In winter, American beech exhibited low DE (1.66 kcal/g) and DMD (33.60%) values with a moderate DP (2.30 g/100g forage; Figure 1.5).

Both *I* and *C* were positively correlated with DE and DMD in winter ($0.62 < r < 0.76$, $P < 0.05$; Figure 1.5). In contrast, nutritional metrics and diet metrics were not significantly related in summer ($-0.55 < r < 0.49$, $p > 0.05$; Fig 1.4).

Browse Utilization Models

Local browse intensity at the feeding station level, as measured by the number of stems browsed on at plot, was best fitted in both seasons by a zero-inflated negative binomial model, with α (the dispersion parameter) for the global model being 1.10 (SE: 0.16) in summer and 2.39 (SE: 0.88) in winter. In winter, model selection uncertainty centered on the inclusion of conifer as an interfering vegetation type. During winter, browse intensity was predicted to peak at ~4,200 kg/ha. Model selection uncertainty (based on $\Delta AIC < 2.0$) was observed in summer with respect to interaction terms and whether total available browse was better fit as a linear or quadratic form (Table 1.2). The top ranked model in summer indicated the effect of total browse biomass on browse intensity saturated at ~31,250 kg/ha in the absence of other covariates (Figure 1.6), however model selection uncertainty may suggest that the second ranked model, with 10 degrees of freedom as opposed to 12 in the top ranked model, may be a more appropriate choice. This

model does not indicate a saturation in browse intensity as biomass increases as indicated by the top model, but instead indicates a linear increase in browse intensity with increasing biomass availability. The proportion of stems in the patch comprised of beech had a negative effect on browse intensity in both seasons (Table 1.3), as did conifer cover in summer. Predictions from both models indicate a reduction in browse intensity as beech coverage increases at low biomass levels with this discrepancy being reduced as browseable biomass increases (Figure 1.6a). Also included in both models is a compounding negative effect of beech and conifer coverage on browsing intensity (Figure 1.6c). The top model additionally includes an interaction between biomass and conifer, indicating that at low biomass levels, conifer coverage levels have a relatively uniform impact on browsing intensity across their range, while high conifer coverage has a larger negative impact at high levels of biomass availability (Figure 1.6b).

DISCUSSION

The diversity of species browsed by Adirondack moose was similar to that observed for moose in New Hampshire (Pruss and Pekins 1992), although quite different from moose diets in Maine (Ludwig and Bowyer 1985). Although red maple, pin cherry and quaking aspen were used by New Hampshire and Adirondack moose alike, speckled alder (*Alnus incana*) browsed by moose in New Hampshire was not observed in New York moose diets despite the species being widely encountered in our wetland plots. In Maine, winter moose diets were dominated by balsam fir (70.5%), American beech (11.4%) and hawthorn (*Crataegus sp.*, 9.3%; Ludwig and Bowyer 1985). Whereas Ludwig and Bowyer (1985) attributed high use of balsam fir by moose to competition with white-tailed deer, generally herbivore diet selection correlates with relative nutritional content (Hanley 1997, Hobbs and Swift 1985). For Adirondack moose, diet composition in winter was directly related to dry matter digestibility (and by extension digestible

energy) and inversely related to fiber concentrations, with balsam fir being one of the highest quality browse species in winter along with quaking aspen. Protein of winter browse in NY was slightly lower compared to the larger region, with balsam fir, striped maple, red maple and hobblebush being 1-2% units lower in crude protein in this study (Mautz et al. 1976; Raymond et al. 1996). However, this discrepancy could be due to the difference in laboratory analysis techniques between the studies. Surprisingly, no regional differences in nutrition were detected within NY despite meaningful differences in terrain and soil characteristics across the Adirondack Park (Miller 1914) and the expectation that nutritional components, specifically relating to plant secondary compounds, are quite spatially diverse within species (Gusewell and Koerselman 2002,). It is likely that differences in nutritional quality of forage exist in the Adirondacks, but sample sizes in this study were too small (summer: 1-2 samples/region, winter: 1-11 samples/region) to detect such differences.

Although comparative studies in the northeastern US are lacking with respect to summer moose diets, Renecker and Schwartz (1997) identified aspen, birch and willow as species highly utilized by moose across their range. Birch species comprised 34% of the summer diet of Adirondack moose in this study, while aspen was relatively rare and generally utilized in proportion to its availability, and willow comprised <1% of the diet in each season. Generally speaking, moose were less selective of browse species in summer compared to winter in this study, and selection indices did not reflect plant nutritional quality during summer. It is possible that moose base summer diet choices on nutrients or minerals that were not measured in this study such as copper, sodium or selenium (Custer et al. 2004, O'Hara et al. 2001). Moreover, moose make ready use of aquatic vegetation and herbaceous forage during summer, reducing their dependence on browse for meeting their nutritional requirements. Interestingly, in a related

study the total protein available in browse proved more limiting to Adirondack moose in summer than to winter, although utilization of aquatic and herbaceous vegetation may bolster protein availability and decrease the likelihood of a protein limitation (Peterson, chapter 2).

In both seasons, the proportion of beech on a plot modified the estimate of twigs browsed and interacted with total browse biomass. However, the interaction between beech coverage and biomass of principal browse species indicated that where beech was prevalent moose browsed low biomass plots less intensively and high biomass plots more intensively (Figure 1.6b) perhaps because their bites were more concentrated on the desirable species within an otherwise beech-dominated foraging patch. The relationship between browse intensity and the beech:browse biomass availability interaction appears to flip near 5,000 grams/8m² plot, near the 95% percentile of observed biomass values in browse selection plots and well over the average biomass density recorded across the landscape (Figure 1.6b, Peterson Ch. 2). Given this, it is apparent that the conditions most often encountered by moose while foraging result in a negative effect of beech coverage on browsing intensity.

Summer browse intensity declined with increasing available browse biomass when plots were dominated by conifer, potentially because moose did not utilize balsam fir in summer and so avoided dense conifer plots altogether in summer. Additionally, summer foraging sites with high browse biomass and high conifer dominance (~50%, Figure 1.6b) are typically canopy openings in mature conifer forests with a mix of young conifer and deciduous regeneration. Previous research has indicated that moose exhibit differential fine-scale habitat use among seasons based on thermoregulatory needs. When heat stress is a limiting factor during the summer, moose may utilize mature forests at a higher rate than open areas, particularly open pine or spruce stands (van Beest et al. 2012). Therefore, it is likely that a behavioral tradeoff between

foraging intensity and thermoregulation could explain why conifer dominance results in such a marked reduction in browse intensity by Adirondack moose during the summer.

MANAGEMENT IMPLICATIONS

As moose are bulk feeders requiring large amounts of nutrients to maintain their large body size, effective use of foraging time is critical. According to this research, browsing intensity is impacted by the availability of browseable biomass as well as beech and conifer coverage.

Maximum summer browsing intensity was achieved at approximately 20,000 grams of browseable biomass per plot (2.5kg/m^2 , Figure 1.7). At this biomass level, the highest value of beech coverage appears to maximize browsing intensity, while lower values of conifer coverage provide ideal foraging conditions for moose. However, managing forest stands for this level of browse biomass availability is likely not feasible. At lower, more reasonable levels of biomass such as 0.05 kg/m^2 , the average observed value of browseable biomass in harvested stands during summer (Peterson Ch 2), lower levels of beech coverage, as well as low levels of conifer coverage, would maximize browsing intensity (Figure 1.6a). This information is useful as managers work with private landowners in either curating high quality moose habitat or attempt to mitigate issues associated with over browsing of commercially important species.

TABLES: CHAPTER 1

Table 1.1

Browse metrics, including proportion of diet (*Pr*), Ivlev’s Index (*I*), Chesson’s Index (*C*), and Utilization (*U*) along with nutritional quality, including Digestible Energy (kcal/g, *DE*), Digestible Protein (g/100g feed, *DP*) and Dry Matter Digestibility (% , *DMD*), for principal browse species consumed by moose in summer and winter within the Adirondack Park, NY, 2016-17. *N*₁ is the number of browse selection transects on which a given species was observed. *N*₂ is the number of nutritional samples collected for laboratory analysis of a certain species. Values in parentheses are standard deviations. For *I* and *C*, 95% confidence intervals that do not overlap 0 indicated by *.

Season	Principal Browse Species	Browse Metrics				Nutritional Quality			
		<i>N</i> ₁	<i>Pr</i>	<i>I</i>	<i>C</i>	<i>N</i> ₂	<i>DE</i>	<i>DP</i>	<i>DMD</i>
Summer	<i>Acer pensylvanicum</i>	19	<0.01	+0.81(0.42)*	0.04(0.10)	8	2.62(0.15)	2.40(1.03)	53.65(3.21)
	<i>Acer rubrum</i>	59	0.21	-0.06(0.63)	0.28(0.29)*	6	2.36(0.16)	2.24(0.80)	49.07(2.80)
	<i>Acer saccharum</i>	23	0.05	-0.27(0.57)*	0.23(0.26)*	2	2.47(0.01)	2.79(0.10)	52.56(1.02)
	<i>Acer spicatum</i>	3	<0.01	-0.06(0.83)	0.22(0.22)	-	-	-	-
	<i>Betula alleghaniensis</i>	48	0.19	+0.11(0.52)	0.36(0.30)*	4	2.00(0.14)	3.12(1.12)	39.96(2.68)
	<i>Betula papyrifera</i>	15	0.07	+0.05(0.66)	0.25(0.23)*	3	2.12(0.30)	3.68(0.82)	40.97(4.79)
	<i>Betula populifolia</i>	11	0.08	+0.25(0.43)	0.33(0.27)*	7	2.23(0.21)	2.66(1.00)	43.13(3.87)
	<i>Ostrya virginiana</i>	7	0.01	-0.37(0.80)	0.24(0.38)	-	-	-	-
	<i>Populus grandidentata</i>	6	0.02	+0.30(0.45)	0.28(0.19)*	1	2.76(n.a.)	0.77(n.a.)	53.00(n.a.)
	<i>Populus tremuloides</i>	13	0.05	-0.00(0.50)	0.20(0.13)*	-	-	-	-
	<i>Prunus pensylvanica</i>	13	0.06	-0.22(0.55)	0.22(0.30)*	3	2.76(0.12)	6.20(1.24)	55.25(2.38)
	<i>Viburnum lantanoides</i>	17	0.02	-0.53(0.59)*	0.17(0.27)*	2	2.31(0.13)	3.30(0.54)	48.21(2.40)
<i>Viburnum nudum cassinoides</i>	18	0.09	-0.03(0.58)	0.23(0.19)*	5	2.85(0.21)	1.58(0.28)	56.15(4.04)	
Winter	<i>Abies balsamea</i>	24	0.17	-0.31(0.50)*	0.22(0.30)*	18	2.68(0.20)	2.80(0.95)	49.60(3.54)
	<i>Acer pensylvanicum</i>	20	0.06	-0.15(0.49)	0.18(0.21)*	5	2.18(0.09)	-0.35(0.24)	44.36(1.18)
	<i>Acer rubrum</i>	38	0.39	+0.17(0.52)*	0.39(0.28)*	3	2.02(0.08)	0.19(0.46)	42.27(2.25)
	<i>Acer saccharum</i>	14	0.01	-0.58(0.51)*	0.09(0.14)*	3	1.66(0.05)	0.37(0.44)	33.80(1.06)
	<i>Acer spicatum</i>	5	0.01	-0.31(0.72)	0.22(0.30)	3	-	-	-
	<i>Betula alleghaniensis</i>	17	0.10	-0.57(0.44)*	0.06(0.06)*	2	1.67(0.19)	2.89(1.91)	32.82(3.39)
	<i>Populus grandidentata</i>	6	0.01	+0.09(0.63)	0.21(0.13)*	3	2.23(0.02)	2.61(0.52)	43.82(0.62)
	<i>Populus tremuloides</i>	11	0.03	+0.20(0.55)	0.31(0.27)*	4	2.63(0.15)	3.78(1.50)	50.85(2.74)
	<i>Prunus pensylvanica</i>	9	0.02	-0.40(0.63)	0.10(0.13)*	2	1.69(0.00)	0.96(0.91)	33.73(0.47)
	<i>Prunus serotina</i>	21	0.07	-0.54(0.50)*	0.10(0.15)*	1	1.85(n.a.)	3.23(n.a.)	34.76(n.a.)
	<i>Viburnum lantanoides</i>	17	0.03	-0.13(0.65)	0.22(0.26)*	3	2.17(0.09)	1.62(0.57)	45.27(1.15)
	<i>Viburnum sp.</i>	9	0.06	-0.01(0.46)	0.21(0.24)*	2	2.43(0.07)	0.34(0.06)	46.62(1.20)

Table 1.2.

Comparison of top 10 candidate models (summer cumulative weight = 0.58, winter cumulative weight = 0.96) predicting local browse intensity by moose in the Adirondack Park, NY, 2016-17 as a function of the principal browse biomass (M; fitted as a linear or polynomial), proportion stems beech (B), proportion stems conifer (C), and interactions as indicated. For each model, the model degrees of freedom (df), estimated log-likelihood (\mathcal{LL}), difference in AICc value (ΔAIC_c), and AIC model weight (w) are reported.

Season	Model	Main Effects	Interactions	df	\mathcal{LL}	ΔAIC_c	w
Summer	1	M+M ² , B, C	MxB, MxC, BxC	12	-872.29	0.00	0.11
	2	M, B, C	MxB, BxC	10	-874.73	0.42	0.09
	3	M, B, C	MxB, MxC, BxC	11	-873.75	0.69	0.08
	4	M+M ² , B+B ² , C	MxC, BxC	12	-872.76	0.94	0.07
	5	M, B, C	MxC, BxC	10	-875.25	1.46	0.05
	6	M+M ² , B+B ² , C	BxC	11	-874.22	1.62	0.05
	7	M+M ² , B, C	MxC	10	-875.43	1.82	0.04
	8	M+M ² , B+B ² , C	MxB, BxC	12	-873.37	2.16	0.04
	9	M+M ² , B		8	-877.80	2.19	0.04
	10	M+M ² , B+B ² , C	MxB, MxC, BxC	13	-872.29	2.26	0.03
Winter	1	M+M ² , B		8	-578.66	0.00	0.35
	2	M+M ² , B, C		9	-578.14	1.27	0.19
	3	M+M ² , B	MxB	9	-578.58	2.14	0.12
	4	M+M ² , B, C	MxC	10	-578.09	3.50	0.06
	5	M+M ² , B, C	MxB	10	-578.11	3.55	0.06
	6	M+M ² , B, C	BxC	10	-578.14	3.61	0.06
	7	M+M ²		7	-581.70	3.81	0.05
	8	M+M ² , C		8	-581.08	4.84	0.03
	9	M+M ² , B, C	MxB, MxC	11	-578.08	5.87	0.02
	10	M+M ² , B, C	MxC, BxC	11	-578.09	5.88	0.02

Table 1.3.

Standardized coefficient values for zero-inflated negative binomial regression models describing the local browse intensity (BI) by moose in the Adirondack Park, NY, given the amount of browseable biomass as well as potentially interfering species (beech and conifer). Data were standardized within a season prior to model fitting (see Appendix 1 for standardization values).

Covariate	Summer				Winter			
	β	SE	z	P	β	SE	z	P
Intercept	3.11	0.11	27.51	<0.01	3.67	0.13	27.39	<0.01
Browse Biomass	0.60	0.16	3.67	<0.01	0.71	0.17	4.14	<0.01
Browse Biomass ²	-0.04	0.02	-1.73	0.08	-0.14	0.04	-3.62	<0.01
Proportion stems beech	-0.95	0.22	-4.29	<0.01	-0.27	0.11	-2.48	0.01
Proportion stems conifer	-0.65	0.19	-3.45	<0.01	-	-	-	-
Biomass × Beech	0.22	0.24	0.92	0.36	-	-	-	-
Biomass × Conifer	-0.25	0.17	-1.46	0.14	-	-	-	-
Beech × Conifer	-1.06	0.39	-2.74	0.01	-	-	-	-

FIGURES: CHAPTER 1

Figure 1.1

Adirondack Park study area in northeastern New York state showing public lands (light gray) and private lands (white) along with water bodies (dark gray). Locations where GPS-moose were back-tracked are indicated (black circles) along with locations where nutritional samples were collected (white circles) and the grouping of nutritional samples (large boxes) to test for geographic variation in plant quality.

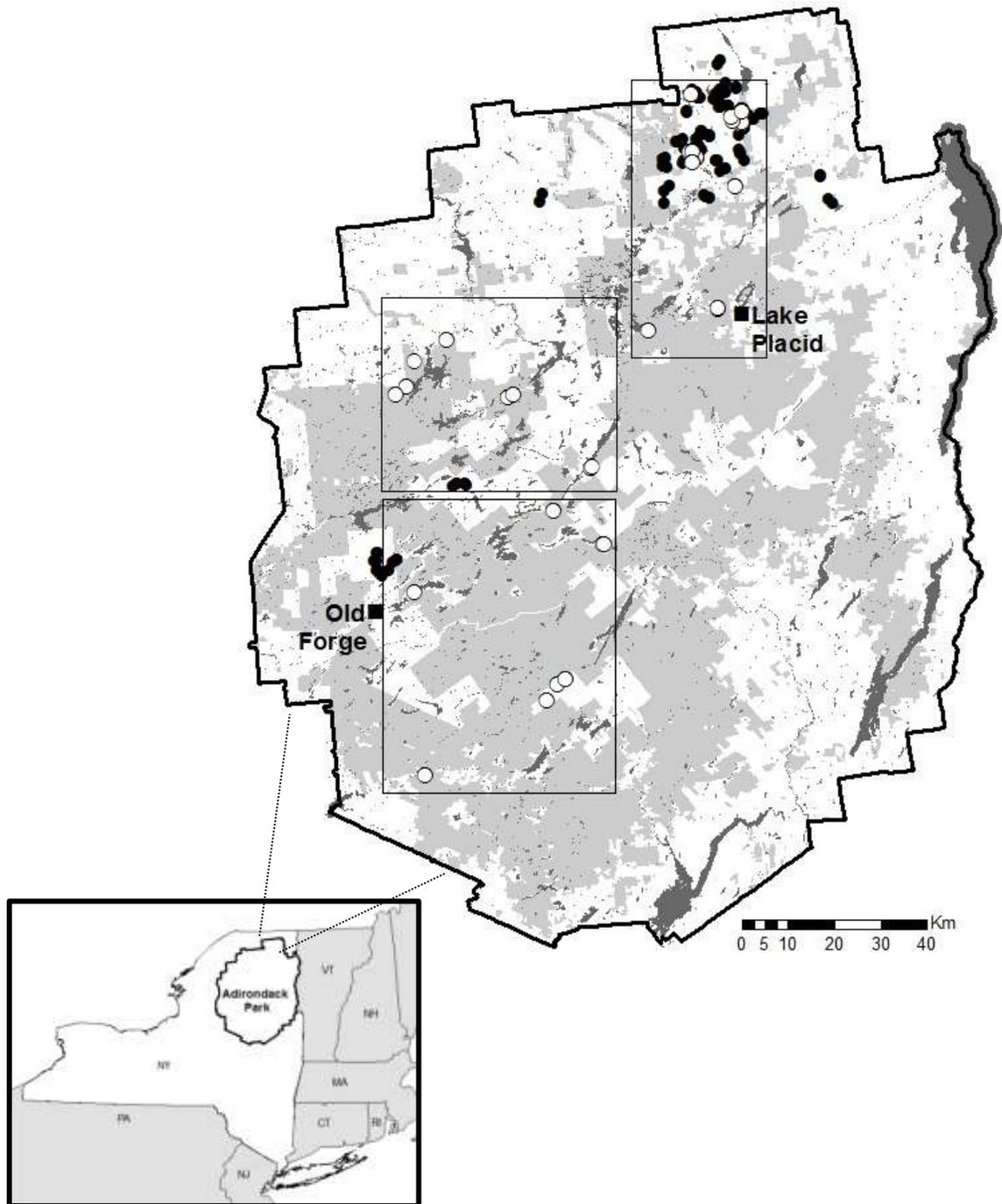


Figure 1.2

Diagram of field sampling layout used to conduct browse selection surveys for moose in Adirondack Park, NY. Sampling design consisted of three 4m x 2m plots (feeding stations) spaced 10m apart on a transect. Plots were centered on an observed foraging patch that was located using GPS collared female moose. Edges of the foraging patch were delineated by walking concentric circles around an area of observed browse until no signs of moose browsing remained visible.

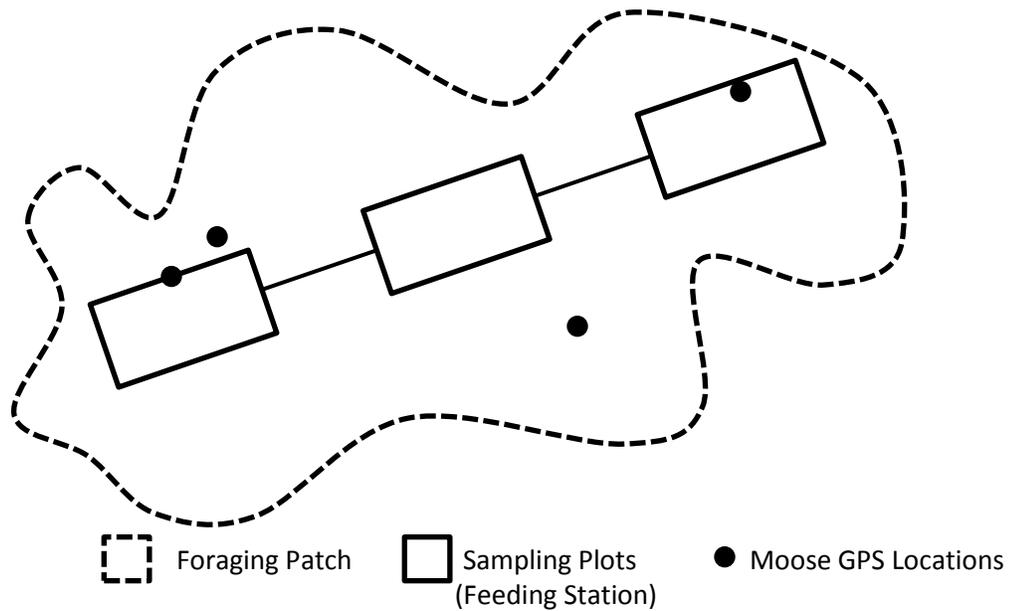


Figure 1.3

Nutritional values, showing mean with 95% confidence interval, of principal browse species consumed by moose during the summer (Jun-Aug 2016) in Adirondack Park, NY. American beech, a potentially interfering browse type, is shown for comparison.

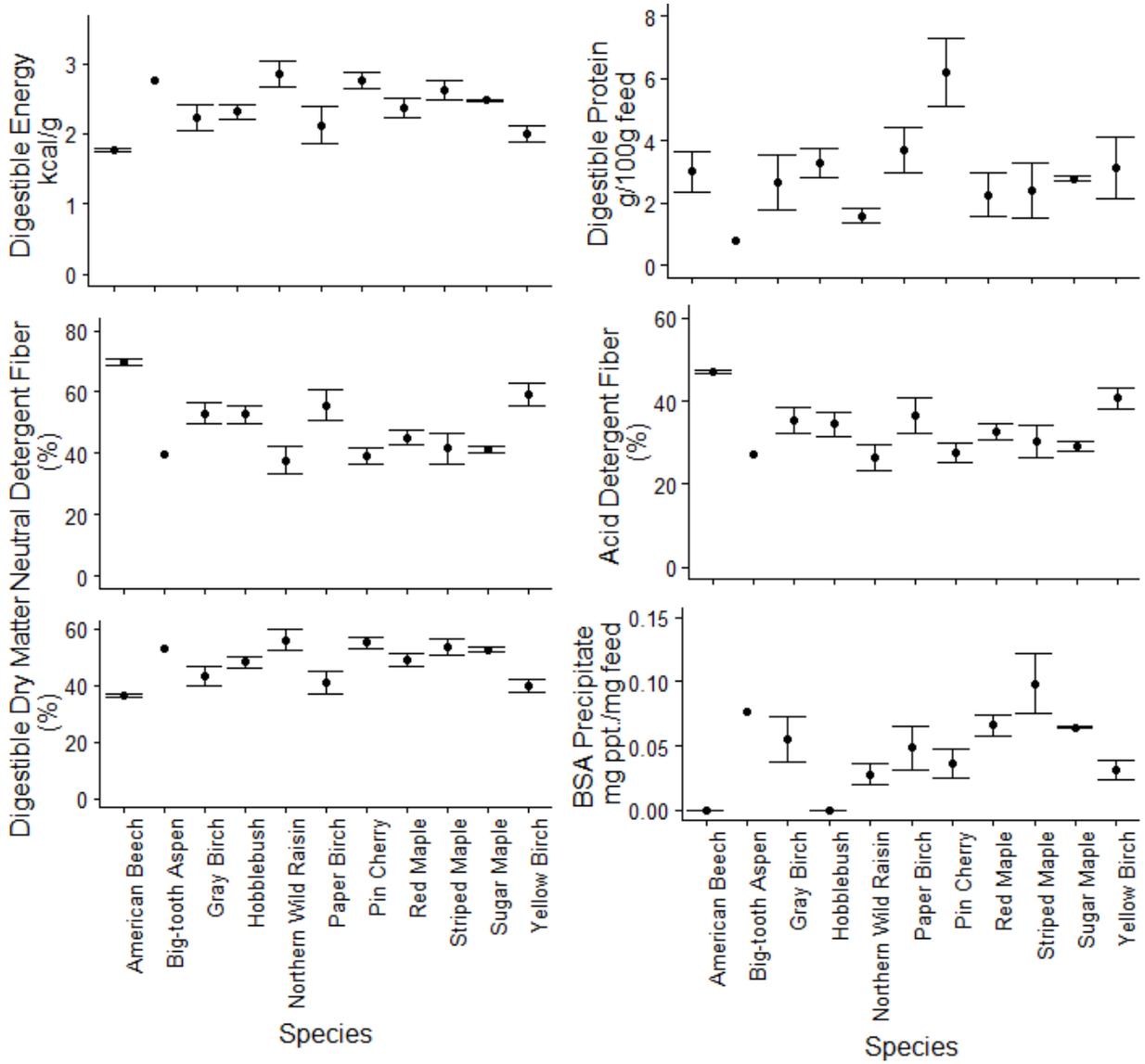


Figure 1.4:

Nutritional values, showing mean with 95% confidence interval, of principal browse species consumed by moose during the winter (Dec-Feb 2017) in Adirondack Park, NY. For black cherry, replicates were not available and mean values are plotted without confidence intervals. American beech, a potentially interfering browse type, is shown for comparison.

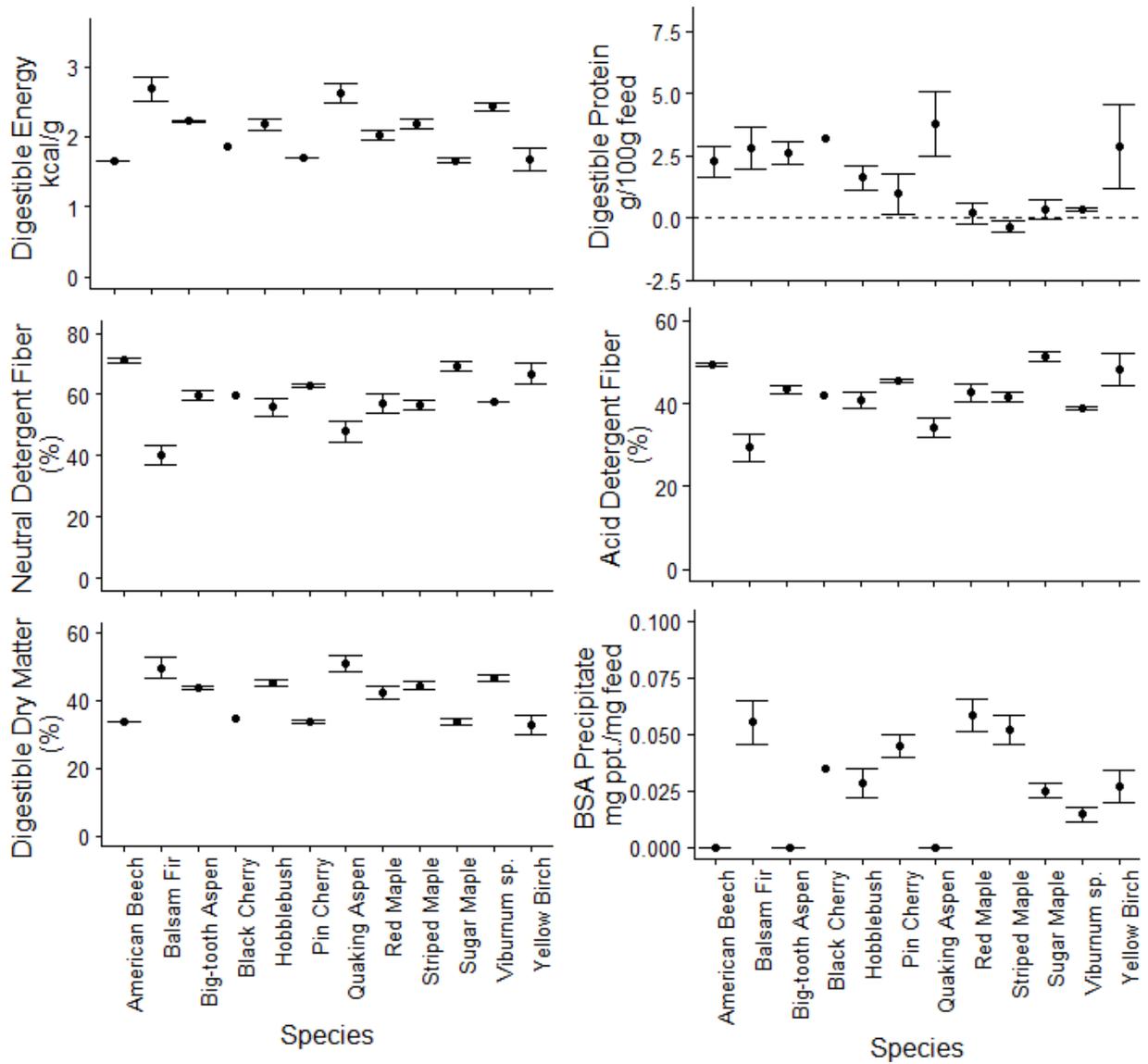


Figure 1.5:

Ivlev's Electivity Index (top panels) and Chesson's Index (bottom panels), with 95% confidence intervals, plotted as a function of Dry Matter Digestibility (DMD) in summer (left panels) and winter (right panels) for moose principal browse species and American Beech (FaGr) in Adirondack Park, NY, 2016-17. Species are labeled using the first two letters of their genus and species (see Table 2 for scientific names).

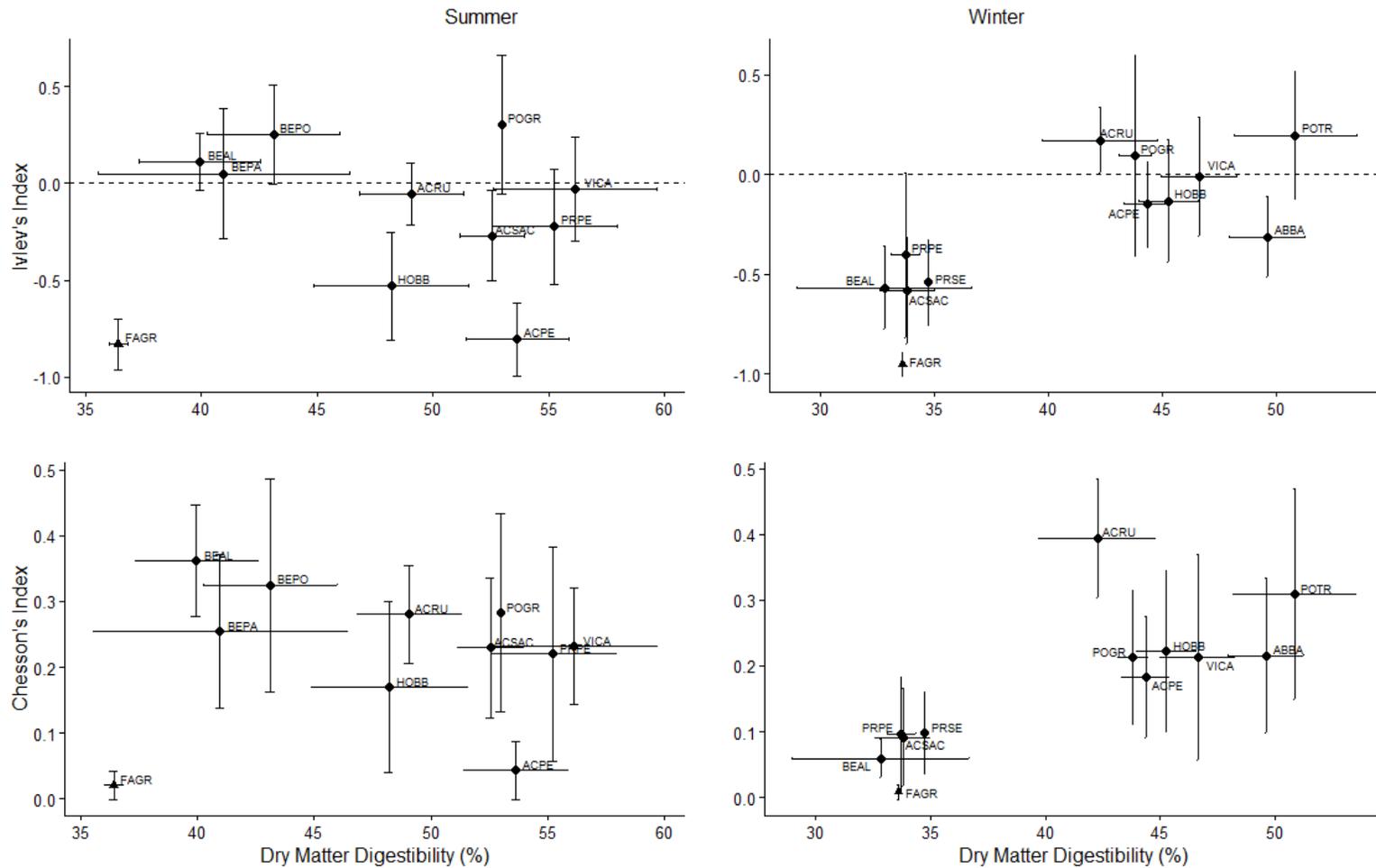


Figure 1.6:

Partial slope plots of biomass, conifer coverage and beech coverage interactions for models predicting browsing intensity (number of stems browsed) of moose during summer at a given location in Adirondack Park, NY. Browsed stems are estimated at the feeding station (8m² plot) level. Biomass values (x-axis, panels A and B) are shown in g/8m² plot, and span the range of 95% of observed values of biomass (Peterson 2018, Ch. 2). Levels of beech and conifer coverage are also restricted to 95% of observed values for each variable (~75% coverage for each). Vertical dashed lines represent average browse biomass estimated in regenerating forest (400g/8m², or 0.05 kg/ha; Peterson 2018, Ch. 2).

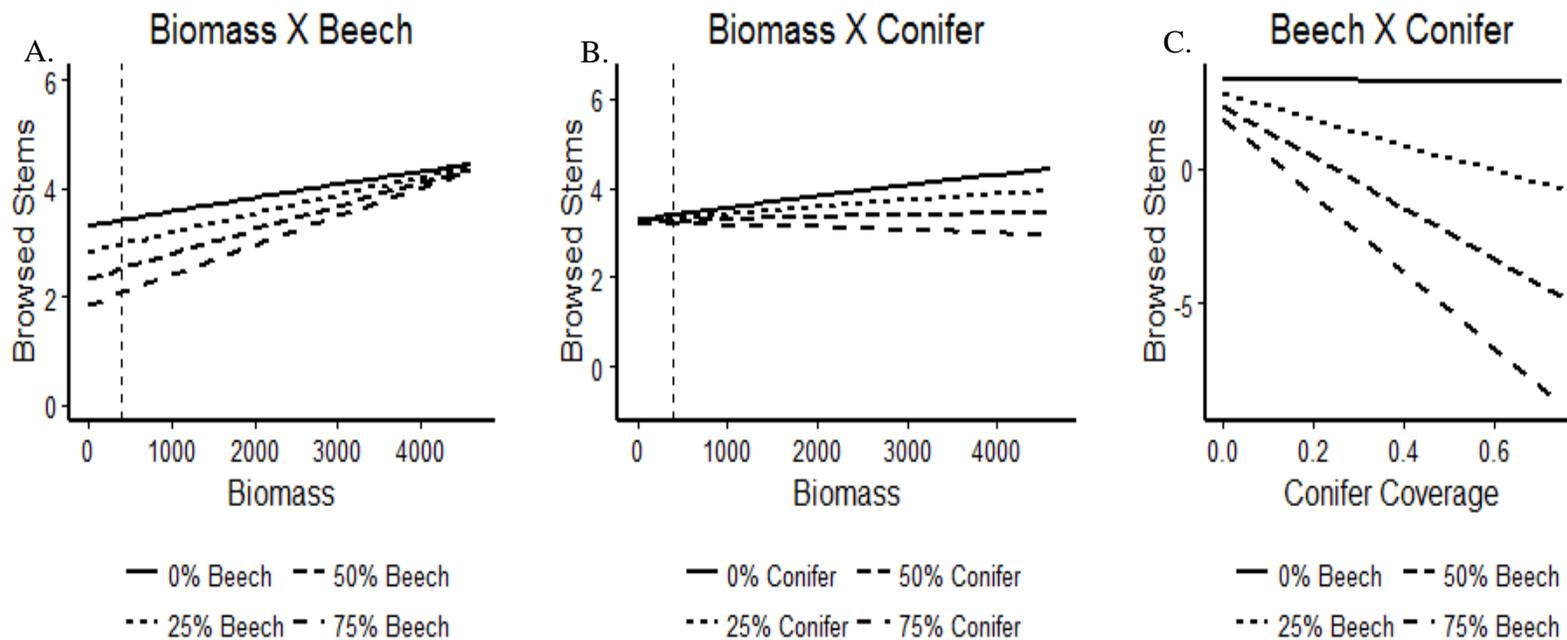
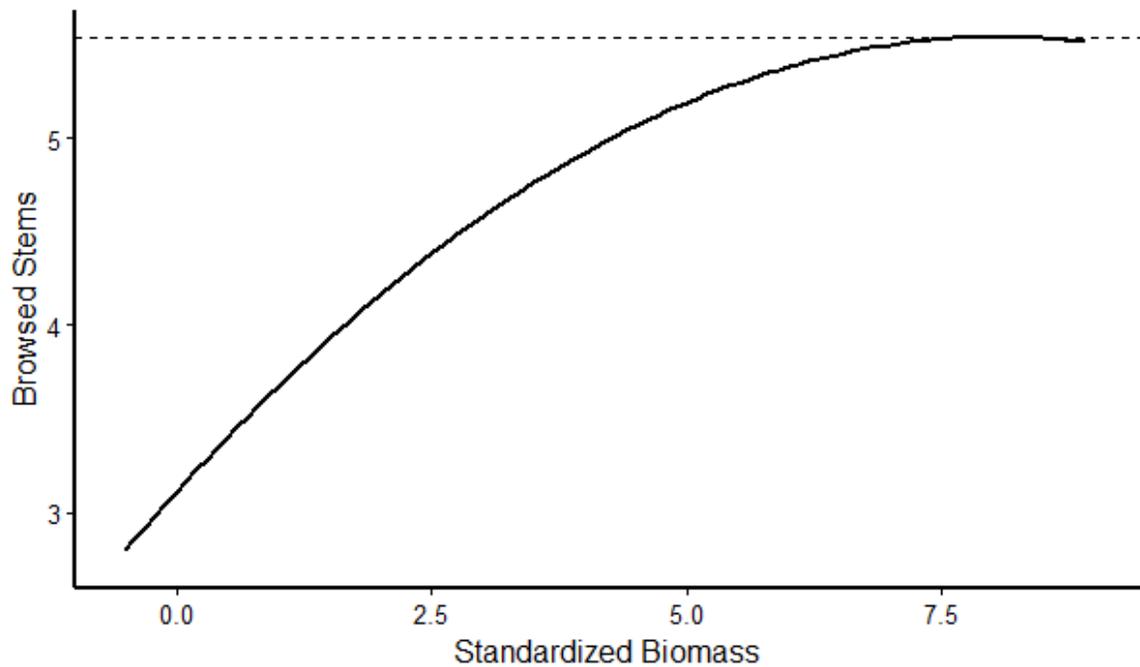


Figure 1.7:

Plot of browse intensity by moose in summer across the observed range of standardized browseable biomass values, holding beech and conifer coverage at a value of 0. Maximum browsing intensity is encountered at approximately 7.5 standardized biomass units (2.5 kg/m², see Appendix 2 for standardization values).



CHAPTER 2: BIOMASS ESTIMATION AND NUTRITIONAL LIMITATIONS

ABSTRACT

Despite an abundance of undeveloped forest habitat for moose in northern NY state, browse availability may be limiting to moose in the late successional, 'Forever Wild', stands across the 5.8 million acre Adirondack Park and Forest Preserve. Assuming alternative nutritional requirements and foraging constraints, I calculated the number of cow-calf pairs (summer) or lactating cows (winter) potentially supported by available browse within the park. I built allometric equations to predict available browse biomass for moose on individual plants, sampled within 300 plots across the park, and scaled-up biomass estimates to 6 major cover types. Protein availability proved most limiting to moose in summer, with areas regenerating following timber harvest supporting ~7 times more moose than the mixed wood stands and wetlands that dominate the forest preserve. The number of moose potentially supported by available browse in winter, which additionally included energy-rich balsam fir, was 8-135 times higher than summer (with energy being the limiting factor in winter). Error associated with estimates of moose diet selection contributed the greatest variance to carrying capacity estimates (22%), compared to predictions of biomass availability or crude protein content (each <1%). This research corroborates high quality summer range as a key factor limiting northern ungulate populations, potentially helps explain the persistently small moose population within the Adirondack Park, and provides insights for enhancing moose habitat, and by extension increasing moose numbers in the Park, should that be a management goal.

INTRODUCTION

Unregulated market hunting and broad-scale forest clearing drove local extinctions of moose across much of the northeastern United States by the late 1800's. By the late 1980's, following harvest restrictions and broad-scale forest regeneration, moose had recolonized their former range as far south as northern Connecticut and the Adirondack Park in northern New York (Aagaard 2008). Whereas moose numbers in neighboring Vermont and New Hampshire have been estimated as high as 5,000 and 4,500 in the past decade (Wattles and Destefano 2011), the Adirondack population is currently estimated at 394 animals (55 SE; J. Frair, unpub. data). Despite the considerably greater extent of undeveloped forest habitat in New York compared to neighboring states, standard indices used to track moose population growth (e.g., moose-vehicle-collisions) indicate the Adirondack population has remained low for decades (Wattles and Destefano 2011). One key difference between NY and the other northeastern states may be the extent and frequency of forest disturbances, such as timber harvest, that set back forest succession and create the abundant and high quality browse required by moose. Being large-bodied and broad-muzzled, moose require dense concentrations of quality browse to meet their high nutritional requirements (Shipley et al. 1994, Illius and Gordon 1987). Like most eastern forests, stands within the Adirondack Park are dominated by late seral successional stages, most notably in areas designated as forest preserve –collectively 2.6 million acres of the park maintained as 'forever wild' and protected from anthropogenic changes. As a result, closed-canopy forest conditions, combined with chronic overbrowsing by white-tailed deer (Rooney 2001, Côté et al. 2004), provide limited understory development across much of the park.

Canopy disturbances from pathogens and storms drive small gap dynamics in the region (Runkle 1982; Seymour et al. 2002), which produce diffuse patches of early seral vegetation.

Since the early 1900's, one such disturbance, beech bark disease, which kills adult trees and leads to regenerating thickets of beech in the understory, may negatively affect browse availability for moose by competing with more desirable species (Peterson Ch 1). Across the region, a potentially more important forest disturbance agent for moose has been beaver (*Castor canadensis*), whose wetland creation activities set back forest succession in larger patches than the typical gap dynamics in the northeast, and also create patches of aquatic vegetation readily exploited by moose (Belovsky 1981, Naiman et al. 1986). Indeed, the recovery of beaver across northeastern forests purportedly facilitated moose recolonization of the region (Aagaard 2008). Yet, across their geographic range, moose are known to depend heavily on the large concentrations of deciduous browse produced within regenerating timber cuts or other large-scale forest disturbances (Ball 2009, Bowler et al. 2012). Research in New Hampshire and Vermont has indicated that moose densities are highest in areas with active timber harvest operations and that moose will actively select these habitats, likely for the high levels of deciduous browse made available by timber operations (Bergeron et al. 2011, Millette et al. 2014). The natural, large-scale return interval in inland forests in this region is 1000-7500 years, and more often involves winter damage (e.g., ice storms breaking limbs or causing mast failures) and small patches rather than large swaths of blown-down trees (Lorimer and White 2003, Millward and Kraft 2004). These forms of natural disturbance contrast heavily with the more temporally and spatially predictable disturbance arising from timber harvest operations. Within the Adirondack Park, timber harvest is restricted to private lands, some of which are under conservation easement with the New York State Department of Environmental Conservation (NYS-DEC). Most timber harvest activity occurs on properties designated under the "Resource Management" classification, which covers approximately 25% of the Adirondack

land base. Knowledge of the composition, quality and abundance of forage produced by these different disturbances, specifically by regenerating forest cuts, wetlands, and mature forests within the park, is needed to evaluate the potential carrying capacity and factors limiting to moose.

Hobbs and Swift (1985) laid the foundation for contemporary estimates of food-based carrying capacity, with their estimates based on the nutritional quality of principal forage types, the available biomass of each type, and the mixture of types needed to meet the target animal's nutritional requirements. They specifically estimated the amount of food required to achieve a diet of a specific quality (what they considered the 'food supply'), which, when divided by daily dry matter intake rates for the target animal, gave an estimate of 'animal use days' that might be supported. Hobbs and Swift (1985) applied this approach in the Rocky Mountains, Colorado, to better elucidate differences in habitat quality between burned and unburned forests for bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) in comparison to traditional range supply models. Hanley et al. (2012) expanded upon this approach for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) by using a linear programming model to determine the maximum amount of forage biomass that can be pooled from available forage types while meeting specified nutritional requirements under specific constraints such as foraging time, bite size, and diet composition. Importantly, such estimates provide a 'snapshot' of carrying capacity, i.e., if you harvested all the available forage biomass from a given area at a given point in time, how many days would that forage support captive animals at the nutritional plane desired. Such instantaneous estimates ignore plant-herbivore interactions, feedback loops, plant phenology, and dynamic metabolic requirements among other complexities. As such, they are best interpreted as an index of habitat quality and, therefore, as a means of comparing the quality

of different forage types, cover types, treatments, or areas at a given point in time (e.g., Cook et al. 2016). Though current models are best used as indices, incorporating additional constraints and properly measuring uncertainty may yield results that are more comparable to reality in the field.

One potentially underappreciated aspect of estimating range quality is the compounding of error as estimates of available biomass are scaled up from individual plants to local plot or transect measures, and again to the level of specific cover types or study areas, potentially producing biased or overly confident estimates of range capacity differences across heterogeneous landscapes. For example, error may be grossly underestimated when considered at a single level only, e.g., accounting for inter-plot variation in biomass while ignoring the error associated with allometric predictions of the biomass available on a given plant (McWilliam et al. 1993). Monte Carlo simulation provides a useful approach to account for error propagation across multiple scales or processes (Harmon et al. 2007), and has been successfully used to estimate CO₂ uptake in pine forests (Bowler et al. 2012), carbon pools in subtropical forests (Conti et al. 2014), and nitrogen density in northeastern hardwood forests (Yanai et al. 2010). Herein, I applied Monte Carlo simulations to scale up estimates of available browse biomass from individual plants to cover types sampled across the heterogeneous Adirondack Park. Moreover, I extended the Monte Carlo approach when estimating range capacity so as to formally account for uncertainty in forage quality and foraging constraints. My approach enabled identification of the degree to which each component, whether measured empirically in this study or drawn from the literature, contributed to potential bias in and variance around range capacity estimates. Like the majority of range capacity studies for cervids, I focused on digestible energy and protein as the two most commonly limiting nutritional factors (Moen 1973;

Short 1981; White 1993). Likewise, I restricted my estimates of range capacity to female moose, the productive segment of the population (Hanley et al. 2012), and the segment to which growth rates in northern ungulate populations are most sensitive (Nelson and Peek 1982; Gaillard et al. 1998). Ultimately, I compared the value to moose of different plants and cover types within the park to identify potentially limiting factors in the region of direct management relevance.

STUDY AREA

My study area was delineated as the 5.8 million acre Adirondack Park of New York (43°57'08.9"N 74°16'57.5"W; Figure 1), which includes 2.8 million acres of forest preserve (public land designated as 'Forever Wild') interspersed with private land. The majority of privately owned land is designated for resource management, which may include timber harvest. Forest canopies in the region are dominated by American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and paper birch (*Betula papyrifera*). Common conifer species include white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), and balsam fir (*Abies balsamea*). Elevation in the park ranges <50 m on the shore of Lake Champlain to over 1600 m in the High Peaks region. During this study, monthly precipitation averaged 84.6 mm May-Sep 2016, 84.2 mm Dec 2016 – Mar 2017, and 128.3 mm May-Sep 2017 (n=17 weather stations; NOAA National Centers for Environmental Information). Potential predators of moose in this region include black bear (*Ursus americanus*) and coyote (*Canis latrans*), with the major competitor for browse being white-tailed deer (*Odocoileus virginianus*).

METHODS

Allometric Equations

To more efficiently sample and quantify the browse available to moose across the Park, I developed allometric equations following McInnes et al. (1992) and Visscher et al. (2006) for the 14 species that comprised $\geq 95\%$ of moose diets in winter and summer within the Adirondack region (S. Peterson, 2018, Chapter One). For each species, I sampled 11-32 ($\bar{x} = 21$) independent individuals across the Park (Figure 2.1). Within a species, individuals were sampled so as to represent the full range of sizes observed during the park-wide transect surveys described later. On each individual plant, I measured the basal diameter of the main stem (10 cm above the substrate) given a tree-like growth form or the tallest height, longest width, and perpendicular width (to calculate volume) given a shrub-like growth form (Figure 2.2A). From each sampled individual, I clipped all twigs within a 0.5-3 m height stratum to 8-mm diameter, a cutoff expected to provide a liberal estimate of available biomass for moose based on Seaton (2002). Leaves and woody mass were separated and dried to a constant mass in a forced air oven at 90°C for 24 hours. Summer samples were collected Aug-Sep 2016 and 2017 and winter samples were collected Dec 2016 – Jan 2017.

The dried mass (g) of each individual (leaves+twigs in summer, twigs only for deciduous species in winter, twigs+needles for balsam fir in winter) was *ln*-transformed to achieve normally distributed errors, and then related to size and site covariates using linear regression. Canopy cover was included as a site covariate and determined as the average proportion of overstory covering a location from 4 measurements (facing each edge of the plot) with a convex densiometer. Elevation, percent slope, and aspect were derived from a 90-m resolution Digital Elevation Model (US Geological Survey) using ArcGIS (ESRI, Redlands, CA). Aspect was represented as a binary covariate, with northwest values (0-40 degrees and 221-359 degrees) being assigned a 0 and southeast values (41-220 degrees) assigned a 1. After initial inspection of

the relationship between size and biomass, I collapsed species (and size classes within species) into 11 groups prior to fitting final models (Table 2.1). All model covariates were centered and standardized prior to model fitting (Schielzith 2010). Candidate models included all plausible covariate pairs having $r < 0.7$ when $P < 0.05$ (Dormann et al. 2012), as well as interactions between size and site covariates. Size covariates (basal diameter or volume) were included in alternative models as a single term (log-log model) or a second-order polynomial (power law model). Candidate models were evaluated using Akaike's Information Criterion (AIC; Burnham and Anderson 2002). In the case of model selection uncertainty, i.e. where $\Delta\text{AIC} < 2$, I chose to predict biomass using the highest ranked, lowest AIC value, model that satisfied model assumptions. Model assumptions were examined using the Shapiro-Wilk test for normality, Durbin-Watson test for autocorrelation, and Breusch-Pagan test for heteroskedasticity. From the selected model for each species the residual error, ε , was used for Monte Carlo simulations as described later.

Parkwide Biomass Surveys

Woody species were sampled along transects distributed across the park (N = 114; Figure 2.1). Transects were allocated proportional to the areal coverage of, Upland Mixed Forest (≥ 497 m elevation, N = 38), Lowland Mixed Forest (< 497 m, N = 34), Conifer Forest (N = 13), and Wetland (N = 19), based on a generalized classification of The Nature Conservancy's Terrestrial Habitat Map for the Northeast US and Atlantic Canada (Ferree and Anderson, 2013; Appendix 1). Based on field observations, Wetland transects were divided *a posteriori* into Open Wetland (N = 15) and Forested Wetland (N = 4) classes to effectively capture vegetation patterns. I added additional transects (N = 13) in the Chateaugay Woodlands area, northern region of the park, to capture timber harvests of known age (cut 6-8 years ago, J. Santamour, LandVest Inc.

unpub. data). Transects started from random locations within each cover type and involved three 2×4 -m plots spaced 50-m apart (Figure 2.2B). The direction of each transect was initially chosen at random, and modified as needed to ensure all sample plots fell within the same cover type. Within a plot, for each woody plant I recorded the species and basal diameter or volume along with the proportion of browse contained within the plot. Individual plants were recorded only when they had twigs <8 mm diameter with non-dessicated leaves and stems within the 0.5-3 m height stratum. Percent canopy cover was estimated directly over each plot using a convex spherical densitometer as the average of 4 measurements made from the center of the plot facing each edge.

Scaling up Available Browse Biomass across the Park

Available browse biomass was ultimately estimated for each cover type, with Monte Carlo sampling employed to account for variation in predictions to individual plants, plots, transects, and cover types (Figure 2.2B). First, allometric equations were applied to predict the available browse biomass on each individual i , yielding prediction \bar{x}'_i . I multiplied \bar{x}'_i by the proportion of the browse on individual i falling within sampling plot j to yield \bar{x}'_{ij} . I then drew 1000 Monte Carlo resamples (MC1; Figure 2.2B) from a normal distribution having mean \bar{x}'_{ij} and error ϵ (from the appropriate allometric model) to produce a vector containing 1000 possible values of the browseable biomass on individual i , from which I derived a grand mean \bar{x}_{ij} and standard deviation σ_{ij} . Within each plot (j), I summed the \bar{x}_{ij} and σ_{ij} across all individuals of species k yielding B'_{jk} with standard deviation σ'_{jk} . Drawing from these values, a second Monte Carlo sampling (MC2; Figure 2.2B) generated 1000 new values for plot-level biomass for each species, from which I derived mean \bar{B}_{jk} and standard deviation σ_{jk} . Across each transect (t), I summed values of \bar{B}_{jk} and σ_{jk} across the three k to yield B'_{jt} with standard deviation σ'_{jt} . Drawing from

these values, a third Monte Carlo sampling (MC3; Figure 2.2B) generated 1000 new values of transect-level biomass for each species, from which I derived mean \bar{B}_{jt} with standard deviation σ_{jt} . Ultimately, across cover type (c), I summed \bar{B}_{jt} and σ_{jt} across transects to yield B'_{jc} and σ'_{jc} . Drawing from these values, a final Monte Carlo sampling (MC4; Figure 2.2B) generated 1000 new values of cover type-level biomass for each species, from which I derived mean \bar{B}_{jc} with standard deviation σ_{jc} . These final biomass estimates were converted to kg/ha for inclusion in range capacity estimates.

Estimating Range Capacity and Limiting Factors

To quantify the range capacity of each forage type and cover type for moose, I used the Forage Resource Evaluation System for Habitat (FRESH) developed for deer Hanley et al. (2012) and later extended to moose. I specified the model based on the energy and nutrient requirements of a pregnant female moose in winter and lactating female moose in summer. To determine energetic requirements, I set the mean body weight (BW) for an adult female moose in this region to 350 kg based on harvest data from New Hampshire, Vermont and Maine (N=274, 2.5-14.5 years old, 1988-1996; K. Rines, New Hampshire Fish and Game Dept. unpub. data) and using Live Weight = Carcass Weight \times 1.46 (Crichton 1997). During winter, I assumed a daily weight loss of 0.4 kg/day (Renecker and Hudson 1989). I set daily dry matter intake in summer to 11,570 g/day and winter to 2,075 g/day following McArt et al. (2010) and Renecker and Hudson (1985; Table 2.2). I set metabolizable energy (ME) requirements as 55,400 and 27,827 kJ/day in summer and winter, respectively, following Dungan et al. (2010), Renecker and Hudson (1989) and Schwartz et al. (1988; Table 2.2). Crude protein (CP) requirements were considered to be 6.86% in winter (Schwartz et al. 1987) and 9.12% in summer (VanBallenberghe and Miquelle 1990, Dungan et al. 2010). The CP and digestible energy (DE) available in

principal forage species was available from a related study of moose diets in the Adirondack region (Table 2.3; Peterson 2018, Chapter One). The FRESH model uses an energy constraint based on ME requirements, but requires DE values for the input of different forage species. This discrepancy is addressed using $ME \approx DE \times 0.82$ (D. Spalinger, University of Alaska-Anchorage, pers. comm.). Foraging time and bite size values were drawn from the literature (Table 2.2).

The FRESH model also includes a model input called “MAX” that allows the user to define the maximum amount of biomass of a given forage that can be included in an individual’s diet. This allows for the consideration of species that may appear to be nutritionally valuable, but cannot be consumed in great quantities (due to toxins, for example). I decided to define this field using the observed utilization rate of each species during browse selection surveys (Peterson 2018 Ch. 1) Following Raffel et al. (2009), Harrison (2011), and Gallant et al. (2014), I calculated a relative utilization index for each species as

$U_i = \# \text{ browsed twigs} / \# \text{ available twigs}$ using data available from Peterson (2018, Chapter One). U_i was quantified at a transect level, then averaged for each species i within each cover type c (\bar{U}_{ic} , σ_{ic}) for use here. Moreover, I adjusted the available browse biomass value predicted for each cover type to account for changes in local moose browsing intensity due to interfering vegetation (i.e., beech and conifer cover; Peterson 2018, Chapter 1). To do so, I calculated a forage reduction coefficient (F_c) representing a ratio between the local browse intensity expected under competing vegetation and the intensity expected in the absence of competition. I calculated F_c at the cover type level by quantifying the average total biomass of principal browse species, percentage cover of beech, and percentage cover of conifer within each cover type and solving the Peterson (2018, CH 1) model with and without the effects of beech and conifer included. Ultimately, F_c was applied as a weight (summer = 0.81-0.99, winter = 0.94-0.98) to

the biomass value for each forage given cover type in the FRESH model. Across cover types, the estimated reduction in browse intensity ranged 2.3% (Open Wetland) to 18.5% (Upland and Lowland Deciduous/Mixed Forest) in summer and 1.1% (Conifer Forest) to 5.5% (Open Wetland) in winter. FRESH estimates of the Animal Use Days (AUD) supported by available browse were compared with and without including the F_c adjustment.

Applying point estimates for each component in the FRESH model, initial estimates of Animal Use Days (AUD) were achieved under 2 alternative constraints: 1) Metabolizable Energy (ME constraint = values in Table 2.2, CP constraint = 0.1), and 2) Crude Protein (CP constraint = values in Table 2.2, ME constraint = 0.1). Further runs of the model explored the magnitude of effect of diet choices (U_i) and interfering vegetation (F_c) by excluding each of these processes individually and collectively. To account for uncertainty associated with the predicted biomass of a given species within each cover type ($\bar{B}_{jc}, \sigma_{jc}$), plant nutrient values (Table 2.3), and the relative magnitude of use of each species by moose (U_{ic}, σ_{ic}), I applied Monte Carlo simulations in connection with the FRESH calculations (these runs each included a static adjustment by F_c). To calculate the potential bias and contributions to total variance of each component, I first ran simulations with all error included in the estimates (as explained above) and repeated the process allowing one source of error only to vary at a time (Yanai et al. 2010). Given the computation demands involved with FRESH calculations, I conducted 100 MC iterations for each scenario. To decompose total variance, I divided the estimated variance from each alternative model scenario (varying only a single source of error) by the estimate when all three sources of error were included simultaneously.

Total range capacity across the park was calculated by multiplying the AUD/ha of each cover type by the areal extent of each type, across the landscape. Comprehensive mapping of the

amount of Regenerating Forest is lacking for the Adirondack Park, so I estimated its coverage from my field samples of sites on private lands classified *a priori* as Conifer Forest, Upland Deciduous/Mixed Forest and Lowland Deciduous/Mixed Forest (based on The Nature Conservancy's Terrestrial Habitat Map) that proved to be regenerating forest (20, 21, and 4% of sampled plots, respectively). The final distribution of cover types across the park was thus 30.9% Upland Deciduous/Mixed Forest (685,396 ha), 33.3% Lowland Deciduous/Mixed Forest (737,710 ha), 10.4% Conifer Forest (230,043 ha), 4.4% Open Wetland (97,557 ha), 10.2% Forested Wetland (225,280 ha), and 4.6% Regenerating Forest (102,214 ha). For each scenario, I divided the mean AUD by 180 days (length of the summer or winter season), multiplied the resulting value by 0.2—a cropping rate ensuring sufficient regeneration without long-term damage to the range (Allen et al. 1987), and ultimately considered the season, constraint, and cover types producing the lowest mean AUD to be most limiting to moose in this system.

Model Validation

Whereas the estimates above focused on cover types at the level of the whole park, spatially-explicit estimates of AUD were also possible by multiplying the estimated AUD/ha of a given cover type by the local proportion of that cover type within a defined area. I expected spatially-explicit estimates of AUD to correlate positively with local moose density estimates. Spatially-explicit estimates of moose density were available within a sample of 3×10 km blocks surveyed across the park in winter 2016 (J. Frair, unpub. data). For this analysis, survey blocks were excluded from consideration where reliable information on regenerating timber cuts was not available, yielding 18 blocks for this comparison. Within these blocks I calculated AUD using the scenario indicated as most limiting for moose in each season, as well as total browse biomass

available in each season, and regressed predicted AUD or biomass against estimated moose density.

Sensitivity to Potential Landscape Changes

Following model validation, I applied the FRESH model under the most limiting conditions to predict potential changes in AUD for moose under 3 scenarios of plausible future landscape changes in the region: 1) warmer and drier conditions leading to 10% conversion of wetland areas (Open and Wooded Wetland types; 33,147 ha) to lowland mixed forest, 2) increased development leading to 10% conversion of conifer and deciduous forests (176,193 ha) to non-habitat on private lands, and 3) increased timber harvest on private lands leading to 2 and 1% conversion of deciduous/mixed (30,276 ha) and conifer forest (2,481 ha), respectively, to regenerating forest. I ran each of these scenarios using 1000 Monte Carlo simulations.

RESULTS

Allometric Models

Prior to model fitting, beech samples were divided into groups representing small (basal diameter <60 mm; N = 9) versus large (diameter \geq 60 mm; N = 2) individuals given gross differences in the pattern of biomass availability between them. Small beeches represented individual stems within stump sprouts and seedlings whereas large beeches represented intact, mature individuals. The small sample size (N=2) of the large beech group warranted an intercept only model in both seasons, whereas basal diameter and slope predicted available browse biomass on small beeches ($R^2 = 0.69$; Table 2.1, Appendix 2.2-2.3). Red and Sugar maple were combined into a single group, but divided between small (diameter <55 mm; N = 15) and large individuals (diameter \geq 55 mm; N = 17), given similar patterns of browse distribution and abundance. Similar to large beeches, a size-related covariate was not supported in models for the 'Large Maple' group (best

performing model with size covariate $\Delta AIC=2.26$ and 2.54 in summer and winter), although the availability of browseable biomass declined slightly with increasing elevation ($R^2 = 0.29-0.32$; Table 2.1). The best model for the ‘Small Maples’ group included a size covariate in both seasons, and, in winter browse availability further declined with increasing slope ($R^2 = 0.62-0.71$; Table 2.1). A separate model was fit for striped and mountain maple, which were grouped as ‘Maples 3’ ($N = 16$) prior to model fitting. The most parsimonious Maples 3 models included a nonlinear relationship between browse availability and size in summer (linear relationship in winter), and a decline in browse availability along SE-facing aspects modified to some degree by an interaction between aspect and size ($R^2 = 0.85-0.88$; Table 2.1). I assigned American hophornbeam and the three birches (Gray, Paper and Yellow) into a single ‘Birches’ growth-form group ($N = 27$). The best model for the Birches group included a nonlinear effect of size in both seasons, a negative effect of canopy cover in summer but a positive effect in winter, and a negative effect of slope in summer, with the effect of size mediated to some degree by an interaction with slope in summer and canopy cover in winter ($R^2 = 0.83-0.84$). The two aspen species (quaking and big-toothed) were assigned to a single ‘Poplars’ group ($N = 21$), with available browse biomass predicted best by a nonlinear relationship with size in both seasons without site covariates ($R^2 = 0.83-0.86$; Table 2.1). The two cherry species (pin and black) were assigned to a ‘Cherries’ group ($N = 24$), with their available browse biomass best predicted by a nonlinear effect of size and a negative effect of increasing slope, with a size \times slope interaction in summer ($R^2 = 0.79-0.87$; Table 2.1). The two species having shrub-like growth forms, hobblebush ($N=19$) and northern wild raisin ($N = 21$), were modeled individually. For hobblebush, available browse biomass varied nonlinearly with shrub volume in summer and linearly in winter ($R^2 = 0.94-0.97$). Available browse biomass on northern wild raisin increased

linearly with shrub volume and decreased with increasing elevation and slope in both seasons ($R^2 = 0.94-0.95$). Consistent across species, we did not detect a difference among sampling years (models including year effects $\Delta AIC > 2$), although sample sizes were limiting. Our selected models met the assumptions of normally-distributed (SW = 0.90 – 0.98), independent (DW = 1.40 – 3.87), and homoscedastic errors (BP = 0.15 – 10.60; all $P > 0.05$), with the exception of the wild raisin model in summer, which indicated dependent errors (DW = 1.40, $P = 0.04$). For wild raisin, all competing best models ($\Delta AIC < 2$) violated assumptions of either normally distributed errors, independent errors or homoscedastic errors. The first model that met all model assumptions included size (linear) and canopy cover covariates only, was less supported ($\Delta AIC = 2.20$), and predicted values that differed from the best-supported model by ~1% only. As a result, the best supported model for northern wild raisin was selected.

Modeling Available Browse Biomass

Within parkwide biomass sampling plots, the most commonly available browse species during summer were hobblebush (*Viburnum lantanoides*; 27.7% of predicted browse biomass) and striped maple (*Acer pensylvanicum*; 23.8%), followed by red maple (11.4%) and yellow birch (9.20%; Table 2.4)—with these 4 species being observed to some degree in every cover type. Although northern wild raisin (10.2% of predicted browse biomass) and sugar maple (9.7%) provided a similar amount of browse biomass as red maple and yellow birch, these species were more patchily distributed among cover types. In winter, balsam fir dominated browse availability (57.4% of predicted browse biomass; Table 2.5), and was so common that its inclusion increased apparent levels of browse availability by 28.6% over summer (moose did not consume balsam fir in summer; S. Peterson, 2018). Excluding balsam fir, there was a 45.2% decline in the browse available for moose in winter compared to summer. In winter, striped

maple (14.9% of available browse) and yellow birch (8.7%) provided the most deciduous browse for moose (Table 2.5).

Across cover types, estimates of available browse biomass ranged from 86.96 kg/ha in Lowland Deciduous/Mixed Forest to 556.51 kg/ha in Regenerating Forest during summer (Table 2.4), and from 146.74 kg/ha in Upland Deciduous/Mixed Forest to 375.99 kg/ha in Wooded Wetlands during winter (Table 2.5). In summer, the majority of principal browse species (N = 7) produced their highest browseable biomass within Regenerating Forest, followed by Upland Deciduous/Mixed Forest and Open Wetlands (N = 2 species each), and Lowland Deciduous/Mixed Forest (N = 1; Table 2.4). Regenerating Forest provided 2-6 times more available browse in summer than other cover types, and yielded 64% more browse than the dominant cover type (Upland and Lowland Deciduous/Mixed Forest covering 63% of the landscape). In contrast, during winter browse biomass was more evenly distributed across several cover types, with Wooded Wetland (23.1% of available browse) and Open Wetland (21.3%) providing the most browse for moose followed closely by Regenerating Forest (18.5%; Table 2.5). Whereas the available browse in wetland types was dominated by balsam fir (58.5-93.7% of available browse), browse within Regenerating Forest was dominated by a combination of yellow birch (38.4%) and several maple species (35.3% in combination). In both seasons, the amount of available browse biomass for moose was more homogeneous among patches regenerating follow timber harvest (CV = 13.0% summer, 8.9% winter) compared to other cover types (\bar{x} CV = 41.5% and 22.8% in summer and winter, respectively).

Predicted Range Capacity

Summer range in the Adirondack Park was estimated to support fewer adult female moose (0.00 – 5.97 AUD/ha across cover types) compared to winter (0.23 – 26.54 AUD/ha; Table 2.6).

During summer, protein proved more limiting than energy, while the opposite was observed for winter (Table 2.7). Only Upland Deciduous/Mixed Forest and Regenerating Forest provided browse sufficient to meet the protein needs of lactating moose in summer, with Regenerating Forest supporting 6× more AUD/ha than Upland Deciduous/Mixed Forest based on protein requirements (Table 2.6). Moreover, the browse within Regenerating Forest and Wooded Wetland provided the highest sources of available energy for moose in summer. In contrast, during winter every habitat type produced browse sufficient to meet the protein and energy requirements of pregnant moose (Table 2.6), due in large part to the lower energetic requirements by pregnant compared to lactating moose in combination with the inclusion of balsam fir in winter but not summer moose diets. In winter, the greatest amount of available browse was predicted within Wooded and Open Wetlands due largely to the predominance of balsam fir.

The total number of reproductive female moose predicted to be supported solely by available browse (under a protein constraint) were 873 (360 SD), which was of a similar order of magnitude as the total population estimate for moose within the Adirondack Park (394 moose, 13% CV, 95% CI = 298-522; J. Frair, unpub. data; Table 2.7). Spatially-explicit estimates of summer AUD under a crude protein constraint (the apparent most limiting nutritional factor), within individual aerial survey blocks, explained a moderate amount of variation in local moose density ($R^2 = 0.76$, $P < 0.01$, $N = 18$), with $\text{total moose}/30 \text{ km}^2 = 0.61 + 8.71 * \text{AUD}_{\text{summer}}$ (Figure 2.3). In contrast, block-level density estimates for moose were poorly explained by AUD estimates given a summer energy constraint ($R^2 = 0.45$, $p < 0.01$), winter energy constraint ($R^2 = 0.36$, $p < 0.01$), or winter protein constraint ($R^2 = 0.12$, $p = 0.15$). Summer biomass availability within each sampling block showed a fairly strong relationship with estimated moose density (R^2

=0.64, $p < 0.01$), while winter biomass was a poor predictor of estimated density ($R^2 = -0.06$, $p = 0.90$).

Due to high computational demands, additional runs of the FRESH model to evaluate the effects of moose diet selection and interfering vegetation, and to partition variance among key model components, were limited to summer under a protein constraint. Ignoring uncertainty, moose diet selection, and the potential reductions in browse intensity due to interfering vegetation yielded a point estimate for summer range capacity of 587 reproductive female moose. Accounting for moose diet selection alone reduced estimates of AUD by 82.2% whereas accounting for interfering vegetation alone reduced AUD estimates by 11.4% (Table 2.8). In combination, these factors contributed to a 84.3% reduction in the estimated AUD, indicating a large potential bias in estimates of range capacity that ignore diet selectivity. Failing to properly account for uncertainty in key model components (i.e., estimates of biomass availability, nutritional quality of species, and diet selection) likewise contributed to substantial potential bias in final estimates of range capacity given an estimate of 92 reproductive females (Table 2.8) without accounting for uncertainty and 873 after accounting for uncertainty (Table 2.7). Uncertainty in diet selectivity by moose explained the greatest proportion of total variance in final estimates (mean CV = 22% across types and scenarios). In contrast, uncertainty in the estimated crude protein content of species and in predicted biomass availability by cover type contributed a minor component of total variance in final estimates (<1% each).

Model Application

Removal of mature forest yielded the largest changes in potential range capacity for moose within the Adirondack Park in summer be that a reduction in range capacity under forest conversion to non-habitat (continued development scenario) or an increase in range capacity

following mature forest conversion to regenerating forest (increased timber harvest scenario; Figure 2.4). In contrast, loss of wetlands (drier conditions scenario), or more specifically conversion of wetlands to lowland deciduous/mixed forest (the only scenario we considered that would add additional forest over current conditions), yielded a relatively minor impact on range capacity for moose compared to the other scenarios. In contrast, my models predicted that timber harvest to convert 30,000 ha of mixed forest and 2,400 ha of conifer forest to regenerating forest might increase moose range capacity by 30% in summer. In winter, all tested landscape change scenarios resulted in a decrease in predicted range capacity, although these decreases were relatively minor (< ~5% change).

DISCUSSION

This study provides compelling evidence that the persistently small moose population within the vast Adirondack Park may be limited fundamentally by the rarity of early successional forest in the region. Available protein on summer range proved most limiting to moose in this study, with the amount and quality of browse within regenerating forest stands supporting 150% more moose/ha than the mature deciduous/mixed forest stands that dominate the park. Although the leaves and stems of woody species dominate moose diets (Belovsky 1978, Rodgers 2001), aquatic vegetation also provides important nutrients for moose during summer (Crête and Jordan 1981, MacCracken et al. 1993). Aquatic vegetation is not likely limiting to moose in the Adirondacks given that wetlands are widespread and common (14.6% of the landscape classified as Open or Forested Wetland), maintained in part by a saturated population of beaver (*Castor canadensis*; Saunders 1988). As a result, my estimate of summer range capacity, while of a similar order of magnitude as the total population estimate from aerial surveys, is likely biased low. In contrast, my estimate for winter range capacity is likely biased high because I did not

take into account potential reduction in availability of browse due to snow during winter (e.g., Visscher et al. 2006). However, a 99% reduction in winter browse would be needed to match the apparent limitations of summer range for moose in the Adirondacks. Moreover, in contrast to estimates of winter range capacity, the estimates of summer range capacity in the Adirondacks explained a significant and substantial amount of variation in local moose density, indicating that the availability of deciduous browse is likely the key determinant of moose distribution and relative abundance in the region. Even so, where the current population level stands with respect to range capacity, and the effects of other potentially limiting factors, is less certain.

Imbalances in energy and protein intake in the winter are normal for many cervids as the nutritional quality of browse typically declines as the winter season progresses (Parker et al. 2005, Peterson et al. CH 1). The physiological processes associated with this imbalance have been summarized into three different phases (Torbit et al. 1985): 1) catabolism of fat and protein reserves, 2) increased mobilization of fat reserves, and 3) major protein catabolism. As nutrient imbalances continue into the late winter, females are forced to re-allocate fat and protein reserves from fetal growth to maintain a body condition sufficient for survival. When stage 3 of fat and protein catabolism is reached and adipose tissues are depleted, starvation is possible. Some ungulates have been shown to delay this process through urea nitrogen recycling (Parker et al. 2005), however body condition leading into winter also impacts the amount and severity of protein catabolism necessary in the winter. As a result, summer protein availability can be an important limiting factor for northern ungulates, as observed here and for other moose populations (McArt et al. 2009). That said, food limitation per se does not seem to explain the persistently low moose numbers observed within the park.

Low productivity is expected in ungulate populations near carrying capacity (Couturier et al. 2009, Ytrehus et al. 1999). Yet, calf:cow ratios observed during recent winter surveys of the Adirondack moose population have been indicative of moderate-high productivity. This particularly contradicts my findings of a protein limitation, as the link between maternal nutritional condition and birth mass of young is well documented for ungulates (Robinette et al. 1973, Cook et al. 2004, Adams 2005, Bender et al. 2007). However, Sams et al. (1995) found that short term (2 year) protein deficiency in white tailed deer has little impact on the immunocompetence of their fawns, and that a chronic deficiency is likely more important. Given that the Adirondack moose population established ~40 years ago, it is possible that the negative impacts of protein deficiency have not yet been observed in calf productivity. An alternative explanation for consistently low moose numbers in the Adirondack region may be a high prevalence (12% of incidental mortalities) of parasitic infections, such as brainworm and liver fluke (K. Schuler, unpub. data), which may interact with animal nutritional status. The spatial availability of nutrients, specifically protein, is likely important in order for an animal's nutritional plane to remain above potential thresholds below which they may be more susceptible to parasitism.

Positively increasing range capacity for moose within the Adirondack region, should that be a management goal, seems to depend critically upon increasing the amount of regenerating forest in the landscape. Timber harvesting and forest disturbance have long been associated with the creation of moose browsing habitat (Koitzsch 2002, Rempel et al. 1997). Renecker and Schwartz (1997) demonstrated that production of willow (*Salix spp.*), an important component of moose diets in the western U.S., peaked 15 years post-fire (Spencer and Hakala 1964), balsam fir peaked ~8 years post-cutting (Parker and Morton 1978), and the general availability of browse

biomass peaked ~10 years post-burn (Oldemeyer and Regelin 1987). Likewise, Westworth et al. (1989) showed 10-year old clear cuts to produce the highest densities of preferred moose browse. Similarly, Visscher and Merrill (2008) identified the highest woody browse biomass for elk in Alberta approximately a decade after harvest operations. Not surprisingly, my estimates of range capacity for moose within the Adirondacks were most sensitive to the availability of regenerating forest. Increasing the amount of mature forest available, which corresponded to a scenario of wetlands drying under warmer climate conditions, actually reduced range capacity for moose in the region. In contrast, conversion of the dominant deciduous/mixed forest within the Adirondack Park to non-habitat, e.g., urbanization, was predicted to substantively reduce moose carrying capacity. But, importantly, a relatively minor increase in the amount of mature forest converted to regenerating forest had an inordinately large and positive effect on the number of moose potentially supported within the park.

MANAGEMENT IMPLICATIONS

Management goals for Adirondack moose, an iconic wilderness species, are likely to include maintaining or increasing their distribution or abundance to help ensure their persistence under future landscape and climatic changes. Whereas winter tick have been observed on moose in the Adirondack Park (J. Frair, unpub. capture data), the levels of hair loss associated with severe tick infestations have not yet been reported. Maintaining moose at the current low density of moose may be important given that the higher moose densities observed elsewhere in the northeastern U.S. have coincided with high burdens of winter tick, correspondingly high levels of calf mortality, and related population declines (Musante et al. 2007, Ellingwood and Pekins unpub. data). Yet, given a current population estimate less than 500 animals, the Adirondack moose population is small and thus at risk of local extinction due to stochastic forces. Whereas moose

occur at very low density across much of the forest preserve (0.01 moose/ha), areas regenerating from timber harvest support relatively high moose densities (0.13-0.25 moose/ha) and concentrated in three geographic “hotspots” where regeneration conditions are prime. As such, a second reasonable management goal might be to expand the number of these hotspots or subpopulations help buffer the Adirondack moose population against stochastic forces that might decimate one or more of these areas.

The FRESH model appears to be a useful tool for managers in creating management plans or comparing alternatives. Model inputs could be easily modified to reflect a change in nutritional quality, diet shifts or biomass availability as landscape, climactic and moose behavioral changes occur in the future. Additionally, this model could be used to outline specific guidelines that should be used in expanding or contracting moose habitat in specific areas given local management goals. For example, if managers and land owners had the goal of establishing an area of quality moose habitat, biomass surveys of the local area could be conducted and compared to ideal foraging conditions for moose according to this model. Actions could then be taken to improve the foraging habitat, namely by increasing availability of critical browse species such as red maple and pin cherry. Additionally, spatially-explicit estimates of AUD (in this case, using a summer crude protein constraint), can effectively predict winter moose densities depending on the level of precision desired. This may be a useful as a cheap alternative to expensive and time consuming aerial surveys. Simply estimating biomass is also somewhat effective at achieving these predictions, however the additional effort of running the FRESH model to retrieve AUD estimates is likely worth the increase in predictive ability (Biomass: $R^2=0.64$ vs. AUD: $R^2=0.74$)

This study indicates that manipulation of habitat, via creation of early seral stage forest regeneration, will be crucial to meeting goals for increasing either local moose numbers or the number of effective moose subpopulations. Yet, forest management within the Adirondack Park is tightly restricted, and the ‘Forever Wild’ forest preserve (state lands) is not expected to undergo significant changes in its mature forest condition except from insect or pathogen outbreaks or other forms of natural disturbance (e.g., storm damage). Although pathogen outbreaks might have large-scale effects, locally they are unlikely to create the large stand removals that provide abundant moose browse, so will be unlikely to influence large changes in the overall distribution or abundance of moose within the Park. While local storm damage may create large patches of early seral forest that moose respond positively to, storm effects are likely to be relatively small-scale with long and unpredictable return intervals, compared to timber management operations. As a result, timber harvest on private lands will likely remain the primary driver of changes in the Adirondack moose population in the near term.

Importantly, even at the currently low moose population level, damage from moose browsing poses conflict with private timber land managers (E. Reed, NYS DEC, pers. comm.). On timber lands in Maine, a primary means of mitigating damage from moose browsing has been to cut more and larger patches – an option that is not available to New York forest managers. As a result, wildlife managers and private timberland managers need to collaboratively identify moose population goals and options that ensure both robust moose populations and robust timber operations.

TABLES: CHAPTER 2

Table 2.1

Allometric models predicting the browseable biomass available to moose in winter and summer, 2016-17 as a function of \ln basal diameter (BD), volume (V), percent canopy cover (C), elevation in m (E), percent slope (S), and aspect (A). Models were fit to groups of similarly growing species as indicated below. N indicates the number of samples within each group. Interactions among covariates are indicated by “:”.

Group	Species included	N	Season	Model	Adj. R ²
Balsam fir	<i>Abies balsamea</i>	17	Winter	$+8.39 + 0.88BD - 0.01E + 1.04A$	0.88
Maples Sm ^a	<i>Acer rubrum</i> , <i>A. saccharum</i>	15	Summer	$-2.09 + 2.05BD$	0.62
			Winter	$-1.43 + 1.89BD - 0.13S$	0.71
Maples Lg ^b	<i>A. rubrum</i> , <i>A. saccharum</i>	17	Summer	$+14.53 - 0.02E$	0.29
			Winter	$+14.92 - 0.02E$	0.32
Maples 3	<i>A. pennsylvanicum</i> , <i>A. spicatum</i>	16	Summer	$-8.25 + 6.75BD - 0.85BD^2 - 3.51A + 0.31(BD^2:A)$	0.88
			Winter	$-0.01 + 1.17BD - 13.79A + 4.12(BD:A)$	0.85
Birches	<i>Betula populifolia</i> , <i>B. papyrifera</i> , <i>B. alleghaniensis</i> , <i>Ostrya virginiana</i>	27	Summer	$+0.7 + 3.66BD - 0.52BD^2 - 0.02C - 0.79S + 0.17(BD:S)$	0.84
			Winter	$-26.44 + 15.49BD - 1.85 BD^2 + 0.2C - 0.11(BD:C)$ $+ 0.01(BD^2:C)$	0.83

Beech Sm ^c	<i>Fagus grandifolia</i>	9	Summer	$+0.84 + 1.53BD - 0.36S$	0.69
			Winter	$+0.46 + 1.57BD - 0.40S$	0.69
Beech Lg ^d	<i>Fagus grandifolia</i>	2	Summer	+5.04	NA
			Winter	+4.57	NA
Hobblebush	<i>Viburnum lantanoides</i>	19	Summer	$+4.44 + 0.89V + 0.05V^2$	0.97
			Winter	$+2.96 + 0.96V$	0.94
Poplars	<i>Populus grandidentata</i> , <i>P. tremuloides</i>	21	Summer	$-8.07 + 6.22BD - 0.71BD^2$	0.83
			Winter	$-8.98 + 6.26BD - 0.71BD^2$	0.86
Cherries	<i>Prunus serotina</i> , <i>P. pensylvanica</i>	24	Summer	$+11.49 + 2.19BD - 0.04BD^2 - 2.02S + 1.36(BD:S) - 0.23(BD^2:S)$	0.87
			Winter	$-16.07 + 11.42BD - 1.47BD^2 - 0.13S$	0.79
Wild raisin	<i>Viburnum nudum cassinoides</i>	21	Summer	$+9.11 + 0.99V - 0.01E - 0.02S$	0.95
			Winter	$+8.97 + 1.00V - 0.01E - 0.03S$	0.94

^a Basal diameter < 55 mm; ^b Basal diameter ≥55 mm; ^c Basal diameter < 60 mm; ^d Basal diameter ≥60 mm

Table 2.2

Nutritional requirements and foraging constraints set for a 350 kg, pregnant or nursing, female moose in the FRESH Cervid model used to estimate Animal Use Days per hectare (AUD/ha) by cover type in the Adirondack Park, NY.

Constraint	Season	Value	Formula	Sources
Dry matter intake	Summer	11,570 g/day	$143 \times BW^{0.75}$	McArt et al. (2010),
	Winter	3,075 g/day	$38 \times BW^{0.75}$	Renecker and Hudson (1985)
Metabolizable energy	Summer	55,400 kJ/day	$0.82 \times (835\text{kJ} \times BW^{0.75})$	Dungan et al. (2010),
	Winter	27,827 kJ/day	$0.82 \times (124\text{kcal} \times BW^{0.75}) \times 0.29\text{kcal/kJ}$	Renecker and Hudson (1989), Schwartz et al. (1988)
Crude protein	Summer	9.12%		Dungan et al. (2010), VanBallenberghe and Miquelle (1990)
	Winter	6.86%		Schwartz et al. (1987)
Foraging time	Summer	534 min/day		Dungan et al. (2010),
	Winter	347 min/day		Risenhoover (1986)
Bite size	Summer	1.5 g dry mass		Moen (1995),
	Winter	1.0 g dry mass		Moen et al. (1997)

Table 2.3

Digestible energy (DE; kcal/g) and crude protein (CP; %) of principal browse species for moose in the Adirondack Park, NY. N indicates the number of field samples used to quantify browse quality in summer (Jul-Aug 2016) and winter (Jan-Feb 2017). Two species of *Viburnum*, *V. nudum cassinoides* and *V. lentago* were indistinguishable in the winter, so nutritional samples of each species may have been included in the group *V. spp.* for this season.

Species	Summer			Winter		
	N	DE	CP	N	DE	CP
<i>Abies balsamea</i>	----	NA----	---- NA ----	18	2.68 (0.2)	7.89 (0.98)
<i>Acer pensylvanicum</i>	8	2.62 (0.05)	8.0 (1.16)	5	2.18 (0.09)	4.46 (0.25)
<i>A. rubrum</i>	6	2.36 (0.16)	7.43 (0.84)	3	2.02 (0.08)	5.12 (0.48)
<i>A. saccharum</i>	2	2.47 (0.01)	7.99 (0.10)	3	1.66 (0.04)	4.88 (0.45)
<i>Betula alleghaniensis</i>	4	2.00 (0.14)	7.93 (1.15)	3	1.67 (0.19)	7.62 (2.03)
<i>B. papyrifera</i>	7	2.23 (0.21)	8.75 (1.12)	----	NA ----	---- NA ----
<i>B. populifolia</i>	7	2.23 (0.21)	7.74 (1.13)	----	NA ----	---- NA ----
<i>Fagus grandifolia</i>	3	1.77 (0.02)	7.40 (0.81)	2	1.66 (0.01)	6.63 (0.74)
<i>Populus grandidentata</i>	1	2.76	5.98	3	2.22 (0.02)	6.98 (0.56)
<i>P. tremuloides</i>	----	NA ----	---- NA ----	4	2.63 (0.15)	8.24 (1.62)
<i>Prunus pensylvanica</i>	3	2.76 (0.12)	0.04 (0.01)	2	1.69 (0.00)	5.78 (0.91)
<i>P. serotina</i>	----	NA ----	---- NA ----	1	1.85	0.29
<i>Viburnum lantanoides</i>	2	2.31 (0.13)	7.72 (0.58)	3	2.17 (0.09)	6.27 (0.6)
<i>V. nudum cassinoides</i>	5	2.85 (0.21)	6.23 (0.21)	----	NA ----	---- NA ----
<i>V. spp.</i>	----	NA ----	---- NA ----	2	2.43 (0.07)	4.72 (0.11)

Table 2.4

Estimated density of browseable biomass (kg/ha) for moose during summer in the Adirondack Park, 2016-17. Estimates correspond to principal browse species only, those making up 95% of moose seasonal diets, with mean values (with standard deviation) reported by primary cover type (see text for definition).

Species	Conifer forest	Upland decid/ mixed forest	Lowland decid/ mixed forest	Wooded wetland	Open wetland	Regenerating forest	Species total
<i>Acer pensylvanicum</i>	73.25 (21.04)	40.18 (12.25)	23.17 (8.72)	54.52 (26.70)	1.35 (0.89)	107.57 (19.90)	300.04 (89.50)
<i>A. rubrum</i>	1.02 (1.50)	7.18 (1.69)	13.70 (2.65)	51.87 (7.02)	6.02 (0.01)	64.34 (7.48)	144.13 (20.35)
<i>A. saccharum</i>	1.12 (0.75)	3.80 (1.28)	12.85 (1.89)	0.00 (0.00)	0.00 (0.00)	105.10 (14.66)	122.87 (18.58)
<i>Betula alleghaniensis</i>	3.65 (0.84)	20.29 (2.11)	9.35 (0.84)	22.29 (3.77)	9.26 (1.67)	51.37 (3.18)	116.21 (12.41)
<i>B. papyrifera</i>	2.83 (0.05)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	15.56 (4.13)	0.78 (0.61)	19.19 (4.80)
<i>B. populifolia</i>	0.09 (0.00)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	0.08 (0.02)	0.26 (0.08)	0.45 (0.11)
<i>Ostrya virginiana</i>	0.00 (0.00)	1.05 (0.17)	14.04 (1.44)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	15.09 (1.61)
<i>Populus grandidentata</i>	0.00 (0.00)	3.03 (1.27)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	3.03 (1.27)
<i>P. tremuloides</i>	0.00 (0.00)	0.00 (0.00)	2.25 (1.26)	0.00 (0.00)	9.50 (4.57)	0.53 (0.35)	12.28 (6.18)
<i>Prunus pensylvanica</i>	0.00 (0.00)	6.45 (1.55)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	44.25 (4.60)	50.70 (6.15)
<i>Viburnum lantanoides</i>	44.23 (28.80)	29.58 (8.13)	11.60 (4.97)	17.46 (14.71)	64.69 (56.88)	182.31 (21.45)	349.87 (134.94)
<i>V. nudum cassinoides</i>	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	129.29 (88.03)	0.07 (0.05)	0.00 (0.00)	129.36 (88.08)
Cover type total	126.19 (52.99)	111.60 (28.46)	86.96 (21.77)	275.43 (140.23)	106.53 (68.22)	556.51 (72.31)	1263.22 (365.40)

Table 2.5

Estimated density of browseable biomass (kg/ha) for moose during winter in the Adirondack Park, 2016-17. Estimates correspond to principal browse species only, those making up 95% of moose seasonal diets, with mean values (with standard deviation) reported by primary cover type (see text for definition).

Species	Conifer forest	Upland decid/mixed forest	Lowland decid/mixed forest	Wooded wetland	Open wetland	Regenerating forest	Species total
<i>Abies balsamea</i>	172.94 (29.68)	41.06 (8.29)	172.53 (47.81)	220.01 (50.52)	323.77 (82.46)	2.53 (1.29)	932.84 (220.05)
<i>Acer pensylvanicum</i>	40.37 (5.17)	76.43 (12.28)	29.48 (4.47)	28.45 (4.51)	0.41 (0.09)	66.82 (4.26)	241.96 (30.78)
<i>A. rubrum</i>	0.00 (0.00)	4.94 (0.95)	11.89 (2.17)	52.56 (7.70)	4.06 (0.86)	18.06 (1.92)	91.51 (13.60)
<i>A. saccharum</i>	1.05 (0.39)	0.65 (0.10)	9.68 (1.44)	0.00 (0.00)	0.00 (0.00)	21.29 (2.29)	32.67 (13.22)
<i>Betula alleghaniensis</i>	2.03 (0.28)	5.87 (0.28)	5.64 (0.26)	10.05 (0.83)	2.47 (0.17)	115.52 (2.25)	141.58 (17.07)
<i>Ostrya virginiana</i>	0.00 (0.00)	1.56 (0.69)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.56 (0.69)
<i>P. tremuloides</i>	0.00 (0.00)	0.00 (0.00)	1.11 (0.67)	0.00 (0.00)	4.64 (2.36)	0.25 (0.16)	6.00 (3.19)
<i>Prunus pensylvanica</i>	0.00 (0.00)	4.31 (0.05)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	18.99 (0.10)	23.30 (0.15)
<i>P. serotina</i>	0.00 (0.00)	4.21 (0.05)	0.00 (0.00)	0.00 (0.00)	0.84 (0.02)	1.27 (0.02)	6.32 (0.09)
<i>Viburnum lantanoides</i>	6.73 (1.71)	7.71 (2.31)	2.52 (0.87)	3.84 (2.74)	9.48 (6.81)	55.84 (14.42)	86.12 (28.86)
<i>V. nudum cassinoides</i>	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	61.08 (41.62)	0.03 (0.02)	0.00 (0.00)	61.11 (41.64)
Total	223.12 (37.23)	146.74 (25.00)	232.85 (57.70)	375.99 (107.92)	345.70 (92.80)	300.53 (26.71)	1624.97 (369.34)

Table 2.6

The estimated number of Animal Use Days (AUD) per hectare (with standard deviation) for moose in 6 different cover types within the Adirondack Park, NY. Error from biomass availability, nutritional content of browse and diet selection habits of moose (Peterson Ch. 1) were incorporated through a series of Monte Carlo simulations.

Cover Type	Summer limitation		Winter limitation	
	Protein	Energy	Protein	Energy
Conifer forest	--	0.48 (0.52)	13.81 (11.14)	13.51 (11.17)
Upland decid/mixed forest	0.28 (0.23)	0.70 (0.34)	5.74 (3.30)	3.16 (2.69)
Lowland decid/mixed forest	--	0.71 (0.34)	16.18 (14.47)	15.84 (14.03)
Wooded wetland	--	5.97 (5.05)	26.02 (21.43)	15.93 (15.10)
Open wetland	--	0.57 (0.46)	23.74 (21.04)	26.54 (22.90)
Regenerating forest	1.95 (1.69)	5.61 (2.87)	11.28 (9.23)	0.23 (0.22)

Table 2.7

Estimates of park-wide nutritional carrying capacity of reproductive female moose in Adirondack Park, NY. Values shown incorporate error from biomass availability, nutritional quality of forage and diet selection habits (U_i) of moose. Browse intensity values (F_c) are also included in these estimates.

	Summer		Winter	
	Crude Protein	Energy	Crude Protein	Energy
Mean	873.12	3,453.21	32,897.65	26,998.71
SD	360.66	1,267.06	12,341.75	11,612.14

Table 2.8

Effects of diet selection and interfering vegetation (which reduces local browsing intensity) on estimates of the range capacity (K) for adult female moose during summer under a protein constraint within the Adirondack Park, NY. Estimates displayed do not account for error in FRESH model inputs

Diet selection	Interfering vegetation	K	Percent change
--	--	587.0	
--	Included	520.1	-11.4%
Included	--	104.3	-82.2%
Included	Included	92.2	-84.3%

FIGURES: CHAPTER 2

Figure 2.1

Study area in northeastern New York state. Public lands (light gray; Wild Forest, Wilderness, Primitive Use and Canoe Areas), private lands (white; Rural, Low, Moderate, Industrial and Intensive Use, Hamlets and Resource Management Areas), and water bodies (dark gray) are indicated. Also indicated are locations where browse biomass was sampled to build allometric equations (stars), transects where browse components were measured in the field and biomass – predicted using allometric equations (black circles), and locations where browse nutritional samples were collected (white circles).

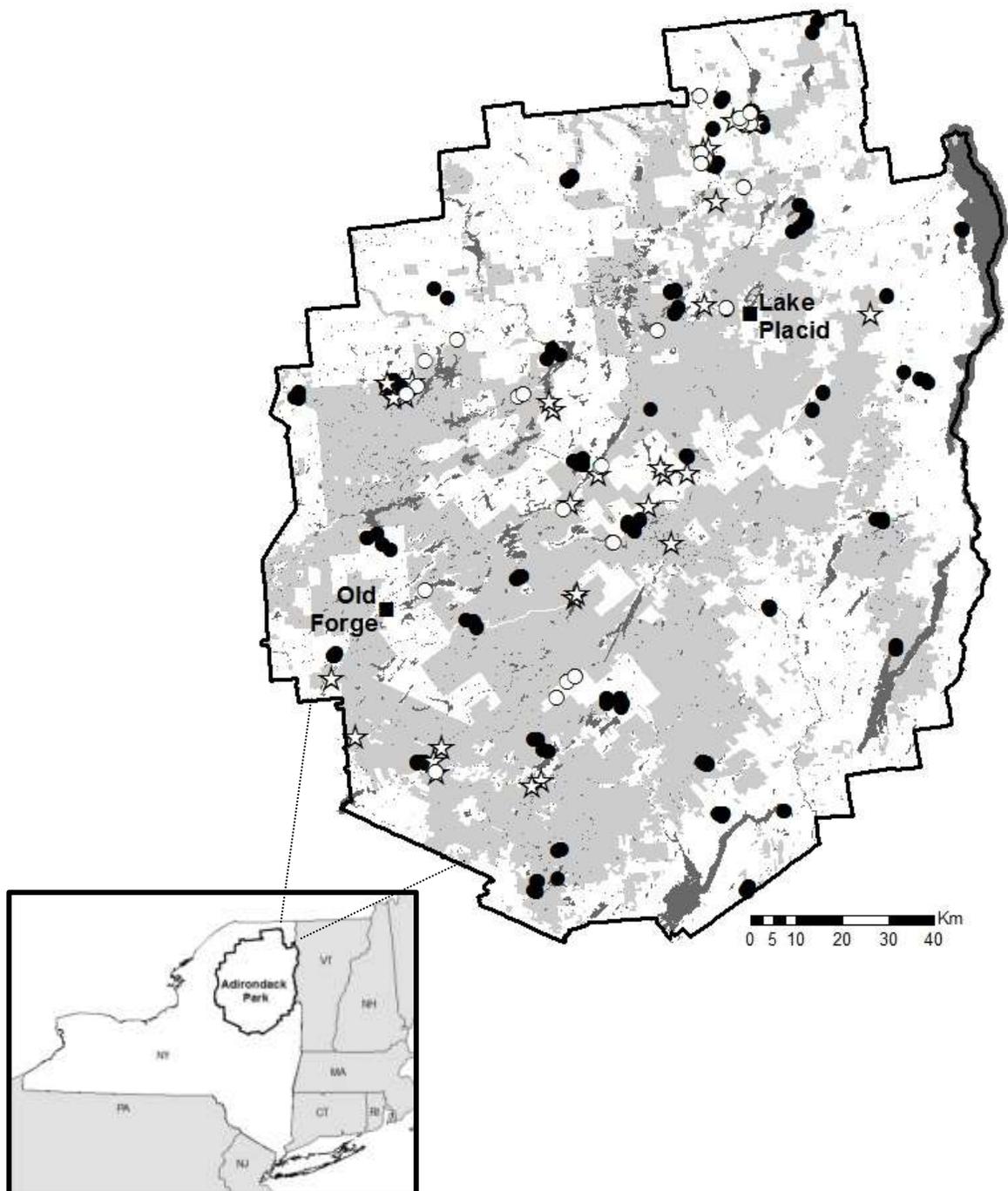


Figure 2.2

Sampling design for building allometric models (A) and scaling up predictions of the browseable biomass from individual plant to cover type (B).

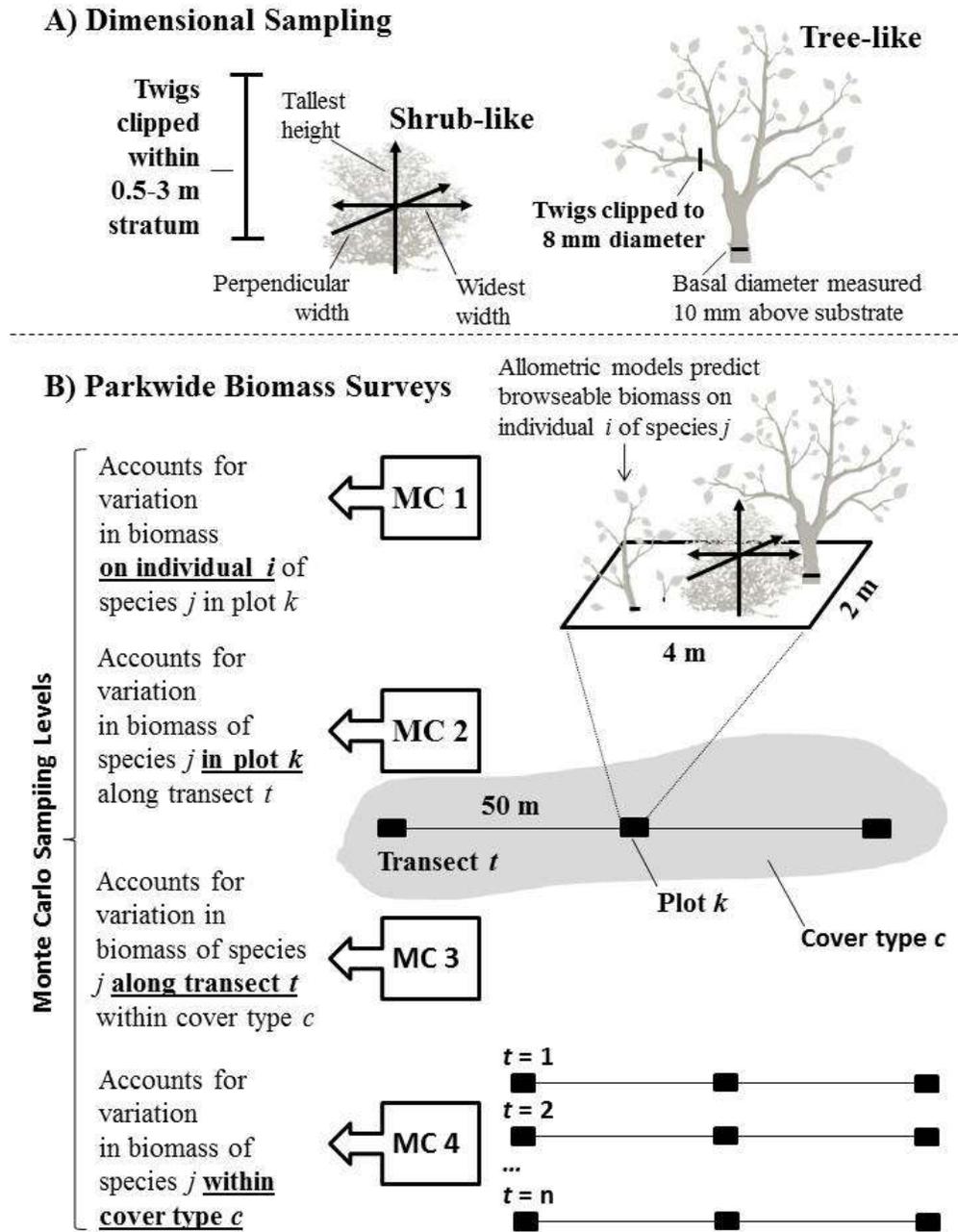


Figure 2.3

Predicted number of reproductive female moose supported by available summer browse within 18, 3 x 10 km² survey blocks (based on protein requirement) compared to the empirically-estimated density of moose in those blocks during winter 2016.

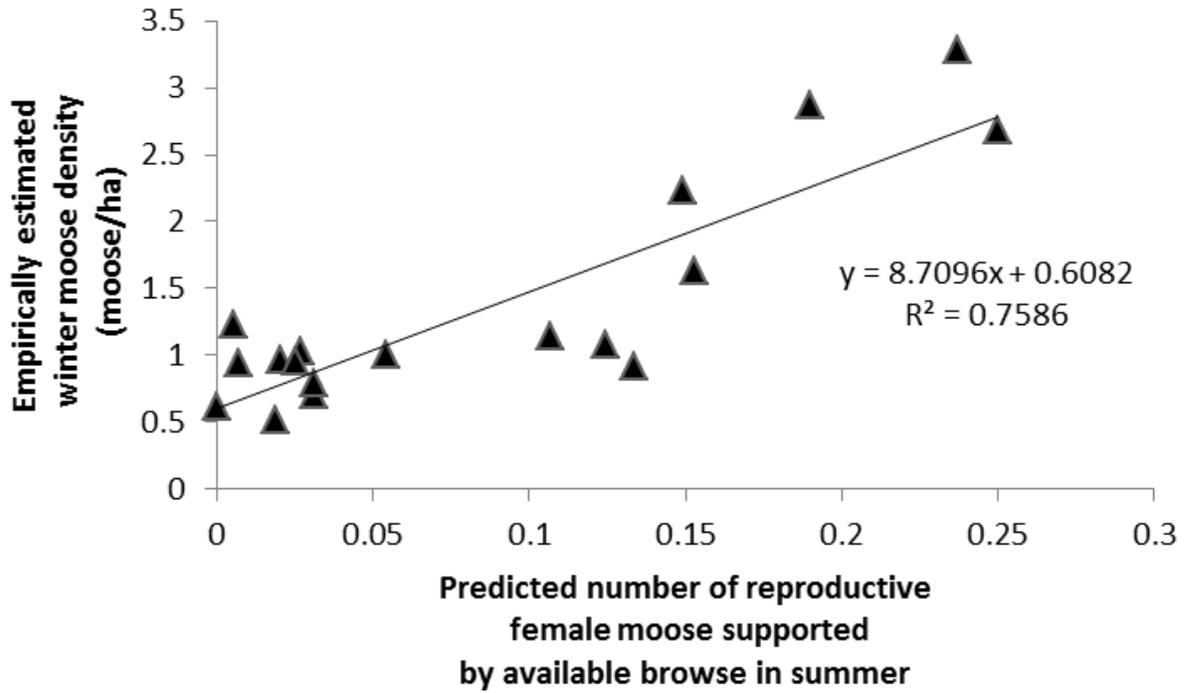
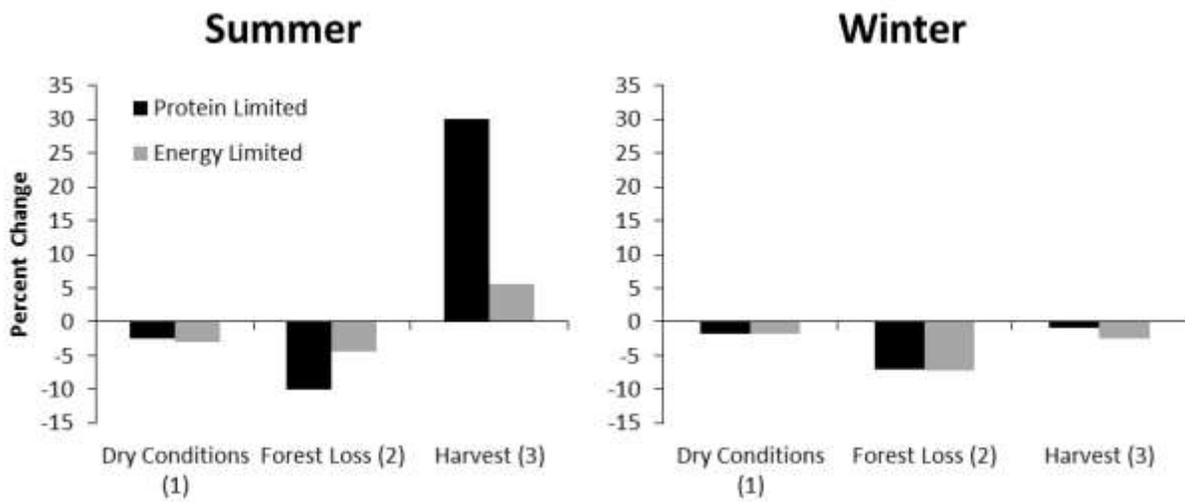


Figure 2.4

Predicted changes in the total number of reproductive female moose supported by available browse in the Adirondack Park under 3 landscape change scenarios. Scenarios represent drying conditions leading to a 10% conversion of wooded and open wetland habitat to lowland deciduous/mixed forest, increased development leading to 10% conversion of conifer and deciduous/mixed forest to non-habitat, and increased timber harvest leading to 1% conversion of conifer forest and 2% conversion of deciduous/mixed forest to regenerating forest. Values indicate the percent change in the number of female moose relative to contemporary range conditions.



CONCLUSION

Ultimately, it is likely that there is no “silver bullet” explanation for the limited moose population within Adirondack Park, especially at a local level. However, this research does indicate that forage availability, specifically pertaining to regenerating forests, influences the range and density of moose on a broad spatial scale. More locally, other issues such as disease may interact with forage availability in limiting this population. Continued surveillance of disease prevalence and population demographics and vital rates will aid in maintaining this population into the future. Additionally, establishing a larger network of metapopulations to encourage proper gene flow and guard against population decreases caused by environmental and demographic stochasticity could prove to be an effective management approach. The information summarized by this research, specifically regarding diet composition and selection, can aid in mitigating conflicts with forest managers. Incorporating this information and the values of stakeholders from a wide spectrum will ensure the continued persistence of this iconic wilderness species in one of the largest protected areas in the United States.

LITERATURE CITED

- Aagaard, P. 2008. The rewilding of New York's north country: beavers, moose, canines and the Adirondacks. Thesis. University of Montana, USA.
- Adams, L. G. 2005. Effects of maternal characteristics and climatic variation on birth masses of Alaskan caribou. *Journal of Mammalogy* 86(3):506-513.
- Adirondack Park Agency [APA]. 2018. Adirondack Park land use and development plan and state land map database. <<https://apa.ny.gov/gis/stats/colc201803>> Accessed 20 March 2018.
- Alexander, C E. 1993. The status and management of moose in Vermont. *Alces* 29:187-195.
- Allen, C. D., and D. D. Breshears. 1998. Drought-induced shift of a forest-wetland ecotone: rapid landscape response to climate variation. *Proceedings of the National Academy of Science of the United States of America* 95:14839-14842.
- Bailey, D. W., J. E. Gross, E. A. Laca, L. R. Rittenhouse, M. B. Coughenout, D. M. Swift and P. L. Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. *Journal of Range Management* 49(5):386-400.
- Ball, K. R. D. 2009. Moose density, habitat and winter tick epizootics in a changing climate. Thesis: University of New Hampshire.
- Belovsky, G. E. 1981. Optimal activity times and habitat choice of moose. *Oecologia* 48:22-30.
- Bender, L. C., Lomas, L. A., and J. Browning. 2007. Condition, survival, and cause-specific mortality of adult female mule deer in north-central New Mexico. *Journal of Wildlife Management* 71(4):1118-1124.
- Bergeron, D. H., Pekins, P. J., Jones, H. F. and W. B. Leak. 2011. Moose browsing and forest regeneration: a case study in northern New Hampshire. *Alces* 47: 39-51.

- Bliss, C. I. and R. A. Fisher. 1953. Fitting the negative binomial distribution to biological data. *Biometrics* 9(2):176-200.
- Bolker, B., H. Skaug, A. Magnusson and A. Nielsen. 2012. Getting started with the glmmADMB package.
- Bowler, R. A. L. Fredeen, M. Brown, T.A. Black. 2012. Residual vegetation importance to net CO₂ uptake in pine-dominated stands following mountain pine beetle attack in British Columbia, Canada. *Forest Ecology and Management* 269:82-91.
- Bose, A. K., A. Weiskittel and R. G. Wagner. 2017. A three decade assessment of climate associated changes in forest composition across the northeastern USA. *Journal of Applied Ecology* 54:1592-1604.
- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.
- Caputo, J., C. M. Beier, T. J. Sullivan, G. B. Lawrence. 2016. Modeled effects of soil acidification on long-term ecological and economic outcomes for managed forests in the Adirondack region (USA). *Science of the Total Environment* 565:401-411.
- Conti, G., N., L. Enrico, F. Casanoves and S. Díaz. 2013. Shrub biomass estimation in the semiarid Chaco forest: a contribution to the quantification of an underrated carbon stock. *Annals of Forest Science* 70:515-524.
- Conti, G., N. Pérez-Harguindeguy, F. Quétier, L. D. Gorné, P. Jaureguiberry, G. A. Bertone, L. Enrico, A. Cuchietti and S. Díaz. 2014. Large changes in carbon storage under different land-use regimes in subtropical seasonally dry forests of southern South America. *Agriculture, Ecosystems and Environment* 197:68-76.

- Cook, J. G., Johnson, B. K., Cook, R. C., Riggs, R. A., Delcurto, T., Bryant, L. D., and L. L. Irwin. 2004. Effects of summer-autumn nutrition and parturition date on reproduction and survival of elk. *Wildlife Monographs* 155:1-61.
- Cook, J. G., R. C. Cook, R. W. Davis, L. L. Irwin. 2016. Nutritional ecology of elk during summer and autumn in the Pacific Northwest. *Wildlife Monographs*, 195:1-81.
- Côte, S. D., Rooney, T. P., Tremblay, J. P., Dussault, C. and D. M. Waller. 2004. Ecological impacts of deer overabundance. *Annual Review of Ecology, Evolution and Systematics* 35:113-147.
- Couturier, S., Côté, S. D., Huot, J., and R. D. Otto. 2009. Body-condition dynamics in a northern ungulate gaining fat in winter. *Canadian Journal of Zoology*. 87:367-378.
- M. Crête and P.A. Jordan. 1981. Régime Alimentaire des Orignaux du Sud-Ouest Québécois pour les Mois d'Avril à Octobre. *Can. Field-Nat.* 95:50-56.
- Crete, M. and P. A. Jordan. 1982. Production and quality of forage available to moose in southwestern Quebec. *Canadian Journal of Forest Research*. 12:151-159.
- Crichton, V. 1997. Hunting. Pages 617-653 in A. W. Franzman and C. C Schwartz, editors. *Ecology and management of the North American moose*. Smithsonian Institution Press, Washington, D.C.
- Custer, T. W., E. Cox, and B. Gray. 2004. Trace elements in moose (*Alces alces*) found dead in northwestern Minnesota, USA. *Science of the Total Environment* 330:81-87.
- Dawson, C. P. 2009. Forestry in the Adirondacks. Pages 128-143 in W. F. Porter, J. D. Erickson and R. S. Whaley, editors. *The great experiment in conservation: voices from the Adirondack Park*. Syracuse University Press. Syracuse, NY.

- Dorman, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., García Marquéz, J. R., Gruber, B., Lafourcade, B., Leitão, P. J., Münkemüller, T., McClean, C., Osborne, P. E., Reineking, B., Schröder, B., Skidmore, A. K., Zurell, D. and S. Lautenbach. 2012. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36(1):27-46.
- Driscoll, C. T., G. B. Lawrence, A. J. Bulger, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard and K. C. Weathers. 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. *BioScience*, 51(3):180:198.
- Drucker, D. G., Hobson, K. A., Ouellet, J. P. and R. Courtois. 2010. Influence of forage preferences and habitat use on ^{13}C and ^{15}N abundance in wild caribou (*Rangifer tarandus caribou*) and moose (*Alces alces*) from Canada. *Isotopes in Environmental and Health Studies*. 46(1):107-121.
- Dungan, J. D., L. A. Shipley, R. G. Wright. 2010. Activity patterns, foraging ecology, and summer range carrying capacity of moose (*Alces alces shirasi*) in Rocky Mountain National Park, Colorado. *Alces*, 46:71-87.
- Dungan, J. D. and R. G. Wright. 2005 Summer diet composition of moose in Rocky Mountain National Park, Colorado. *Alces* 41: 139-146.
- Ferree, C. and M. G. Anderson. 2013. A map of terrestrial habitats of the northeastern United States: methods and approach. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

- Forchhammer, M. and D. Boertmann. 1993. The muskoxen *Ovibos moschatus* in north and northeast Greenland: population trends and the influence of abiotic parameters on population dynamics. *Ecography* 16:299-308.
- Foster, D R., G. Motzkin, D. Bernardos, and J. Cardoza. 2002. Wildlife dynamics in the changing New England landscape. *Journal of Biogeography*, 29:1337-1357.
- Gallant, D., C. H. Bérubé, T. Termbly and L. Vasseur. 2004. An extensive study of the foraging ecology of beavers (*Castor Canadensis*) in relation to habitat quality. *Canadian Journal of Zoology* 82: 922-933.
- Giencke, L. M., M. Dovciak, G. Mountrakis, J. A. Cale, and M. J. Mitchell. 2014. Beech bark disease: spatial patterns of thicket formation and disease spread in an aftermath forest in the northeastern United States. *Canadian Journal of Forest Research* 44:1042-1050.
- Goering, H. K and P. J. Van Soest. 1970. Forage analyses (apparatus, reagents, procedures and some applications). United States Department of Agriculture Agricultural Handbook 379.
- Goodwin, G.G. 1936. Big game animals in the northeastern United States. *Journal of Mammalogy*, 17:48-50.
- Gusewell, S. and W. Koerselman. 2002. Variation in nitrogen and phosphorus concentrations of wetland plants. *Perspectives in Plant Ecology* 5(1):37-61.
- Hanley, T. A. and J. D. McKendrick. 1985. Potential nutritional limitations for black-tailed deer in a spruce-hemlock forest, southeastern Alaska. *The Journal of Wildlife Management* 49(1):103-114.
- Hanley, T. A. 1997. A nutritional view of understanding and complexity in the problem of diet selection by deer (*Cervidae*). *Oikos* 79(2):209-218.

- Hanley, T. A., D. E. Spalinger, K. J. Mock, O. L. Weaver and G. M. Harris. 2012. Forage resource evaluation system for habitat-deer: an interactive deer habitat model. USFS Pacific Northwest Research Station General Technical Report PNW-GTR-858.
- Harmon, M. E., D. L. Phillips, J. Battles, A. Rassweiler, R. O. Hall, W. K. Lauenroth. 2007. Quantifying uncertainty in net primary production measurements. Pages 238-260 in T. J. Fahey, A. K. Knapp, editors. Principles and standards for measuring primary production. New York: Oxford University.
- Harrison, A. M. 2011. Landscape influences on site occupancy by beaver and resultant foraging impacts on forest composition and structure (Adirondack mountains, NY, USA). Thesis: State University of New York College of Environmental Science and Forestry.
- Hicks, A. 1986. History and current status of moose in New York. *Alces* 22:245-252.
- Hjeljord, O., F. Sundstol and H. Haagenrud. 1982. The nutritional value of browse to moose. *The Journal of Wildlife Management* 46(2):333-343.
- Hobbs, N. T. and D. M. Swift. 1985. Estimates of habitat carrying capacity incorporating explicit nutritional constraints. *The Journal of Wildlife Management* 49(3):814-822.
- Holdaway, R. J., S. J. McNeill, N. W. H. Mason, and F. E. Carswell. 2014. Propagating uncertainty in plot-based estimates of forest carbon stock and carbon stock change. *Ecosystems* 17:627-640.
- Holmes, J. C. 1995. Population regulation: a dynamic complex of interactions. *Wildlife Research* 22(1):11-19.
- Hornberg, S. 2001. The relationship between moose (*Alces alces*) browsing utilization and the occurrence of different forage species in Sweden. *Forest Ecology and Management* 149:91-102.

- Houston, D. R. 1994. Major new tree disease epidemics: beech bark disease. *Annual Review of Phytopathology* 32:75-87.
- Houston, D. R. 2001. Effect of harvesting regime on beech root sprouts and seedlings in a north-central Main forest long affected by beech bark disease. USDA Forest Service Research Paper NE-717.
- Illius, A.W. and I.J. Gordon. 1987. The allometry of food intake in grazing ruminants. *J. Anim. Ecology*. 56:989–99
- Irwin, L. L. 1975. Deer-moose relationships on a burn in northeastern Minnesota. *Journal of Wildlife Management*. 39(4):653-662.
- Janzen, F. J. 1994. Climate change and temperature dependend sex determination in reptiles. *Proceedings of the National Academy of Science of the United States of America*. 91:7487-7490.
- Jenkins, J. 2008. Climate change in the Adirondacks. The Wild Center and The Wildlife Conservation Society.
- Jenkins, J. and A Keal. 2004. The Adirondack atlas: a geographic portrait of the Adirondack Park. Syracuse University Press, Syracuse, NY, USA.
- Karmalkar, A. V. and R. S. Bradley. 2017. Consequences of global warming of 1.5°C and 2°C for regional temperature and precipitation changes in the contiguous United States. *PLOS One* 12(1): e0168697.
- Koitzsh, K. B. 2002. Application of a moose habitat suitability index model to Vermont Wildlife Management Units. *Alces* 38:89-107.
- Lo E. 2005. Gaussian error propogation applied to ecological data: post-ice-storm-downed woody biomass. *Ecological Monographs* 75:451-466.

- Lorimer, C. G and A. S. White. 2003. Scale and frequency of natural disturbances in the northeastern US: implications for early successional forest habitats and regional age distributions. *Forest and Ecology Management* 185: 41-64.
- Ludewig, H. A. and R. T. Bowyer. 1985. Overlap in winter diets of sympatric moose and white-tailed deer in Maine. *Journal of Mammalogy*, 66(2):390-392.
- Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald and W. P. Erickson. 2002. *Resource selection by animals: statistical design and analysis for field studies*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Mathisen, K. M., Milner, J. M., van Beest, F., and C. Skarpe. 2013. Long-term effects of supplementary feeding of moose on browsing impact at a landscape scale. *Forest Ecology and Management*. 314:104-111.
- Martin, J. S. and M. M. Martin. 1982. Tannin assays in ecological studies: lack of correlation between phenolics, proanthocyanidins and protein-precipitating constituents in mature foliage of six oak species. *Oecologia* 54:205-211.
- McArt, S. H., D. E. Spalinger, W. B. Collins, E. R. Schoen, T. Stevenson and M. Bucho. 2009. Summer dietary nitrogen availability as a potential bottom-up constraint on moos in south-central Alaska. *Ecology* 90(5):1400-1411.
- McCarty, J. P. 2001. Ecological consequences of recent climate change. *Conservation Biology* 15(2):320-331.
- McInnes, P. F., R. J. Naiman, J. Pastor and Y. Cohen. 1992. Effects of moose browsing on vegetation and litter of the boreal forest, Isle Royale, Michigan, USA. *Ecology* 73(6):2059-2075.

- McWilliam, A. L. C., Roberts, J. M., Cabral, O. M. R., Leitao, M. V. B. R., de Costa, A. C. L., Maitelli, G. T., and C. A. G. P. Zamparoni. 1993. Leaf area index and above-ground biomass of terra firme rain forest and adjacent clearings in Amazonia. *Functional Ecology* 7:310-317.
- Millette, T. L., Marcano, E. and D. Laflower. 2014. Winter distribution of moose at landscape scale in northeastern Vermont: A GIS analysis. *Alces* 50:17-26.
- Millward, A. A. and C. E. Kraft. 2004. Physical influence of landscape on a large-extent ecological disturbance: the northeastern North American ice storm of 1998. *Landscape Ecology* 19: 99-111.
- Moen, R. A. 1995. Moose energetics, foraging strategies and landscape effects: a spatially explicit simulation model. Dissertation, University of Minnesota, St. Paul, Minnesota, USA.
- Moen, R., J. Pastor and Y. Cohen. 1997. A spatially explicit model of moose foraging and energetics. *Ecology* 78(2):505-521.
- Murray, D. L., Cox, E. W., Ballard, W. B., Whitlaw, H. A., Lenarz, M. S., Custer, T. W., Barnett, T. and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. *Wildlife Monographs* 166:1-30.
- Musante, A. R., P. J. Pekins and D. L. Scarpitti. 2007. Metabolic impacts of winter tick infestations on calf moose. *Alces* 43:101-110.
- Naiman, R. J., Melillo, J. M., and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor Canadensis*). *Ecology* 67(5):1254-1269.
- Nelson, L. J., and J. M. Peek. 1982. Effect of survival and fecundity rate on rate of increase of elk. *Journal of Wildlife Management* 46:535-540.

- New York State Department of Environmental Conservation. 2016. New York state industrial timber harvest production and consumption report-2016.
www.dec.ny.gov/docs/lands_forests_pdf/thr2016.pdf
- O'Hara, T. M., G. Carrol, P. Barboza, K. Muelloer, J. Blake, V. Woshner and C. Willetto. 2001. Mineral and heavy metal status as related to a mortality event and poor recruitment in a moose population in Alaska. *Journal of Wildlife Diseases* 37(3):509-522.
- Oldemeyer, J. L. and W. L. Regelin. 1987. Forest succession, habitat management and moose on the Kenai National Wildlife Refuge. *Swedish Wildlife Research* 1:163:179.
- Parker, G. R. and L. D. Morton. 1978. The estimation of winter forage and its use by moose on clearcuts in northcentral Newfoundland. *Journal of Range Management*. 31:300-304.
- Peek, J. M., Urich, D. L., and R. J. Mackie. 1976. Moose habitat selection and relationships to forest management in northeastern Minnesota. *Wildlife Monographs* 48:3-65.
- Porter, W. F. 2009. Forestry in the Adirondacks. Pages 102-113 *in* W. F. Porter, J. D. Erickson and R. S. Whaley, editors. *The great experiment in conservation: voices from the Adirondack Park*. Syracuse University Press. Syracuse, NY.
- Post, E and N. C. Stenseth. 1999. Climatic variability, plant phenology and northern ungulates. *Ecology* 80(4):1322-1339.
- Post, E., R. O. Peterson, N. C. Stenseth and B. E. McLaren. 1999. Ecosystem consequences of wolf behavioral response to climate. *Nature* 401:905-907.
- Pruss, M. T. and P. J. Pekins. 1992. Effects of moose foraging on browse availability in New Hampshire deer yards. *Alces* 28:123-136.
- Raffel, T. R., N. Smith, C. Cortright and A. J. Gatz. 2009. Central place foraging by beavers (*Castor canadensis*) in a complex lake habitat. *American Midland Naturalist* 162: 62-73.

- Raymond, K. S., F. A. Servello, B. Griffith and W. E. Escholz. 1996. Winter foraging ecology of moose on glyphosate-treated clearcuts in Maine. *The Journal of Wildlife Management* 60(4):753-763.
- Reeves, H. M. and R. E. McCabe 1997. Of moose and man. Pages 1-77 *in* A. W. Franzman and C. C. Schwartz, editors. *Ecology and management of the North American moose*. Smithsonian Institution Press, Washington, D.C.
- Rempel, R. S., P. C. Elkie, A. R. Rodgers and M. J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. *The Journal of Wildlife Management* 61(2):517-524.
- Renecker, L. A. and R. J. Hudson. 1985. Estimation of dry matter intake of free-ranging moose. *The Journal of Wildlife Management* 49:785-792.
- Renecker, L. A. and R. J. Hudson. 1989. Ecological metabolism of moose in aspen-dominated boreal forest, central Alberta. *Canadian Journal of Zoology* 67:1923-1928.
- Recnecker, L. A. and C. C. Schwartz. 1997. Food habits and feeding behavior. Pages 403-439 *in* A. W. Franzman and C. C. Schwartz, editors. *Ecology and management of the North American moose*. Smithsonian Institution Press, Washington, D.C., USA.
- Risenhoover, K. L. 1986. Winter activity patterns of moose in interior Alaska. *The Journal of Wildlife Management* 50:727-734.
- Robbins, C. T., T. A. Hanley, A. E. Hagerman, O. Hjeljord, D. L. Baker, C. C. Schwartz and W. W. Mautz. 1987a. Role of tannins in defending plants against ruminants: reduction in protein availability. *Ecology* 68(1):98-107.
- Robbins, C. T., S. Mole, A. E. Hagerman and T. A. Hanley. 1987b. Role of tannins in defending plants against ruminants: reduction in dry matter digestion? *Ecology* 68(6):1606-1615.

- Robinette, W. L., Baer, C. H., Pillmore, R. E., and C. E. Knittle. 1973. Effects of nutritional change on captive mule deer. *Journal of Wildlife Management* 37(3):312-326.
- Rodgers, A. 2001. Moose. Colin Baxter Photography Ltd, Grantown-on-Spey, Scotland.
- Rooney, T. P. 2001. Deer impacts on forest ecosystems: a North American perspective. *Forestry* 74(3): 201-208.
- Runkle, J. R. 1982. Patterns of disturbance in some old-growth mesic forests of eastern North America. *Ecology* 63(5):1533-1546.
- Pearson, R. G. and T. P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate models useful? *Global Ecology & Biogeography* 12:361-371.
- Sams, M. G., Lochmiller, R. L., Hellgren, E. C., Payton, M. E., and L. W. Varner. 1995. Physiological responses of neonatal white-tailed deer reflective of maternal dietary protein intake. *Canadian Journal of Zoology*. 73(10):1928-1936.
- Saunders, D. 1995. Adirondack mammals. State University of New York College of Environmental Science. Syracuse, NY.
- Schielzeth, Holger. 2010. Simple means to improve the interpretability of regression coefficients. *Methods in Ecology and Evolution* 1:103-113.
- Schwartz, C. C., W. L. Regelin, and A. W. Franzmann. 1987. Protein digestion in moose. *The Journal of Wildlife Management* 51(2):352-357.
- Schwartz, C. C., M. E. Hubbert and A. W. Franzmann. 1988. Energy requirements of adult moose for winter maintenance. *The Journal of Wildlife Management* 52(1):26-33.
- Seaton, C. T. 2002. Winter foraging ecology of moose in the Tanana Flats and Alaska Range Foothills. Thesis: University of Alaska Fairbanks.

- Seymour, R. S., White, A. S., and P. G. deMayandier. 2002. Natural disturbance regimes in northeastern North America- evaluating silvicultural systems using natural scales and frequencies. *Forest Ecology and Management* 155:357-367.
- Shipley, L.A., J.E. Gross, D.E. Spalinger, N.T. Hobbs, and B.A. Wunder. 1994 . The scaling of intake rate in mammalian herbivores. *American Naturalist*. 143:1055–1082.
- Spencer, D. L. and J. B. Hakala. 1964. Moose and fire on the Kenai. *Proceedings of the Tall Timbers and Fire Ecology Conference* 3:11-33.
- Thuiller, W., M. Gueguen, M. Bison, A. Duparc, M. Garel, A. Loison, J. Renaud, and G. Poggiato. 2017. Combining point-process and landscape vegetation models to predict large herbivore ditributions in space and time- a case study of *Rupicapra rupicapra*. *Diversity and Distributions* 2017:1-11.
- Torbit, S. C., Carpenter, L. H., Swift, D. M. and A. W. Alldredge. 1985. Differential loss of fat ad protein by mule deer during winter. *Journal of Wildlife Management* 49(1):80-85.
- Wilson, D. E. 1971. Carrying capacity of the key browse species for moose on the north slopes of the Uinta Mountains, Utah. Thesis: Utah State University, 3521.
- van Beest, F., Van Moorter, B. F. A., and Milner, J. M. 2012. Temperature-mediated habitat use and selection by a heat-sensitive northern ungulate. *Animal Behaviour*, 84(3): 723-735.
- VanBallenberghe, V. D. and D. G. Miquelle. 1990. Activity of moose during spring and summer in interior Alaska. *The Journal of Wildlife Management* 54:391-396.
- Van Dyne, G. M., N. R. Brockington, Z. Szocs, J. Duek and C. A. Ribic. 1980. Large herbivore subsystem. Pages 269-538 *in* B.Bobek, K. Perzanowski and W. L. Regelin, editors,

- Global trends in wildlife management 1. Trans. Conc. Int. Union Game Biol. Swiat Press, Krakow-Warszawa, Poland.
- VerCauteren, K. C. 2003. The deer boom: discussions on population growth and range expansion of the white-tailed deer. USDA National Wildlife Research Center Staff Publications 281.
- Visscher, D. R., E. H. Merrill, D. Fortin and J. L. Frair. 2006. Estimating woody browse availability for ungulates at increasing snow depths. *Forest Ecology and Management* 222:348-354.
- Wattles, D. W., and S. DeStefano. 2011. Status and management of moose in the northeastern United States. *Alces* 47:53-68.
- Wattles, D. W. and S. DeStefano. 2013. Space use and movements of moose in Massachusetts: Implications for conservation of large mammals in a fragmented environment. *Alces* 49:65-81.
- Westworth, D., L. Brusnyk, J. Roberts and H. Veldhuzien. 1989. Winter habitat use by moose in the vicinity of an open pit copper mine in north-central British Columbia. *Alces* 25:156-166.
- Whittaker, R. H., F. H. Bormann, G. E. Likens and T. G. Siccama. 1974. The Hubbard Brook ecosystem study: forest biomass and production. *Ecological Monographs* 44:233-252.
- Yanai, R. D., J. J. Battles, A. D. Richardson, C. A. Blodgett, D. M. Wood and E. B. Rastetter. 2010. Estimating uncertainty in ecosystem budget calculations. *Ecosystems* 13:239-248.
- Ytrehus, B. Skagemo, H., Stuve, G., Sivertsen, T., Handeland, K., and T. Vikøren. 1999. Osteoporosis, bone mineralization, and status of selected trace elements in two populations of moose calves in Norway. *Journal of Wildlife Diseases* 35(2):204-211.

APPENDICES

Appendix 1.1

Browse metrics for all species observed during moose browse selection surveys during summer (2016 and 2017) and winter (2016/17) in Adirondack Park, NY. The number of plots on which each species was observed is represented by N, Chesson's index values are represented by C, Ivlev's electivity index values are represented by I, and the proportion of the total observed diet made up by each species is represented by Pr. Standard deviations for C and I are also displayed.

Season	Species	N	C	C (SD)	I	I (SD)	Pr
Summer	<i>Abies balsamea</i>	34	0.00	0.00	-1.00	0.00	0.00
Summer	<i>Acer pensylvanicum</i>	19	0.04	0.10	-0.81	0.42	0.00
Summer	<i>Acer rubrum</i>	59	0.28	0.29	-0.06	0.63	0.21
Summer	<i>Acer saccharum</i>	23	0.23	0.26	-0.27	0.57	0.05
Summer	<i>Acer spicatum</i>	3	0.22	0.22	-0.06	0.83	0.00
Summer	<i>Alnus incana</i>	7	0.00	0.00	-1.00	0.00	0.00
Summer	<i>Amelanchier sp.</i>	7	0.15	0.20	-0.36	0.81	0.01
Summer	<i>Betula alleghaniensis</i>	48	0.36	0.30	0.11	0.52	0.19
Summer	<i>Betula papyrifera</i>	15	0.25	0.23	0.05	0.66	0.07
Summer	<i>Betula populifolia</i>	11	0.33	0.27	0.25	0.43	0.08
Summer	<i>Caprinus caroliniana</i>	1	0.30	N/A	0.71	N/A	0.00
Summer	<i>Cornus sp.</i>	2	0.05	0.08	-0.55	0.64	0.00
Summer	<i>Corylus sp.</i>	3	0.40	0.27	0.39	0.38	0.00
Summer	<i>Fagus grandifolia</i>	37	0.02	0.07	-0.83	0.41	0.03
Summer	<i>Fraxinus americana</i>	7	0.05	0.09	-0.65	0.59	0.00
Summer	<i>Viburnum lantoides</i>	17	0.17	0.27	-0.53	0.59	0.02
Summer	<i>Ilex mucronata</i>	18	0.13	0.20	-0.42	0.64	0.06
Summer	<i>Ilex verticillata</i>	2	0.63	0.53	0.12	0.08	0.01
Summer	<i>Juglans cinerea</i>	1	0.00	N/A	-1.00	N/A	0.00
Summer	<i>Larix laricina</i>	4	0.00	0.00	-1.00	0.00	0.00
Summer	<i>Chamaedaphne calyculata</i>	3	0.00	0.00	-1.00	0.00	0.00
Summer	<i>Ostrya virginiana</i>	7	0.24	0.38	-0.36	0.80	0.01
Summer	<i>Picea rubens</i>	7	0.00	0.01	-0.91	0.23	0.00
Summer	<i>Pinus strobus</i>	1	0.00	N/A	-1.00	N/A	0.00
Summer	<i>Pinus sylvestris</i>	3	0.00	0.00	-1.00	0.00	0.00
Summer	<i>Populus grandidentata</i>	6	0.28	0.19	0.30	0.45	0.02
Summer	<i>Populus tremuloides</i>	13	0.20	0.13	0.00	0.50	0.05
Summer	<i>Prunus pensylvanica</i>	13	0.22	0.30	-0.22	0.55	0.06
Summer	<i>Prunus serotina</i>	19	0.13	0.17	-0.37	0.60	0.01
Summer	<i>Prunus virginiana</i>	8	0.05	0.09	-0.71	0.42	0.00
Summer	<i>Salix sp.</i>	5	0.17	0.15	-0.15	0.59	0.01

Summer	Spirea sp.	4	0.00	0.00	-1.00	0.00	0.00
Summer	Tsuga canadensis	1	0.00	N/A	-1.00	N/A	0.00
Summer	Vaccinium corymbosum	3	0.00	0.00	-1.00	0.00	0.00
Summer	Viburnum cassinoides	18	0.23	0.19	-0.03	0.58	0.09
Summer	Viburnum lentago	2	0.16	0.19	0.02	0.67	0.00
Winter	Abies balsamea	24	0.22	0.29	-0.31	0.50	0.17
Winter	Acer pensylvanicum	20	0.18	0.21	-0.15	0.49	0.06
Winter	Acer rubrum	38	0.39	0.28	0.17	0.52	0.39
Winter	Acer saccharum	14	0.09	0.14	-0.58	0.51	0.01
Winter	Acer spicatum	5	0.22	0.30	-0.31	0.72	0.01
Winter	Alnus incana	2	0.06	0.05	-0.42	0.46	0.01
Winter	Amelanchier sp.	5	0.19	0.17	-0.02	0.59	0.00
Winter	Betula alleghaniensis	17	0.06	0.06	-0.57	0.44	0.10
Winter	Betula papyrifera	9	0.04	0.07	-0.67	0.50	0.01
Winter	Betula populifolia	4	0.07	0.12	-0.64	0.56	0.01
Winter	Cornus sp.	1	0.13	N/A	-0.05	N/A	0.00
Winter	Corylus sp.	1	0.00	N/A	-1.00	N/A	0.00
Winter	Fagus grandifolia	30	0.01	0.03	-0.95	0.16	0.01
Winter	Fraxinus americana	1	0.00	N/A	-1.00	N/A	0.00
Winter	Viburnum lantoides	17	0.22	0.26	-0.13	0.65	0.03
Winter	Ilex mucronata	3	0.13	0.07	-0.01	0.18	0.01
Winter	Larix laricina	1	0.00	N/A	-1.00	N/A	0.00
Winter	Picea rubens	13	0.02	0.09	-0.92	0.29	0.00
Winter	Populus grandidentata	6	0.21	0.13	0.09	0.63	0.01
Winter	Populus tremuloides	11	0.31	0.27	0.20	0.54	0.03
Winter	Prunus pensylvanica	9	0.10	0.13	-0.40	0.63	0.02
Winter	Prunus serotina	21	0.10	0.14	-0.54	0.50	0.07
Winter	Prunus virginiana	3	0.06	0.05	-0.46	0.47	0.00
Winter	Salix sp.	2	0.22	0.01	0.36	0.01	0.00
Winter	Viburnum sp.*	9	0.21	0.24	-0.01	0.46	0.06

Appendix 1.2

Standardization values used to center and standardize data for zero-inflated negative binomial regression to model browse utilization as a function of biomass availability, beech coverage and conifer coverage.

	Summer		Winter	
	Mean	Standard Deviation	Mean	Standard Deviation
Principal Browse Biomass (g/8m ²)	1288.776	2476.36	640.4	898.61
Beech Coverage	0.107	0.23	0.086	0.17
Conifer Coverage	0.143	0.245	0.136	0.252

Appendix 2.1

Reclassification of Ecosystems defined by The Nature Conservancy's Terrestrial Habitat Map for the Northeastern US and Atlantic (Ferree and Anderson 2013). Ecosystems were assigned to either conifer, deciduous/mixed, wetland, wooded wetland or no-sampling based on ecosystem descriptions provided by Ferree and Anderson 2013. The deciduous/mixed class was further separated into upland and lowland forests, using a cutoff of 497m in elevation.

TNC Class	TNC Ecosystem	Reclassification
Upland	Acadian Low Elevation Spruce-Fir-Hardwood Forest	Conifer
Upland	Acadian Sub-boreal Spruce Flat	Conifer
Upland	Acadian-Appalachian Alpine Tundra	No Sampling
Upland	Acadian-Appalachian Montane Spruce-Fir-Hardwood Forest	Conifer
Upland	Agriculture	No Sampling
Upland	Appalachian (Hemlock)-Northern Hardwood Forest: drier	Deciduous/Mixed
Upland	Appalachian (Hemlock)-Northern Hardwood Forest: moist-cool	Deciduous/Mixed
Upland	Appalachian (Hemlock)-Northern Hardwood Forest: typic	Deciduous/Mixed
Upland	Central Appalachian Dry Oak-Pine Forest	Deciduous/Mixed
Upland	Central Appalachian Pine-Oak Rocky Woodland	Deciduous/Mixed
Upland	Developed	No Sampling
Upland	Glacial Marine & Lake Mesic Clayplain Forest	Deciduous/Mixed
Upland	Great Lakes Alvar	No Sampling
Upland	Laurentian Acidic Rocky Outcrop	No Sampling
Upland	Laurentian-Acadian Acidic Cliff and Talus	No Sampling
Upland	Laurentian-Acadian Calcareous Cliff and Talus	No Sampling
Upland	Laurentian-Acadian Calcareous Rocky Outcrop	No Sampling
Upland	Laurentian-Acadian Northern Hardwood Forest: high conifer	Deciduous/Mixed
Upland	Laurentian-Acadian Northern Hardwood Forest: moist-cool	Deciduous/Mixed
Upland	Laurentian-Acadian Northern Hardwood Forest: typic	Deciduous/Mixed
Upland	Laurentian-Acadian Northern Pine-(Oak) Forest	Deciduous/Mixed
Upland	Laurentian-Acadian Pine-Hemlock-Hardwood Forest: moist-cool	Deciduous/Mixed
Upland	Laurentian-Acadian Pine-Hemlock-Hardwood Forest: typic	Deciduous/Mixed
Upland	Laurentian-Acadian Red Oak-Northern Hardwood Forest	Deciduous/Mixed
Upland	North-Central Appalachian Acidic Cliff and Talus	No Sampling
Upland	North-Central Appalachian Circumneutral Cliff and Talus	No Sampling
Upland	Northeastern Interior Pine Barrens	Conifer
Upland	Northern Appalachian-Acadian Rocky Heath Outcrop	No Sampling
Upland	Open Water	No Sampling
Upland	Shrubland/grassland; mostly ruderal shrublands, regenerating clearcuts	No Sampling
Wetland	Boreal-Laurentian Bog: Isolated/small stream	Wetland
Wetland	Boreal-Laurentian-Acadian Acidic Basin Fen: Undifferentiated	Wetland
Wetland	Glacial Marine & Lake Wet Clayplain Forest: Undifferentiated	Wetland

Wetland	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp: Isolated	Wooded Wetland
Wetland	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp: Lake/pond: any size	Wooded Wetland
Wetland	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp: Smaller river floodplain/riparian	Wooded Wetland
Wetland	Laurentian-Acadian Freshwater Marsh: Isolated	Wetland
Wetland	Laurentian-Acadian Freshwater Marsh: Lake/pond: any size	Wetland
Wetland	Laurentian-Acadian Freshwater Marsh: Smaller river floodplain/riparian	Wetland
Wetland	Laurentian-Acadian Large River Floodplain: Acidic Swamp	Wetland
Wetland	Laurentian-Acadian Large River Floodplain: Alkaline Conifer-Hardwood Swamp	Wooded Wetland
Wetland	Laurentian-Acadian Large River Floodplain: Conifer-Hardwood Acidic Swamp	Wooded Wetland
Wetland	Laurentian-Acadian Large River Floodplain: Floodplain Forest	Wooded Wetland
Wetland	Laurentian-Acadian Large River Floodplain: Freshwater Marsh	Wetland
Wetland	Laurentian-Acadian Large River Floodplain: Wet Meadow-Shrub Swamp	Wetland
Wetland	Laurentian-Acadian Wet Meadow-Shrub Swamp: Isolated	Wetland
Wetland	Laurentian-Acadian Wet Meadow-Shrub Swamp: Lake/pond: any size	Wetland
Wetland	Laurentian-Acadian Wet Meadow-Shrub Swamp: Smaller river floodplain/riparian	Wetland
Wetland	North-Central Appalachian Acidic Swamp: Isolated	Wetland
Wetland	North-Central Appalachian Acidic Swamp: Lake/pond: any size	Wetland
Wetland	North-Central Appalachian Acidic Swamp: Smaller river floodplain/riparian	Wetland
Wetland	North-Central Appalachian Large River Floodplain: Acidic Swamp	Wetland
Wetland	North-Central Appalachian Large River Floodplain: Acidic Swamp	Wetland
Wetland	North-Central Appalachian Large River Floodplain: Freshwater Marsh	Wetland
Wetland	North-Central Appalachian Large River Floodplain: Rich Swamp	Wetland
Wetland	North-Central Appalachian Large River Floodplain: Rich Swamp	Wetland
Wetland	North-Central Appalachian Large River Floodplain: Wet Meadow-Shrub Swamp	Wetland
Wetland	North-Central Interior and Appalachian Acidic Peatland: Undifferentiated	Wetland
Wetland	North-Central Interior and Appalachian Rich Swamp: Isolated	Wetland
Wetland	North-Central Interior and Appalachian Rich Swamp: Lake/pond: any size	Wetland
Wetland	North-Central Interior and Appalachian Rich Swamp: Smaller river floodplain/riparian	Wetland
Wetland	North-Central Interior Wet Flatwoods: Undifferentiated	Wetland
Wetland	Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp: Isolated	Wooded Wetland
Wetland	Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp: Lake/pond: any size	Wooded Wetland
Wetland	Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp: Smaller river floodplain/riparian	Wooded Wetland

Appendix 2.2

Model selection table for allometric equations describing browse biomass availability on individual tree and shrub species for moose in Adirondack Park, NY during summer. Models for large (>60mm diameter) American beech are not displayed, as the small sample size warranted an intercept only model. Only candidate models carrying >1% of cumulative model weight are displayed.

	Main Effects	Interactions	df	logLik	AICc	delta	weight
Small Maples	BD		3	-14.22	36.62	0.00	0.19
	BD2		3	-14.40	36.99	0.38	0.16
	BD+D		4	-12.82	37.65	1.03	0.11
	BD2+D		4	-13.04	38.07	1.46	0.09
	BD+S		4	-13.26	38.52	1.90	0.07
	BD2+S		4	-13.36	38.73	2.11	0.07
	BD+BD2		4	-14.09	40.18	3.56	0.03
	BD+ES		4	-14.14	40.27	3.66	0.03
	E+BD		4	-14.17	40.34	3.73	0.03
	BD2+ES		4	-14.30	40.60	3.99	0.03
	E+BD2		4	-14.35	40.70	4.08	0.02
	E+BD+D		5	-12.08	40.83	4.21	0.02
	E+BD2+D		5	-12.38	41.42	4.81	0.02
	BD+BD2+D		5	-12.70	42.06	5.44	0.01
	BD+D+S		5	-12.71	42.09	5.48	0.01
	BD+D+ES		5	-12.81	42.29	5.67	0.01
	BD2+D+S		5	-12.88	42.43	5.81	0.01
Large Maples	Main Effects	Interactions	df	logLik	AICc	delta	weight
	E		3	-24.63	57.10	0.00	0.21
	N		3	-25.38	58.61	1.51	0.10
	CC+E		4	-23.76	58.85	1.75	0.09
	E+BD		4	-24.01	59.36	2.26	0.07
	E+N		4	-24.22	59.77	2.67	0.06
	E+S		4	-24.59	60.51	3.41	0.04
			2	-28.06	60.98	3.88	0.03
	BD+N		4	-24.95	61.24	4.14	0.03
	BD2+N		4	-24.95	61.24	4.14	0.03
	CC+N		4	-25.02	61.36	4.26	0.03
	BD2		3	-26.97	61.79	4.69	0.02
	BD		3	-26.99	61.83	4.73	0.02
	S+N		4	-25.32	61.98	4.88	0.02
	S		3	-27.16	62.16	5.06	0.02
	CC+E+N		5	-23.48	62.42	5.32	0.01

CC+E+BD2		5	-23.68	62.82	5.72	0.01
CC+E+BD		5	-23.69	62.83	5.73	0.01
CC+E+S		5	-23.71	62.88	5.78	0.01
E+BD2+N		5	-23.74	62.94	5.84	0.01
E+BD+BD2		5	-23.74	62.94	5.84	0.01
E+BD+N		5	-23.77	62.99	5.89	0.01
CC		3	-27.67	63.19	6.09	0.01

		df	logLik	AICc	delta	weight
Main Effects						
CC+BD+BD2+S	BD x S	7	-30.16	80.21	0.00	0.09
CC+BD+BD2+S	BD2 x S	7	-30.42	80.73	0.52	0.07
CC+BD+BD2	CC x BD	6	-32.86	81.93	1.72	0.04
CC+BD+BD2	CC x BD+CC x BD2	7	-31.43	82.75	2.54	0.03
CC+BD+BD2+D+S	BD x S	8	-29.76	83.52	3.31	0.02
CC+E+BD+BD2	CC x E+CC x BD	8	-29.78	83.56	3.35	0.02
CC+BD+BD2	CC x BD2	6	-33.68	83.57	3.35	0.02
CC+E+BD+BD2+S	CC x E+CC x S	9	-27.54	83.66	3.45	0.02
CC+BD+BD2+S+N	BD x S	8	-29.88	83.76	3.55	0.02
CC+E+BD+BD2+S	BD x S	8	-29.96	83.91	3.70	0.01
CC+BD+BD2+D+S	BD2 x S	8	-29.96	83.92	3.70	0.01
CC+BD+BD2+S	CC x S	7	-32.03	83.96	3.75	0.01
CC+E+BD+BD2+D+S	CC x E+CC x S	10	-25.14	84.03	3.82	0.01
CC+BD+BD2+S	BD x S+BD2 x S	8	-30.11	84.21	4.00	0.01
CC+BD+S	BD x S	6	-34.01	84.23	4.01	0.01
CC+BD+BD2+S	CC x S+BD x S	8	-30.12	84.24	4.02	0.01
CC+BD+BD2+S	CC x BD2+BD x S	8	-30.12	84.25	4.04	0.01
CC+BD+BD2+S+N	BD2 x S	8	-30.14	84.29	4.07	0.01
CC+BD+BD2+S	CC x BD+BD x S	8	-30.15	84.30	4.09	0.01
CC+E+BD+BD2+S	CC x E+BD x S	9	-27.94	84.47	4.26	0.01
BD+BD2+S		5	-35.86	84.58	4.37	0.01

		df	logLik	AICc	delta	weight
Main Effects						
E+V+V2		5	1	11.8	0	0.12
E+V+V2	ExV	6	0.778801	12.3	0.5	0.09
E+V		4	0.740818	12.4	0.6	0.09
V		3	0.704688	12.5	0.7	0.08
V+V2		4	0.57695	12.9	1.1	0.07
CC+E+V+V2		6	0.367879	13.8	2	0.04
CC+V+V2		5	0.286505	14.3	2.5	0.03
E+V	ExV	5	0.201897	15	3.2	0.02
CC+V		4	0.201897	15	3.2	0.02
A+A2+H		5	0.19205	15.1	3.3	0.02
A+A2+H		5	0.19205	15.1	3.3	0.02
A+A2+V		5	0.19205	15.1	3.3	0.02

E+V+V2		5	0.182684	15.2	3.4	0.02
H+V		4	0.157237	15.5	3.7	0.02
A+V		4	0.157237	15.5	3.7	0.02
A+H		4	0.157237	15.5	3.7	0.02
A+H		4	0.157237	15.5	3.7	0.02
V+V2		4	0.157237	15.5	3.7	0.02
H+V+V2		5	0.157237	15.5	3.7	0.02
A+V+V2		5	0.157237	15.5	3.7	0.02
CC+E+V		5	0.149569	15.6	3.8	0.02
E+V+V2+D		6	0.142274	15.7	3.9	0.02
E+A+A2+V		6	0.142274	15.7	3.9	0.02
E+A+A2+H		6	0.142274	15.7	3.9	0.02
E+A+A2+H		6	0.142274	15.7	3.9	0.02
CC+E+V+V2	ExV	7	0.122456	16	4.2	0.01
E+A+V		5	0.116484	16.1	4.3	0.01

	Main Effects	Interactions	df	logLik	AICc	delta	weight
	BD+BD2		4	-13.39	37.28	0.00	0.33
	CC+BD+BD2		5	-12.53	39.06	1.77	0.14
	BD+BD2+S		5	-12.98	39.95	2.67	0.09
	E+BD+BD2		5	-13.35	40.70	3.42	0.06
	BD+BD2+D		5	-13.39	40.77	3.49	0.06
	CC+E+BD+BD2		6	-11.94	41.88	4.60	0.03
Aspens	CC+BD+BD2+S		6	-12.19	42.39	5.10	0.03
	CC+BD+BD2	CC x BD2	6	-12.36	42.72	5.44	0.02
	CC+BD+BD2	CC x BD	6	-12.41	42.82	5.54	0.02
	CC+BD+BD2+D		6	-12.53	43.05	5.77	0.02
	BD+BD2+D+S		6	-12.76	43.52	6.23	0.01
	BD+BD2+S	BD2 x S	6	-12.97	43.94	6.66	0.01
	E+BD+BD2+S		6	-12.97	43.94	6.66	0.01
	BD+BD2+S	BD x S	6	-12.97	43.95	6.67	0.01

	Main Effects	Interactions	df	logLik	AICc	delta	weight
	BD+BD2+S+Ea	BD x S+BD2 x S	8	-24.88	75.36	0.00	0.16
	E+BD+BD2+S	BD x S+BD2 x S	8	-25.41	76.42	1.06	0.09
	CC+E+BD+BD2+S	BD x S+BD2 x S	9	-23.70	78.26	2.90	0.04
	E+BD+BD2+S		6	-30.91	78.77	3.41	0.03
Cherries	E+BD+BD2+S+N	BD x S+BD2 x S	9	-23.99	78.83	3.47	0.03
	BD+BD2+S		5	-32.84	79.01	3.65	0.03
	E+BD+BD2+S+Ea	BD x S+BD2 x S	9	-24.10	79.05	3.69	0.03
	CC+E+BD+BD2+S	CC x BD2+BD x S+BD2 x S	10	-21.34	79.60	4.24	0.02
	BD+BD2+S	BD x S+BD2 x S	7	-29.41	79.81	4.45	0.02
	BD+BD2+D+S+Ea	BD x S+BD2 x S	9	-24.64	80.13	4.77	0.01

	BD+BD2+S+Ea	BD x S+BD x Ea+BD2 x S	9	-24.72	80.30	4.94	0.01
	BD+BD2+S+Ea+N	BD x S+BD2 x S	9	-24.73	80.32	4.96	0.01
	BD+BD2+S+Ea		6	-31.69	80.33	4.97	0.01
	BD+BD2+S+Ea	BD x S+BD2 x S+BD2 x Ea	9	-24.75	80.36	5.00	0.01
	CC+BD+BD2+S+Ea	BD x S+BD2 x S	9	-24.81	80.48	5.12	0.01
	E+BD+BD2+D+S	BD x S+BD2 x S	9	-24.86	80.59	5.23	0.01
	CC+E+BD+BD2+S	CC x BD+CC x BD2	9	-24.87	80.59	5.23	0.01
	CC+E+BD+BD2+S	CC x BD+BD x S+BD2 x S	10	-21.98	80.88	5.52	0.01
	Main Effects	Interactions	df	logLik	AICc	delta	weight
	E+V+S		5	-2.69	19.40	0.00	0.14
	E+V+N		5	-3.07	20.10	0.75	0.09
	CC+E+V		5	-3.27	20.50	1.15	0.08
	CC+V		4	-5.54	21.60	2.20	0.05
	CC+E+V+S		6	-1.98	21.90	2.56	0.04
	CC+E+V+N		6	-2.00	22.00	2.61	0.04
	E+V+S	E x V	6	-2.00	22.00	2.62	0.04
	E+V+N	E x V	6	-2.11	22.20	2.84	0.03
	CC+V	CC x V	5	-4.18	22.40	2.98	0.03
Northern Wild Raisin	E+V+S	V x S	6	-2.22	22.40	3.06	0.03
	E+V	E x V	5	-4.26	22.50	3.13	0.03
	E+V+S+N		6	-2.39	22.80	3.39	0.03
	CC+E+V	CC x V	6	-2.56	23.10	3.73	0.02
	E+V+N	E x V+V x N	7	-0.61	23.80	4.45	0.02
	CC+V+S		5	-4.93	23.90	4.47	0.01
	E+V+N	V x N	6	-3.03	24.10	4.67	0.01
	V+S+N	V x N	6	-3.03	24.10	4.68	0.01
	CC+E+V	E x V	6	-3.08	24.20	4.78	0.01
	CC+E+V	CC x E	6	-3.27	24.50	5.15	0.01
	CC+V+N	V x N	6	-3.34	24.70	5.29	0.01
	Main Effects	Interactions	df	logLik	AICc	delta	weight
	BD+S		4	-8.435	34.9	0	0.14
	S		3	-12.516	35.8	0.96	0.09
	Intercept		2	-14.96	35.9	1.05	0.08
Small Beech	E		3	-12.771	36.3	1.47	0.07
	BD+E		4	-9.527	37.1	2.18	0.05
	BD		3	-13.411	37.6	2.75	0.04
	BD+D		3	-14.667	40.1	5.26	0.01
	CC		3	-14.827	40.5	5.58	0.01

Appendix 2.3

Model selection table for allometric equations describing browse biomass availability on individual tree and shrub species for moose in Adirondack Park, NY during winter. Models for large (>60mm diameter) American beech are not displayed, as the small sample size warranted an intercept only model. Only candidate models carrying >1% of cumulative model weight are displayed.

	Main Effects	Interactions	df	logLik	AICc	delta	weight
Small Maples	BD+S		4	-15.11	42.21	0.00	0.39
	BD		3	-18.36	44.89	2.68	0.10
	BD+S	BD x S	5	-14.37	45.40	3.19	0.08
	BD+D		4	-16.76	45.51	3.30	0.07
	E+BD+S		5	-14.79	46.25	4.04	0.05
	BD+D+S		5	-15.03	46.73	4.52	0.04
	BD+S+N		5	-15.10	46.88	4.66	0.04
	BD+N		4	-17.53	47.06	4.84	0.03
	BD+D+N		5	-15.22	47.11	4.90	0.03
	BD+N	BD x N	5	-15.58	47.83	5.62	0.02
	E+BD		4	-18.14	48.27	6.06	0.02
	BD+D	BD x D	5	-16.30	49.27	7.06	0.01
	S		3	-20.56	49.30	7.09	0.01
	E+BD+D+N		6	-13.41	49.31	7.10	0.01
Large Maples	Main Effects	Interactions	df	logLik	AICc	delta	weight
	E		3	-25.00	57.85	0.00	0.44
	E+BD		4	-24.53	60.39	2.54	0.12
	E+N		4	-24.94	61.21	3.36	0.08
	E+S		4	-24.99	61.31	3.46	0.08
	N		3	-26.86	61.56	3.71	0.07
			2	-28.86	62.58	4.73	0.04
	E+BD		5	-23.98	63.41	5.56	0.03
	BD		3	-27.94	63.72	5.87	0.02
	S		3	-28.00	63.85	6.00	0.02
	BD+N		4	-26.47	64.28	6.43	0.02
	E+BD+N		5	-24.52	64.49	6.64	0.02
	E+BD+S		5	-24.52	64.49	6.64	0.02
	S+N		4	-26.75	64.84	6.99	0.01
E+S+N		5	-24.93	65.32	7.47	0.01	
Striped Maple	Main Effects	Interactions	df	logLik	AICc	delta	weight
	BD+D	BD x D	5	-18.85	53.70	0.00	0.47
	BD+BD2+D	BD x D	6	-17.60	56.53	2.83	0.11
	BD+BD2+D	BD2 x D	6	-17.60	56.54	2.84	0.11

	BD+D+S	BD x D	6	-18.64	58.60	4.91	0.04
	BD2+D+S	BD2 x D	6	-19.28	59.90	6.20	0.02
	Main Effects	Interactions	df	logLik	AICc	delta	weight
		CC x BD+CC x					
	CC+BD+BD2	BD2	7	-34.00	87.90	0.00	0.17
	CC+BD+BD2	CC x BD	6	-36.43	89.06	1.16	0.09
	CC+BD+BD2+S	BD x S	7	-35.04	89.98	2.08	0.06
	CC+BD+BD2+D	CC x BD	7	-35.63	91.15	3.25	0.03
	CC+BD+BD2+S	BD2 x S	7	-35.65	91.19	3.29	0.03
		CC x BD+CC x					
	CC+E+BD+BD2	BD2	8	-33.62	91.24	3.34	0.03
	CC+BD+BD2	CC x BD2	6	-37.53	91.26	3.36	0.03
		CC x BD+CC x					
	CC+BD+BD2+D	BD2	8	-33.70	91.40	3.50	0.03
		CC x BD+CC x					
Birches	CC+BD+BD2+N	BD2	8	-33.70	91.41	3.51	0.03
	BD+BD2+S	BD x S	6	-37.82	91.85	3.95	0.02
		CC x BD+CC x					
	CC+BD+BD2+S	BD2	8	-33.95	91.90	4.00	0.02
	BD+BD2+S	BD2 x S	6	-38.12	92.44	4.54	0.02
	CC+BD+BD2+N	CC x BD	7	-36.29	92.47	4.57	0.02
	CC+BD+BD2+S	CC x BD	7	-36.36	92.61	4.71	0.02
	CC+E+BD+BD2	CC x BD	7	-36.43	92.74	4.84	0.01
	CC+BD+BD2+D+S	BD x S	8	-34.41	92.82	4.92	0.01
		CC x BD+BD2					
	CC+BD+BD2+D	x D	8	-34.42	92.84	4.93	0.01
		BD x S+BD2 x					
	CC+BD+BD2+S	S	8	-34.46	92.92	5.02	0.01
	CC+BD+BD2+S+N	BD x S	8	-34.51	93.01	5.11	0.01
CC+BD+BD2+D	CC x BD2	7	-36.70	93.30	5.40	0.01	
	Main Effects	Interactions	df	logLik	AICc	delta	weight
Hobblebush	V		3	-7.68	22.95	0.00	0.13
	CC+E	CC x V	6	-2.79	24.57	1.62	0.06
	CC+E+V2	CC x V	7	-0.52	25.23	2.28	0.04
	H		4	-7.20	25.25	2.30	0.04
	E		4	-7.26	25.37	2.42	0.04
	E+V2		5	-5.38	25.38	2.43	0.04
	CC		4	-7.30	25.45	2.50	0.04
	D		4	-7.44	25.74	2.79	0.03
	CC	CC x V	5	-5.60	25.82	2.87	0.03
	CC+V2	CC x V	6	-3.65	26.31	3.35	0.03
	H+V2		5	-5.85	26.31	3.36	0.03
	V2+D		5	-5.99	26.59	3.64	0.02
	E+H		5	-5.99	26.60	3.65	0.02

			6	-4.22	27.44	4.49	0.01
		CC x V2	6	-4.30	27.59	4.64	0.01
			6	-4.46	27.93	4.98	0.01
		Main Effects					
		Interactions	df	logLik	AICc	delta	weight
			4	-12.05	34.60	0.00	0.33
			5	-11.32	36.63	2.04	0.12
			5	-11.45	36.91	2.31	0.10
			5	-11.82	37.65	3.05	0.07
			5	-12.04	38.07	3.48	0.06
			6	-10.83	39.67	5.07	0.03
Aspens		BD2 x D	6	-10.89	39.79	5.19	0.02
		BD x D	6	-11.16	40.32	5.72	0.02
			6	-11.21	40.41	5.82	0.02
			6	-11.23	40.46	5.86	0.02
			6	-11.28	40.56	5.97	0.02
			6	-11.31	40.63	6.03	0.02
			6	-11.35	40.69	6.10	0.02
		BD x S	6	-11.35	40.69	6.10	0.02
		BD2 x S	6	-11.35	40.69	6.10	0.02
		Main Effects					
		Interactions	df	logLik	AICc	delta	weight
			5	-34.04	81.41	0.00	0.15
			6	-32.76	82.46	1.05	0.09
			6	-32.88	82.69	1.28	0.08
			8	-28.80	83.21	1.79	0.06
		CC x BD2	6	-33.67	84.28	2.87	0.04
			7	-31.65	84.31	2.89	0.04
			7	-31.67	84.35	2.93	0.03
			6	-33.82	84.57	3.16	0.03
			6	-33.87	84.69	3.27	0.03
			6	-33.98	84.90	3.48	0.03
Cherries			7	-32.23	85.46	4.05	0.02
			7	-32.27	85.54	4.12	0.02
			7	-32.45	85.90	4.49	0.02
			7	-32.51	86.02	4.60	0.01
			7	-32.53	86.05	4.64	0.01
			8	-30.36	86.32	4.90	0.01
			7	-32.81	86.62	5.20	0.01
			7	-32.83	86.66	5.24	0.01
			7	-32.84	86.67	5.26	0.01
			7	-32.86	86.72	5.31	0.01
			7	-32.87	86.74	5.33	0.01
		Main Effects					
Northern Wild Raisin		Interactions	df	logLik	AICc	delta	weight
			5	-5.57	25.15	0.00	0.20

E+V+N		5	-6.58	27.15	2.01	0.07
CC+E+V		5	-6.85	27.71	2.56	0.06
E+V+S	E x V	6	-5.02	28.03	2.89	0.05
CC+V		4	-8.83	28.16	3.01	0.04
CC+E+V+S		6	-5.14	28.28	3.13	0.04
E+V+S	V x S	6	-5.18	28.37	3.22	0.04
E+V+S+N		6	-5.46	28.92	3.77	0.03
E+V	E x V	5	-7.64	29.27	4.13	0.03
CC+V	CC x V	5	-7.71	29.42	4.27	0.02
CC+E+V+N		6	-5.80	29.60	4.46	0.02
CC+V+S		5	-7.90	29.81	4.66	0.02
E+V+N	E x V	6	-5.91	29.82	4.68	0.02
V+S+N	V x N	6	-6.04	30.09	4.94	0.02
V		3	-11.41	30.22	5.08	0.02
V+S		4	-9.90	30.30	5.16	0.02
CC+E+V	CC x V	6	-6.30	30.60	5.46	0.01
E+V+N	E x V+V x N	7	-4.13	30.87	5.73	0.01
Main Effects						
Interactions		df	logLik	AICc	delta	weight
BD+S		4	-8.914	35.8	0	0.14
S		3	-12.83	36.5	0.64	0.1
Intercept		2	-15.5	37	1.17	0.08
CC		3	-13.11	37	1.2	0.08
BD+CC		4	-10.04	38.1	2.25	0.05
BD		3	-14.1	39	3.17	0.03
D		3	-15.19	41.2	5.35	0.01

Small Beech

Samuel Peterson

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EDUCATION

State University of New York- Environmental Science and Forestry, Class of 2018, Syracuse, NY

- *Masters of Science: Fish & Wildlife Biology and Management (In progress)*
- *Thesis: Diet selection and nutritional carrying capacity for moose in Adirondack Park, NY.*

Colorado State University, Class of 2015, Fort Collins, CO

- *Bachelor of Science in Fish, Wildlife, & Conservation Biology*
- *University Honors Program*
- *GPA: 3.45*
- *GRE (Colorado State University, 2015)*
 - *Quantitative: 158*
 - *Verbal Reasoning: 157*
 - *Analytical Writing: 3.5*

FIELD EXPERIENCE

Research Foundation for SUNY: Research Project Assistant

January 2016-Current

Syracuse, NY

- Conduct vegetation sampling in Adirondack Park to determine nutritional carrying capacity of moose
- Supervise a 3 person field crew during both summer and winter field seasons
- Develop sampling protocols and train technicians for data collection
- Organize project logistics such as housing, transportation, equipment and property access
- Perform data analysis (linear mixed models, resource selection functions) on vegetation and location data using R, Excel and ArcMap
- Assist with walk-in surveys of 15-20 moose to determine calving status and body condition
- Conduct distance sampling by helicopter to collect data for abundance models for moose and deer
- Maintain a positive public image through frequent presentations and daily interactions with hunters, timber companies and the general public

State University of New York: Teaching Assistant for Applied Wildlife Science

January 2017-May 2017

Syracuse, NY

- Instruct a weekly 3 hour computer lab for 34 undergraduate students
- Prepare and deliver presentations on wildlife research techniques such as telemetry, camera trapping, mark recapture, distance sampling, occupancy, matrix population models, and population viability analysis
- Demonstrate data analysis using programs like Mark, Presence, Distance and Excel
- Critique scientific writing pieces submitted by students

Colorado Parks and Wildlife: Wildlife Technician

August 2015-December 2015

Fort Collins, CO

- Tracked over 60 collared chukar partridge over rugged terrain in the Poudre Canyon using radio telemetry
- Recovered dropped collars or deceased individuals and investigate cause of death
- Directed actions of volunteers and interns assisting with project
- Designed data sheets and maintain electronic log of data in Excel
- Conducted aerial surveys for collars to locate mortalities and live individuals
- Assisted with capture and handling of moose both on the ground and as an aerial spotter

Colorado Parks and Wildlife: Wildlife Intern

April 2015- July 2015

Fort Collins, CO

- Tracked over 60 collared moose in Northern Colorado using ATS digital and hand held telemetry equipment
- Recovered deceased animals and investigated cause of death or predator species using available evidence

- Managed and designed data sheets and Excel documents to keep organized records
- Hiked long distances in variable weather on a daily basis

APHIS National Wildlife Research Center: Student Lab Assistant

September 2014- March 2015

Fort Collins, CO

- Analyzed videos and photos collected from camera traps to investigate coyote behavior
- Sorted coyote scat and hair samples

Colorado Parks and Wildlife: Telemetry Intern

September 2014- December 2014

Fort Collins, CO

- Tracked collared chukar partridge using handheld/aerial telemetry devices and GPS devices through rough terrain in all weather conditions in the Cache La Poudre Canyon
- Recorded data about field mortalities of chukar in an organized manner
- Exposed to culture and inner-workings of Colorado Parks and Wildlife

Colorado State University: Mid-Career Training, Indian Forest Service

July 2014-August 2014

Fort Collins, CO

- Worked with scheduling and logistics to host 30 officers from the Indian Forest Service
- Interacted with guests to provide them with an educational experience in Colorado

The Nature Conservancy: Land Stewardship Intern

May 2014-July 2014

Phantom Canyon Preserve, Livermore, CO

- Conducted surveys of multiple species of rare plants around the preserve
- Completed maintenance tasks including invasive plant removal and trail work
- Interacted with guests to provide a pleasant preserve visit
- Led and coordinated volunteer crews on the preserve

The Wildlife Society Camera Committee

Fall 2013-May 2014

Fort Collins, CO

- Worked with CSU students and professors to collect, classify and organize photos from cameras placed in Pineridge Natural Area near Fort Collins
- Assisted middle school students with projects incorporating our data and teach them about food webs and habitat use
- Managed remote cameras to study the release of Black Footed Ferrets on Soapstone Natural Area

Bobcat Ridge Natural Area Camera Study: CSU Honors Thesis

Fall 2013-December

2014

Fort Collins, CO

- Worked with cameras and data compiled by Fort Collins Natural Areas and the Rocky Mountain Cat Conservancy
- Analyzed circadian cycles of black bears and mule deer in the presence of humans versus in their absence
- Presented current work to FC Natural Areas employees in May 2014, Fort Collins Museum of Discovery in August 2014

PROFESSIONAL PRESENTATIONS

Onondaga Audobon Society

February 2018

- Title: Natural History and Current Status of Moose in New York
- Syracuse, NY

51st North American Moose Conference

September 2017

- Title: Estimating the nutritional carrying capacity of moose in Adirondack Park, NY
- Ingonish, Nova Scotia

- Huntington Lecture Series: Adirondack Ecological Center** *July 2017*
- Title: Natural History and Current Status of Moose in New York
 - Newcomb, NY
- SUNY-ESF Society for Conservation Biology Student Chapter** *April 2017*
- Title: Food-Based Carrying Capacity of Moose in New York
 - Syracuse, NY
- NYS-DEC Big Game Team Meeting** *March 2017*
- Title: Food-Based Carrying Capacity of Moose in New York
 - Albany, NY
- New York State Chapter of The Wildlife Society Annual Conference** *March 2017*
- Title: Habitat-Based Carrying Capacity of Moose in New York
 - Hamilton, NY
- SUNY-ESF Student Chapter of The Wildlife Society Annual Conference** *March 2017*
- Title: Habitat-Based Carrying Capacity of Moose in New York
 - Syracuse, NY
- The Wildlife Society 23rd Annual Conference** *October 2016*
- Poster: Carrying Capacity for Moose in Adirondack Park, NY
 - Raleigh, NC
- American Wildlife Conservation Foundation** *June 2016*
- Title: Status of Moose in New York
 - DeWitt, NY
- Federated Sportsmen's Clubs of Oneida County Banquet** *April 2016*
- Title: Status of Moose in New York
 - New York Mills, NY
- Colorado State University Student Chapter of The Wildlife Society** *December 2015*
- Bighorn Sheep Counts in the Poudre Canyon
 - Presented with Mark Vieira (Colorado Parks and Wildlife)
- Celebrating Undergraduate Research Symposium** *April 2015*
- Poster: How do we affect wildlife? An analysis of human/wildlife interactions through recreation.
 - Awarded College Honors Award
- Celebrating Undergraduate Research Symposium** *April 2014*
- Poster (Co-author): Colorado State University Wildlife Camera Educational Outreach with Boltz Middle School
 - Awarded 2nd place in Service and Learning Category
- Colorado Chapter of The Wildlife Society State Meeting** *February 2014*
- Poster (Co-author): Colorado State University Wildlife Camera Educational Outreach with Boltz Middle School

GRANTS, HONORS AND AWARDS

- SUNY-ESF Graduate Student Association Travel Grant** *May 2017*
- State University of New York- Environmental Science and Forestry

- SUNY-ESF Graduate Student Association Research Grant** *April 2017*
- State University of New York- Environmental Science and Forestry
- Charles Lathrop Pack Memorial Award - Travel Grant** *October 2016*
- State University of New York- Environmental Science and Forestry
- American Wildlife Conservation Foundation Research Grant** *September 2016*
- Tuition Scholarship Award** *January 2016*
- State University of New York- Environmental Science and Forestry
- Jim Olterman Outstanding Undergraduate Scholarship** *February 2015*
- Colorado Chapter of the Wildlife Society State Meeting
- Green and Gold Scholarship** *August 2011-May 2015*
- Colorado State University
- Honors Scholarship** *August 2011- May 2015*
- Colorado State University Honors Program
- Donald G. Lauridson Memorial Scholarship** *August 2011*
- Colorado State University- Warner College of Natural Resources
- Douglas County 4-H Council Scholarship** *August 2011*
- Douglas County 4-H, Castle Rock, Colorado
- Stuart Mazanec Memorial Scholarship** *August 2011*
- Douglas County 4-H, Castle Rock, Colorado

ACADEMIC EXPERIENCE

- Quantitative Methods and Models Using R** *Fall 2017*
- Discussed frequentist and Bayesian approaches to ecological modelling
 - Developed code in R to explore different stochastic distributions and deterministic functions, simulate data for power analyses and complete model selection using likelihood analysis
- Population Parameter Estimation in R** *Fall 2017*
- Studied classic and modern models for estimating vital population parameters such as Cormack-Jolly-Seber models, multi-state models, Pradel models, robust design and occupancy analysis
 - Developed models and interpreted model outputs in both program MARK and using the R-MARK package
 - Completed a Pradel analysis and Schwarz-Arnason analysis to determine the status and outlook of a population of piping plovers at Lake Diefenbaker, Saskatchewan
- Foraging Ecology** *Fall 2016*
- Discussed theories and hypotheses that drive foraging processes of both herbivores and carnivores
 - Studied how different factors such as information gathering, handling time, competition, risk evaluation, community dynamics and population dynamics affect foraging behaviors
- Regression Analysis** *Fall 2016*
- Discussed common processes used to analyze data in a linear regression framework such as basic linear regression, multiple linear regression, use of dummy variables, residual analysis, model transformation, and multicollinearity
 - Briefly discussed concepts associated with non-linear regression and linear mixed models
 - Practiced analyzing data using linear regression with SAS

Analysis of Variance and Statistical Design

Spring 2016

- Studied various statistical analysis approaches and assumptions including ANOVA
- Discussed implications of research design and various sampling techniques

Landscape Ecology

Spring 2016

- Studied basic metrics used to summarize the characteristics of a landscape
- Worked with various programs to study landscapes such as ArcGIS, FragStats and R
- Completed final project investigating what environmental factors influenced habitat use of moose in New York

Managing Human-Wildlife Conflicts

Spring 2015

- Exposed to common issues concerning human wildlife conflict, specifically as handled by USDA-APHIS
- Project leader: Management recommendation for the City of Fort Collins concerning prairie dog conflict
- Learned how to properly identify predator species based on evidence left on or near a carcass

Wildlife Data Collection and Analysis

Spring 2014

- Exposure to multiple data collection techniques including point counts and mark-recapture
- Built statistical models such as population growth models, age structure and occupancy models using R-Statistics, Presence and Mark
- Introduced to telemetry equipment and used equipment to track mammals on CSU campus

Natural Resource Ecology and Measurements

Summer 2013

- Conducted field measurements including vegetation plot analysis, forest density, line transects and electrofishing
- Completed analysis of mountain shrub, ponderosa pine, lodgepole pine, spruce-fir and alpine ecosystems
- Developed reports of ecosystems that included management recommendations
- Identified local mammals, birds, grasses, forbs and trees

Design of Fish and Wildlife Projects and Design

Fall 2013

- Practiced use of statistical processes including ANOVA, t-tests and regression
- Used Microsoft Excel to organize and analyze data
- Learned about experimental design and set up
- Developed a full proposal to study the impacts of natural gas development on black bears

Conservation and Management of Large Mammals

Fall 2013

- Participated in debates and discussions surrounding large mammal management today, including wolf reintroduction, bison management, pronghorn migration, elk management and culling, and human dimensions
- Attended field trip to Yellowstone National Park, interacted with park professionals to discuss issues mentioned above
- Gave presentation on interactions of large mammals with energy development across North America

Introduction to Biostatistics

Fall 2012

- Introduced to t-tests, binomial, multinomial and chi-square distributions
- Practiced analyzing datasets using various statistical techniques

CERTIFICATIONS AND RELEVANT SKILLS

- Safe Capture International: Chemical Immobilization of Animals (Feb. 2018)
- Colorado Parks and Wildlife Hunter Education Certificate
- New York State Waterfowl Hunter Education Certificate
- New York State Bowhunter Education Certificate
- Extensive experience conducting backcountry field work in various environments
- Intermediate skills in computer programming, specifically using program R
- Ability to retrieve, process, analyze and display various types of geospatial data using ArcMap and Google Earth
- Decade of experience with 4WD, ATV, heavy machinery and snowmobiles operating in all weather conditions