

Characteristics of Post-Parturition Areas of Moose and Effective Temperature of Cover
Types in Moose Home Ranges in Northeast Minnesota

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Chapter 1: Characteristics of Post-Parturition Areas of Moose in Northeast Minnesota

Overview

Habitat used in the 3-4 weeks after parturition could be important to calf survival. Newborn calves are vulnerable to predation, and the cow needs adequate forage reserves during the period when calf mobility is limited. VHF collared cows were located by helicopters up to 3 weeks after parturition. A post-parturition area was defined as 100 ha surrounding the cow/calf location. We determined cover type composition in post-parturition areas compared to the 95% kernel home ranges of moose. Buffers of 5, 10, 25 and 50 ha were created around post-parturition areas to determine cover type composition at smaller spatial scales. Post-parturition areas were also compared to equivalent areas surrounding cows without calves. Fidelity was measured by comparing distances between consecutive post-parturition locations to distances to random locations distributed within the home ranges. Post-parturition sites had more lowland conifer and shrubland or regenerating/young forest cover types than random locations within the home range. Cows with calves selected areas with larger proportions of lowland conifer, shrublands and regenerating forests than did cows without calves. These cover types could have been used for cover and for foraging, respectively. There was no difference in the amount of water available in post-parturition areas when compared to home ranges ($3.5\% \pm 0.8$). Distances between consecutive post-parturition locations (1.7 ± 0.4 km) were less than expected when compared to distances to random points within the home ranges (3.3 ± 0.4 km), indicating cows may exhibit a degree of fidelity to post-parturition areas.

Introduction

Most calving site studies have been conducted by searching for parturition sites 3-4 days after a moose (*Alces alces*) calf is born (Bowyer et al. 1999, Langley and Pletscher 1994, Leptich and Gilbert 1986). Identifying parturition sites is important, yet calf mobility is limited for the first 3-4 weeks after birth (Altmann 1958, 1963). Cows are choosing an area within their home range which the cow/calf pair will live for 3-4 weeks when they choose a parturition site. This post-parturition area is important to identify because it is used during the period when calves are most vulnerable and the calf must survive to be recruited into the adult population. Identifying habitat characteristics of the post-parturition area for moose in northeast Minnesota may be of importance in a population in which recruitment rates are currently declining.

Cow moose give birth at sites that provide some hiding cover but do not have the highest quality or quantity of forage available (Bowyer et al. 1999, Langley and Pletscher 1994, Leptich and Gilbert 1986). This is often interpreted as a trade-off between avoiding predators and meeting nutritional requirements (Bowyer et al. 1999), and may be important to consider as influencing choice of calving habitat in Minnesota where black bear (*Ursus americanus*) and wolves (*Canis lupus*) are present.

The variability in vegetative cover and density, visibility, and proximity to water has made describing calving sites difficult (Addison et al. 1990). Moose have been reported to give birth on hill tops in Quebec and Ontario (Chekchak et al. 1998, Wilton and Garner 1991) and swim to islands for parturition (Addison et al. 1993). Undisturbed

lowland areas dominated by cedar and near water were important for calving in Maine (Leptich and Gilbert 1986), as were areas with mature, mixed, and coniferous forests when water and islands were not available in New Hampshire (Scarpitti et al. 2007).

This boreal forest mix is the matrix from which moose in northeast Minnesota choose a parturition location. Important home range habitat types for moose are young mixed conifer and deciduous forests, including aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and fir (*Abies balsamea*). Early successional forests 11-30 years post disturbance are used because forage is within reach of moose (Kelsall et al. 1977). Summer ranges consist largely of black spruce lowlands and upland and cut over areas dominated by white birch, aspen, and balsam fir (Peek et al. 1976). In early summer, moose generally use upland, lowland, and plantation areas in proportion to their occurrence (Peek et al. 1976). Calving begins in northeast Minnesota and Ontario around May 10, with peak calving occurring sometime during the following three weeks (Addison et al. 1993, Bowyer et al. 1998a, Lenarz et al. 2005). The parturition site was unknown because helicopter searches were done 1-3 weeks after calving. Because cows restrict movement after giving birth (Poole et al. 2007), we assumed the parturition site was near the post-parturition location of the cow and calf. We defined post-parturition areas as 100 ha (565 m radius) surrounding the post-parturition location (Poole et al. 2007).

If parturition sites are chosen from within a cow's home range, limits are set on where a calf can be born, and the availability of suitable habitat for parturition could become important. Characteristics of this larger area used by the cow-calf pair for the

next few weeks have not been studied in detail. The objective of this study was to 1) identify extended post-parturition habitat and 2) determine post-parturition site fidelity of 36 VHF collared cow moose in northeastern Minnesota.

Study area

Lake and Cook counties (47°30'N, 91°21'W) in the Arrowhead Region of northeastern Minnesota are part of the Northern Superior Uplands (Figure 1) (MN DNR 2010). The southern boundary of the Northern Superior Uplands coincides with the boundaries of the Canadian Shield as it extends into Minnesota. Upland vegetation consists of fire-dependent forests dominated by a mix of white and red pine (*Pinus strobus* and *P. resinosa*), aspen, paper birch, white spruce (*Picea glauca*), balsam fir and white cedar (*Thuja occidentalis*). Jack pine (*Pinus banksiana*) stands and conifer swamps of tamarack (*Larix laricina*) and black spruce (*Picea mariana*) are also present.

Home ranges of radio collared cows were about 40 (± 5 km²) and included one or more of three subsections of ecological land classification within the Northern Superior Uplands (MN DNR 2010). The Highland Moraine subsection is found along Lake Superior and has gently rolling and steep terrain. Climate is moderated by the lake and major land uses are forest management and recreation. The Toimi Uplands are found on the western border of the Highland Moraine and south of the Laurentian Uplands, and are dominated by drumlin fields with a rolling topography. The area is largely forested and under public ownership with timber production being the most common land use. The Laurentian Uplands are till and outwash plains where the most common tree species is aspen. Much of the land is managed for timber production and recreation.

Northeast Minnesota has a humid continental climate with severe winters and short dry summers. Precipitation occurs in the form of snowfall (180 cm annually), with snow cover typically present from December through April, and rainfall (70 cm annually), 40% of which occurs during the growing season.

Methods

Adult female moose were captured beginning in February 2002 and fitted with VHF radio collars (Lenarz et al. 2009). Radio collared moose were monitored weekly for mortality from February 2002 through March 2008. 95% kernel home ranges were calculated for 36 of the collared cows based on locations from weekly radio-telemetry flights (Moen *unpub. data*). Average home range size of radio collared cows in this study was $40 \pm 5 \text{ km}^2$ ($\bar{X} \pm \text{SE}$), ranging from 8 km² to 312 km².

Helicopter flights were used to locate cows with calves from 2004-2008 and radio collared cows were visually located in late May each year. Cows not seen during the first attempt were relocated the following week. The waypoint taken when a calf or calves were seen was the post-parturition location. The position error of cow/calf locations is estimated to be about 100 m (Mike Schrage, *unpub. data*). If calves were not seen with cows it was assumed that either the cow did not give birth or the calves were already lost (Lenarz 2010).

Post-parturition habitat composition

We first identified habitat characteristics of post-parturition areas and then tested with ANOVA for variability of cover type composition near the post-parturition area at the 100 ha scale by generating 16 additional points within the defined area. The 16

points radiated from the center of the known cow/calf location at 90° angles and 100 m intervals within the post-parturition area. These 16 points were also buffered to 100 ha.

To compare cover type composition of post-parturition areas to the home range, 25 random points were generated within each 95% kernel home range using ArcView 3.3. Buffers of 100 ha were applied to each random point and represented potential post-parturition areas. To test whether cows with calves selected for post-parturition cover type characteristics at finer spatial scales, buffers of 50, 25, 10, and 5 ha were also created around all points and locations and each set of random points were compared to the cover type composition within post-parturition areas with ANOVAs. The estimated position error was used to set the smallest buffer size for characterizing cover type composition to 5 ha (126 m radius).

We also estimated cover type composition of post-parturition areas for all instances when cows were observed without calves during May helicopter flights. The group of cows without calves was further divided into cows that were never seen with calves and cows seen with calves in some years and not seen with calves in other years. Locations of cows without calves during the May helicopter flights and random locations within those respective 95% kernel home ranges were examined at the same spatial scales as those of cows with calves and differences in cover type composition were determined using ANOVA and χ^2 .

Cover types of post-parturition areas were identified within the home ranges of cows using two independent satellite imagery classification systems; the Gap Analysis Program (GAP), Level II and the Land Use Land Cover (LULC) classification system.

Both are raster datasets derived from LANDSAT Thematic Mapper (TM) images with 30 m resolution (Minnesota Department of Natural Resources [MNDNR] 2007*b*). GAP Level II classifies 10 different cover types while LULC defines 16. We used the two coverage datasets available in Minnesota that had the highest accuracy and similar land cover classifications. The GAP coverage data was collected in 1991-1993 while LULC was collected from 1995-1996. Because of the amount of time between when the two coverages were classified and because both GAP and LULC have similar cover type classifications it was important to check for consistency between the two available datasets.

Water presence

We measured lakes, rivers and streams, beaver ponds, and other available water within the 100 ha area surrounding each location on screen using Farm Service Administration (FSA) color orthophotos from 2003-2004. The FSA photos were used because the land cover data did not include fine scale water features that may have been of importance to moose. Water bodies were classified as lakes, rivers and streams, beaver ponds, and other water. 200 points were randomly distributed across the spatial extent of the cumulative home ranges of all cows. Water within 100 ha surrounding each random point was used to estimate overall water availability within the study area. Water type and availability within the post-parturition areas were also compared to water type and availability within 100 ha around locations of cows without calves using t-tests.

Post-parturition location fidelity

We compared distance between consecutive post-parturition locations to the distance from post-parturition location to 30 random points within the home range to test whether consecutive post-parturition locations were closer together than would be expected of a random distribution. If cows showed fidelity for the same post-parturition location, the distance between consecutive post-parturition locations would be less than distances from parturition site to the 30 random points.

Statistics

Cover types within the post-parturition areas and within home ranges at different buffer sizes were compared with ANOVA and linear regression using Statistix (version 9.0; Analytical Software, Boca Raton, FL). Post-parturition areas of cows with calves were also compared to areas surrounding the location of cows without calves using a χ^2 test for independence. The amount of different water types were compared using ANOVAs. Differences in percent water type available between post-parturition areas and random areas were compared with *t*-tests. Means are presented throughout as $\bar{x} \pm SE$. We used Excel 2007 (Microsoft Corp., Redmond, WA) for *t*-tests and χ^2 tests.

Results

Cover type composition

The 100 ha post-parturition area we defined covered $4 \pm 6\%$ of the average home range. In both the GAP and the LULC 4 cover types comprised $> 90\% \pm 7$ of the area within home ranges (Table 1). GAP cover type categories covering $> 90\%$ of the area included lowland conifer, shrublands, upland conifer, and upland deciduous forests. In LULC the

4 cover types covering > 90% of the area were conifer and mixed forests, regenerating/young forests, and bog (Fig. 2).

All 70 post-parturition locations were within the 95% kernel home ranges of the cows. Cows with calves selected areas with more lowland conifer and shrublands (GAP), or conifer and regenerating/young forests (LULC) than cows without calves at all spatial scales ($\chi^2 > 5.9, p < 0.004$). This trend became more apparent as post-parturition areas were decreased. Cows without calves had less lowland conifer and shrublands and more upland conifer and deciduous in the GAP coverage. Cows without calves had more conifer and regenerating/young forests and less mixed forest and bog in the LULC coverage.

Cover type composition did not change as areas surrounding post-parturition and random locations were decreased incrementally from 100 ha to 5 ha ($F_{2, 70} < 0.7, p \geq 0.69$). Lowland conifer was about 22% of the area in the random locations and throughout home ranges compared to 24-30% of the post-parturition areas in the GAP coverage (Fig. 3a). Similarly, in the LULC conifer was about 18% of the area in random locations compared to 17-21% of the post-parturition areas (Fig. 3b). Mean area of lowland conifer increased as post-parturition areas decreased from 100 ha to 5 ha, but differences were not significant because of high variability among cows. The contrast between random locations and post-parturition locations suggests that some non-random actions were occurring associated with the lowland conifer cover type. Upland deciduous forest may be negatively correlated with lowland conifer ($p > 0.051, n = 70$) however, the increase in lowland conifer ($R^2 = 0.006, p = 0.12$) and subsequent decrease in upland

deciduous ($R^2 = 0.0014$, $p = 0.48$) were not significant as buffer size was decreased (Fig. 4).

We divided cows with calves into three groups based on lowland conifer present within post-parturition areas compared to lowland conifer within home ranges (Fig. 5). The three groups were defined based on whether lowland conifer in the post-parturition area was above, within, or below the 95% confidence interval of the random potential post-parturition areas within the home range of each cow. The variability among groups indicates why we found no significant differences in mean value of lowland conifer between random and post-parturition areas. Within the group with higher than expected lowland conifer in the post-parturition area (41% of cows) there was a subgroup (5 of 29) with $> 80\%$ lowland conifer in the post-parturition area while home ranges had about 20% lowland conifer available. If lowland conifer was important at the 5 ha level and we assumed those cow/calf pairs using lowland conifer in much greater proportion to availability were representative of the youngest calves, about 6% (LULC) or 8% (GAP) of the study area could be important post-parturition habitat. However, when 5 ha areas across all home ranges consisting of $> 75\%$ lowland conifer were buffered to the 100 ha level, 79% of parturition locations were within what could be considered suitable post-parturition habitat (Fig. 6).

Water

The amount of aquatic cover types in post-parturition areas did not differ from the amount of aquatic cover types in random areas distributed across the study area (Fig. 7). Lakes, rivers and streams, beaver ponds, or other water were present in 80% of post-

parturition areas, 60% of random areas, and 70% of areas surrounding cows without calves. Water covered about $3.5 \pm 0.8\%$ ($\bar{x} \pm \text{SE}$) of the area within 200 100 ha areas randomly distributed throughout the spatial extent of all home ranges. This was the same as the $3.5 \pm 0.8\%$ water measured within 100 ha post-parturition areas. Cows without calves had half as much water within 100 ha ($1.6 \pm 0.5\%$); the largest difference being the absence of lakes. Post-parturition areas and random areas consisted of approximately $2.5 \pm 0.8\%$ lakes, while areas around cows without calves were only about $1.5 \pm 0.3\%$ lakes. Beaver ponds were present in 27% of 100 ha post-parturition areas, 18% of 100 ha random areas, and 37% of 100 ha areas surrounding cows without calves. Beaver ponds are present more often in areas surrounding cows without calves than in random areas ($\chi^2 = 8.48$ $p = 0.0036$).

Post-parturition site fidelity

Of 36 radio collared cow moose observed with calves, 23 gave birth in 2 or more years, resulting in 34 paired parturition events. Post-parturition locations in consecutive years were closer to each other than distances from the post-parturition location to random locations in the home range (Observed: 1.7 ± 0.4 km, $n=34$, Random: 3.3 ± 0.4 km, $n=34$) (Fig. 8). Minimum distance between consecutive post-parturition locations was 39 m and maximum distance was 4,333 m. Many post-parturition locations (34%) were within 1 km and 60% were within 2 km of the previous year's post-parturition location. Distances between post-parturition locations among cows remained small while distances between post-parturition locations and random locations increased as home range size increased.

Discussion

Because VHF collared cows were only located one or two times each May, we cannot be certain the individual cows had not already given birth and lost the calf, that the calf was present and not observed, or that the cow had not yet given birth. We found high variability among cows in use of cover types immediately after calving, which is consistent with previous parturition site studies. Despite the high variability, we identified trends in cover type use among cows with calves, cows without calves, and random locations. Post-parturition areas had more lowland conifer and shrubby areas present than areas used by cows without calves at all spatial scales. Lowland conifer would likely provide hiding cover that has been found to be important in other regions with predators (Bowyer et al. 1999, Stringham 1974, Leptich and Gilbert 1986, Langley and Pletscher 1994). Potential predators present in northeast Minnesota are black bear and wolves. Other cover types probably provide more forage and could be used more by cows without calves that do not have to rely on hiding cover to protect calves.

Defining and identifying specific characteristics associated with a post-parturition area in addition to identifying the parturition location is important because the area near the parturition site must support the presence of the cow/calf pair for up to 3 weeks. Cows with calves use 1-4% of the home range for 5-10% of the year because calf mobility limits movement. We used a post-parturition area of 100 ha around the calf/cow location to compensate for not knowing the actual parturition location. Using this definition of post-parturition area, cows were variable in cover type use. Yet lowland conifer tended to increase at smaller spatial scales compared to random locations.

Factors contributing to variability observed among cows were that we did not know the age of calves or how cow/calf movements changed within the first 3 weeks post-parturition.

We could speculate that the cow/calf pairs found in areas with >75% lowland conifer during the first week of search flights had just given birth and chose lowland conifer as a parturition site. When we identified areas with high levels of lowland conifer across the home ranges and then increased the area surrounding those patches to 100 ha, most post-parturition locations were within potential suitable habitat. If lowland conifer is used for post-parturition habitat, then post-parturition habitat may not be limiting within home ranges of cows in northeast Minnesota. However because >90% of cow/calf pairs were found during the first week of flights and we do not know parturition dates of individuals, this was a weak test of parturition cover type selection. If cow/calf pairs had been relocated during the second week of flights a stronger test of cover type selection against cow/calf use would have been possible.

Reports from observers in the helicopter indicated association of cow/calf pairs with beaver ponds during May post-parturition flights. The amount of water in defined post-parturition areas, in simulated post-parturition areas and in 100 ha buffers around cows without calves was relatively low (generally <3.5%). While many parturition studies reference water near the parturition site, the spatial data available were not at a scale to represent the small water features that may be important and we did not know if 1-3 week old calves were at the parturition site. While moose have used islands as calving sites in other areas (Peterson 1955, Bailey and Bangs 1980, Stephens and Peterson 1984,

Addison et al. 1990, Wilton and Garner 1991), no cow/calf pairs were located on islands during this study.

Calving site fidelity has been defined in calving studies as repeated annual use of calving areas on islands in Algonquin Provincial Park in Ontario (Addison et al. 1990). Islands in lakes would be extreme cases, and because of their relatively small size would result in small distances between consecutive calving locations. Cows in managed forests following Moose Habitat Guidelines in Ontario had higher degrees of parturition site fidelity (< 3 km between consecutive parturition sites) relative to progressively clear-cut forests (4.87 km). 25% of cows ($n = 35$) used parturition sites within 1 km of the site used the previous year (Welch et al. 2000). Using similar criteria for fidelity for our consecutive post-parturition locations we found 60% of cows were within 2 km of the previous year's location and 34% were within 1 km. Even with potential movements of cows away from parturition sites in the weeks following parturition, we were still able to detect post-parturition location fidelity within home ranges.

Study limitations

Though the use of VHF collars and a single helicopter flight location precluded knowing movements of the cow and calves over time, it did allow us to identify at a coarse level which habitat types may be of importance after calving within the home ranges of moose in northeast Minnesota. Helicopter flights to visually observe VHF collared cows occurred after peak calving to ensure most calves were counted. However, some cows may have given birth earlier in May than others, probably introducing some of the variability observed in cover type composition and presence of water.

There was also position error in the locations of cow/calf pairs that had to be considered at times when the helicopter was flying over moving cow/calf pairs. When the cow/calf pairs were moving the locations were representative of where they were when the helicopter was close to overhead, and not necessarily of the locations where pairs were initially sighted. There were also times when the helicopter could not get directly over the cow/calf pair.

For this study we used the available data from the northeast Minnesota VHF project to determine post-parturition habitat use by cow-calf pairs, and this information can be taken into consideration for future management efforts. However, to determine more fine scale habitat selection, especially at the time of parturition, and restricted movement of cow-calf pairs throughout the post-parturition period, more precise measurement methods are needed. Focusing on cow movements and behaviors during parturition will make landscape use more apparent and important cover types will be more readily observable, allowing for more focused management goals for habitat enhancement and protection.

Management implications

Recent advancements of GPS technology leads us to recommend future parturition habitat projects be undertaken in which multiple locations of GPS collared cow moose are recorded for the duration of the pre- and post-parturition period (Welch et al 2000, Poole et al. 2007). This may enable identification of the parturition date, the parturition location, movement rates both before and after birth, and habitat use over time (Poole et al. 2007). Helicopter flights would still be helpful in continued monitoring for calf

presence and to obtain aerial photographs of parturition sites and surrounding areas to aid in habitat analysis. Because GPS locations would be available, cow/calf locations would be known and flights over parturition sites and surrounding areas could be flown at any time of year and would lead to a more efficient use of flight time. A parturition habitat project in conjunction with a calf predation study would provide a more comprehensive view of post-parturition behavior. Current low recruitment rates and the declining calf:cow ratio in northeast Minnesota (Lenarz et al. 2009, 2010) suggests such an approach could be of importance for management.

At this point the variability observed among cows indicates that the presence of multiple cover types in close proximity to one another may be an important characteristic of post-parturition areas in northeast Minnesota. The most common cover types within the home ranges were also important post-parturition habitat. This indicates that moose may conform to local conditions when selecting post-parturition areas. Lowland conifer and shrublands/young and regenerating forests are among the most common forest cover types, though they are less than mixed forests, within the home ranges of VHF collared cows. Cows likely use the most available cover types that provide an acceptable level of hiding cover and forage.

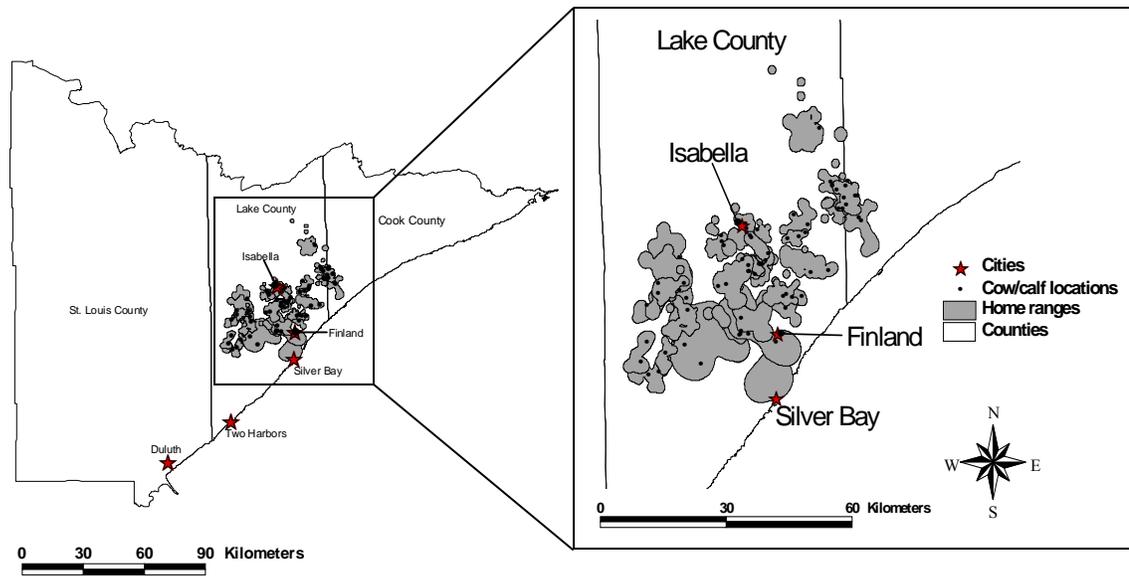


Figure 1.1. 95% kernel home ranges of VHF collared cows are outlined in black within the arrowhead region of northeast Minnesota. Dots indicate cow/calf locations from 2004-2008.

Table 1.1. Cover type composition of the 95% kernel home ranges of 36 VHF collared moose in Northeast Minnesota. Two independent Landsat satellite imagery data classified cover type differently but amount of corresponding cover types calculated using each was consistent.

GAP	% Home Range Cover	LULC	% Home Range Cover
Lowland Conifer	22 ±0.6	Lowland Conifer	18 ±0.5
Upland Conifer	13 ±0.4	Bog	17 ±0.7
Shrubland	19 ±0.5	Regenerating/ Young Forest	14 ±0.6
Upland Deciduous	42 ±0.8	Mixed Forest	42 ±0.8
Sum	96 ±2.6		91 ±7.0

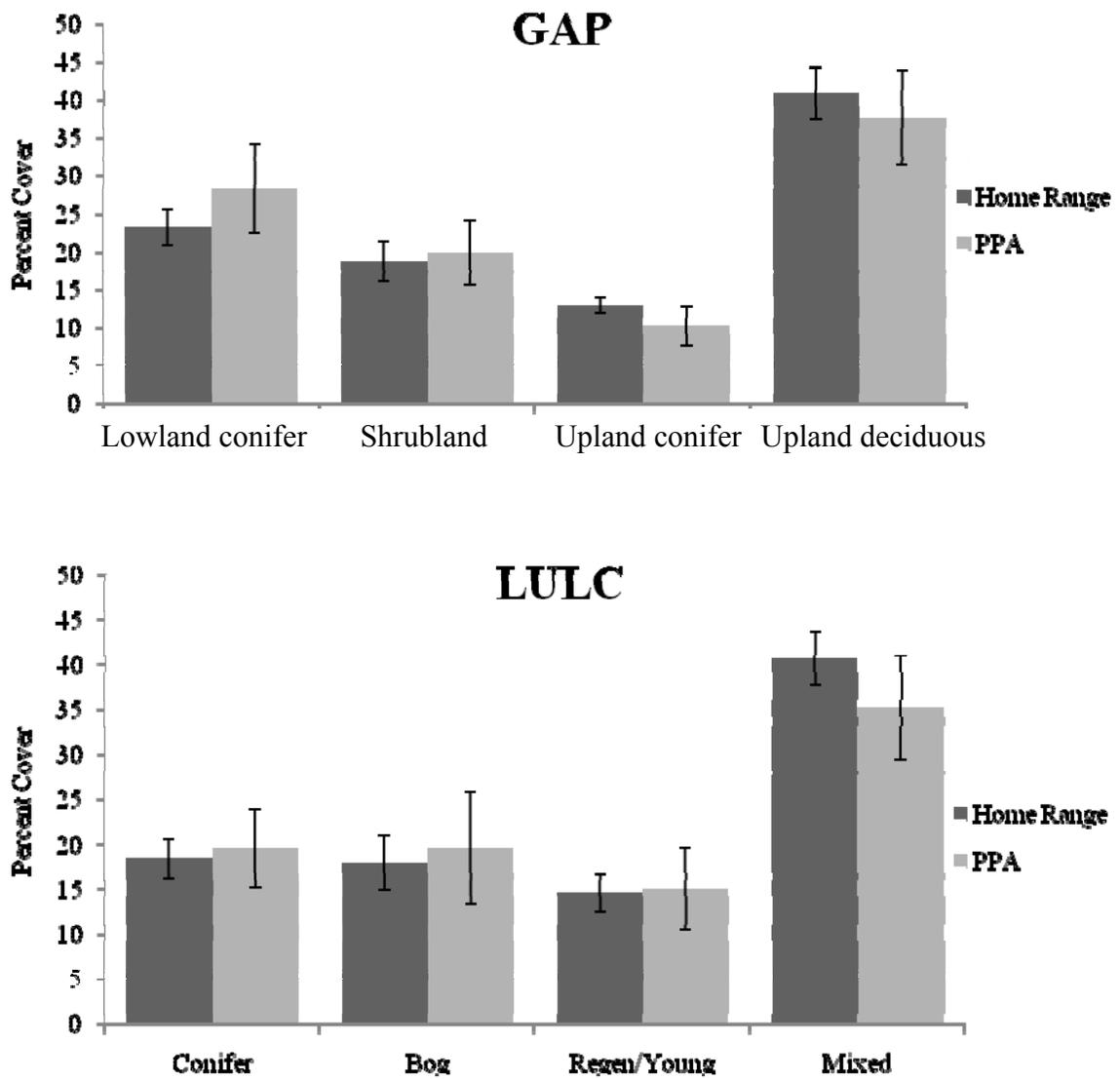
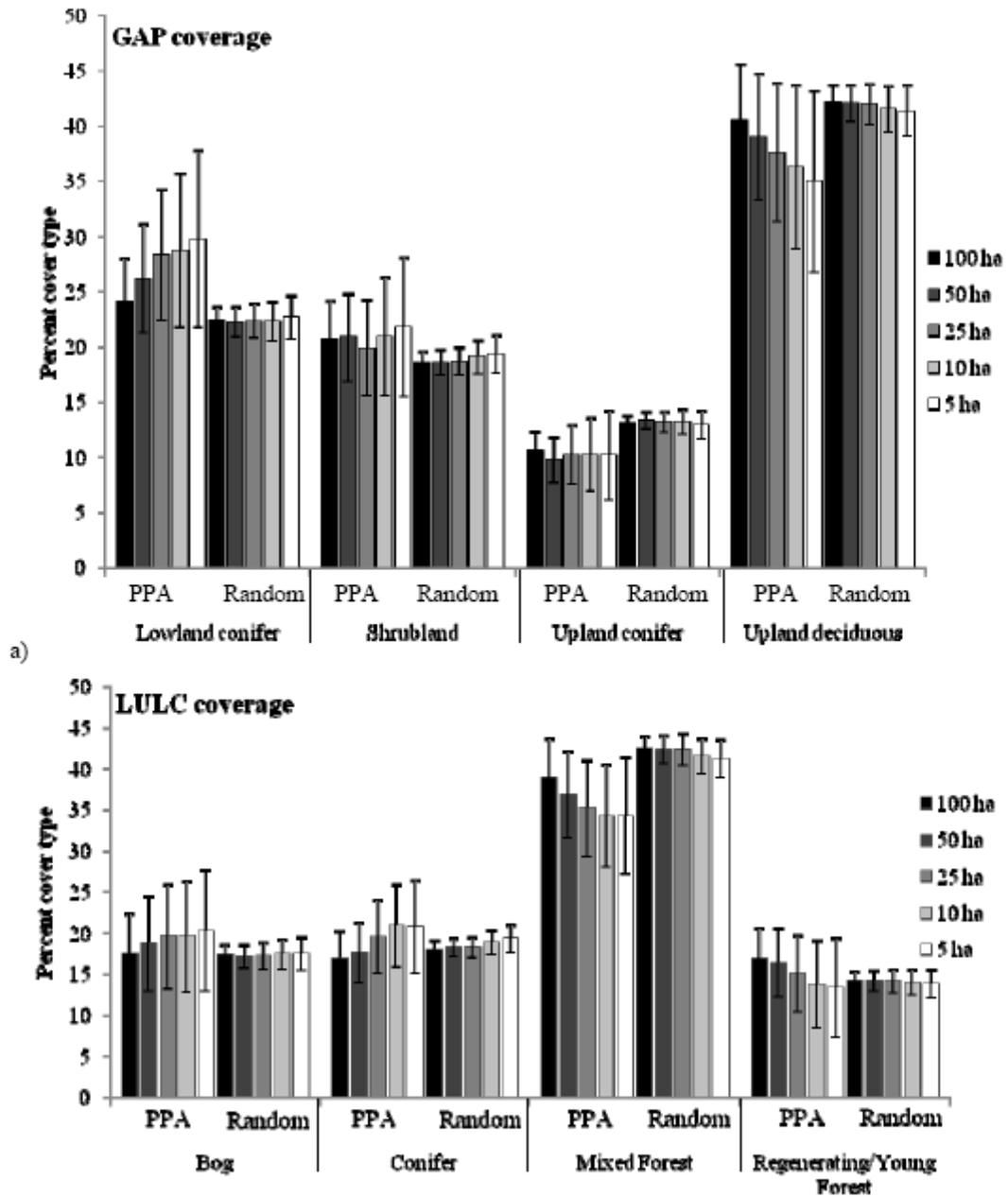


Figure 1.2. Cover types included in analysis of cover type composition of random areas in the home range and post-parturition areas (PPA) using GAP and LULC datasets at the 100 ha level.



b) Figure 1.3 Response of cover type composition as area surrounding known cow/calf locations (PPA) and random locations within home ranges was incrementally reduced using GAP (a). LULC cover type composition (b) in post-parturition areas and random locations within home ranges was similar to the GAP data.

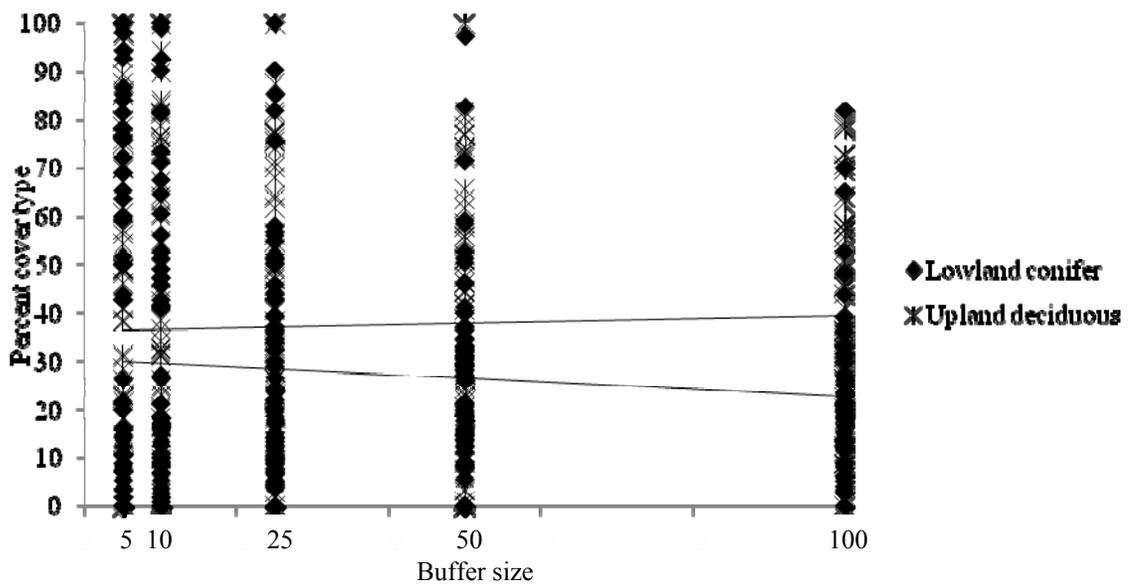


Figure 1.4 Linear regression of decreasing post-parturition areas (x-axis) against presence of lowland conifer (Lcon) and upland deciduous (Udec) within 100, 50, 25, 10, and 5 ha area (y-axis). As area around known cow/calf locations decreased the subsequent increase in lowland conifer and decrease in upland deciduous was not significant. For lowland conifer; $R^2=0.006$, $p=0.12$. For upland deciduous; $R^2=0.0014$, $p=0.48$).

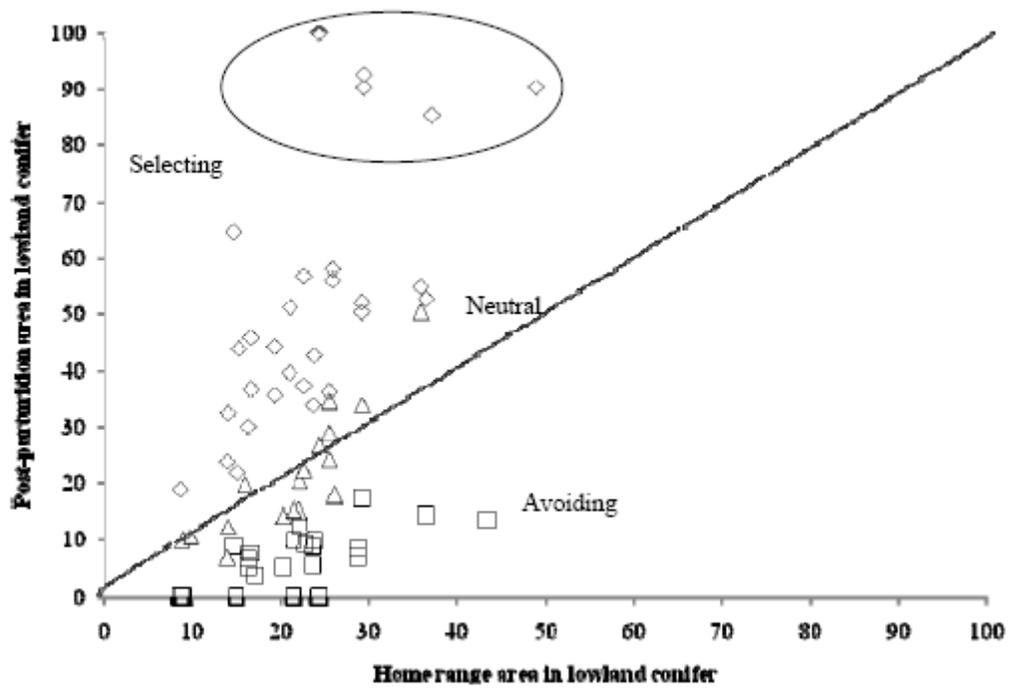


Figure 1.5. Cows selected for lowland conifer (diamonds), used lowland conifer in accordance to its availability (triangles), or avoided lowland conifer (squares). Circled triangles identify a sub-group of cows using lowland conifer in much greater proportion than was available within home ranges.

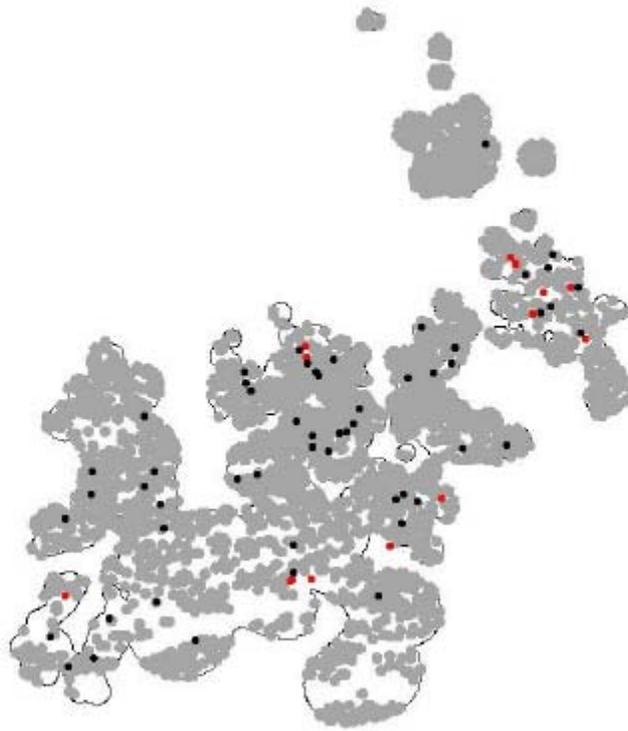


Figure 1.6. Home ranges of VHF collared cows with black dots indicating post-parturition locations. Grey indicates areas identified as post-parturition habitat within the home ranges. Black dots are post-parturition locations within what may be suitable habitat if lowland conifer is an important component of post-parturition areas, while red dots are outside suitable habitat.

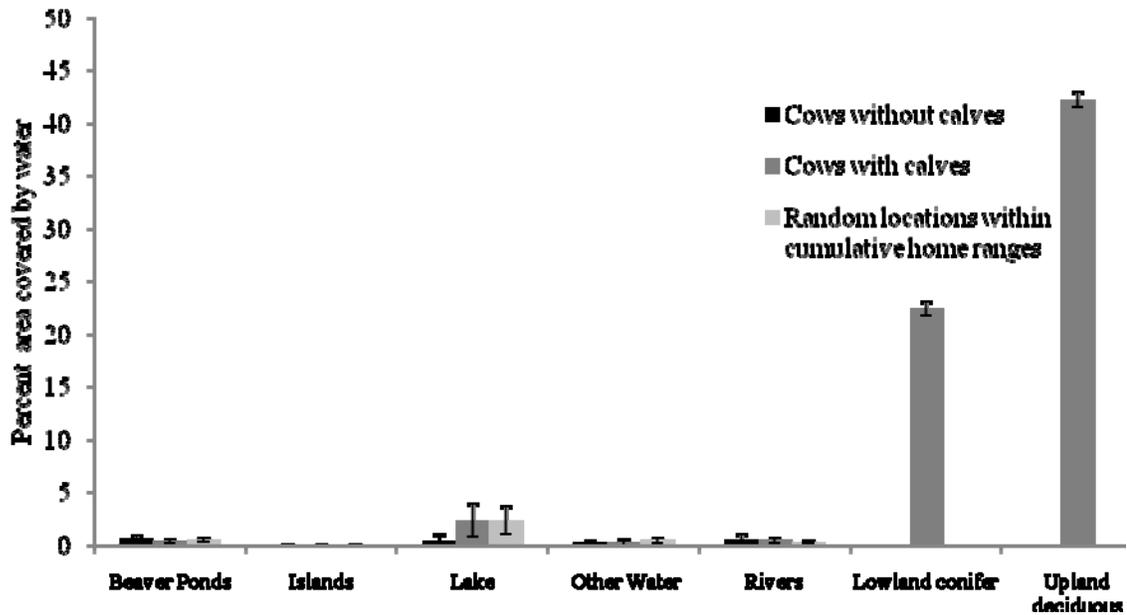


Figure 1.7. Amount of each water type found within post-parturition areas, random areas, and areas surrounding cows not seen with calves (barren cows). There were no differences in water types used by cows with or without calves when compared to water found in random areas. Vertical error bars represent 95% confidence intervals. Presence of islands was included because moose will potentially use islands for parturition.

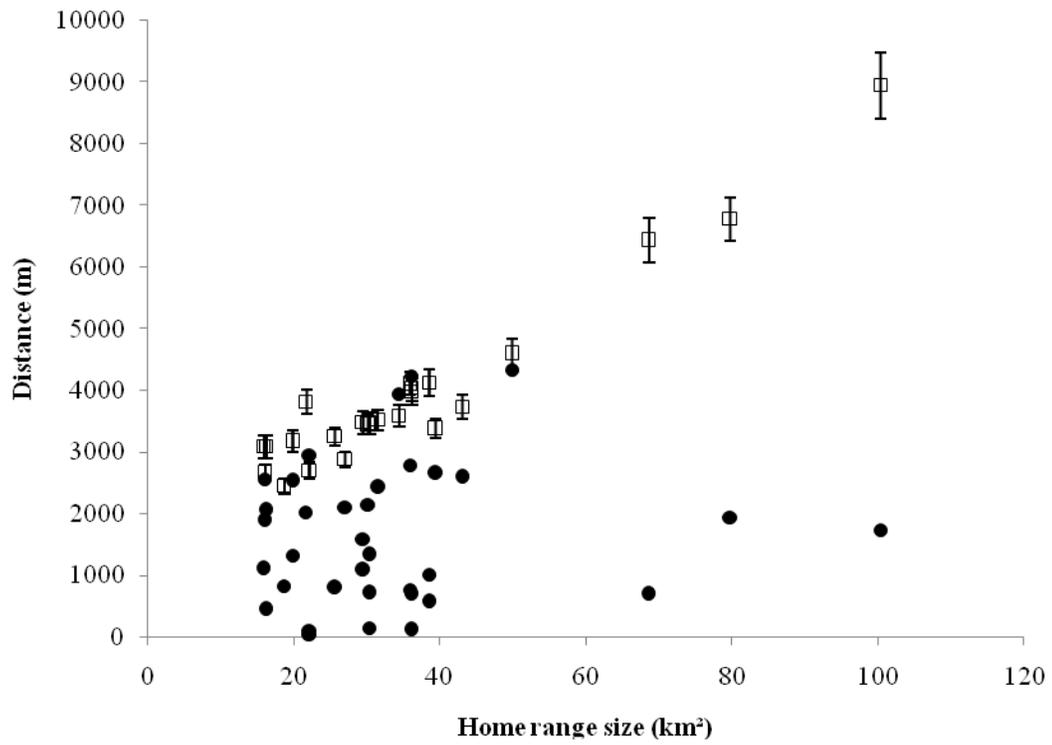


Figure 1.8. Distance between annual post-parturition locations of individual cows (x's) compared to average distance to 30 random points within the home ranges of individuals (squares). Vertical error bars represent 95% confidence intervals of distance to random locations within the home range.

Chapter 2: Effective Temperature of Cover Types Found in Moose Home Ranges in Northeast Minnesota

Overview

Moose are sensitive to warm temperatures in both summer and winter and may select habitats with cooler temperatures on warm days. We used black globe thermometers to measure temperatures in 4 cover types (mixed forest, treed bogs, coniferous forest, and deciduous forest) that comprise about 85% of home ranges of radio collared moose (*Alces alces*) in northeastern Minnesota. Ambient temperature measurements from a weather station in Isabella, MN, within the study area, exceeded physiological thresholds of 14°C and 20°C for 50% and 33% of the study period, respectively. The greatest differences in temperature were measured between deciduous and coniferous cover types. Temperature differences increased among cover types as ambient temperatures increased. The greatest difference in temperature between two cover types was about 2°C and occurred during warm periods when skies were clear ($p = 0.012$, $F_{39,3} = 4.27$). The biological significance of these temperature differences among cover types is not clear and suggests the presence of alternative cooling mechanisms of cover types, such as the ability of soil and duff layers to act as heat sinks, should also be considered.

Introduction

Food supply, habitat composition, and climate all influence the distribution of moose (*Alces alces*). Climate influences on moose survival and distribution may be most pronounced and play a larger role in limiting populations near the southern edge of the range (Kelsall and Telfer 1974). As a circumboreal species moose are well adapted to cold but are intolerant of warm temperatures and will have both physiological (Renecker and Hudson 1986) and behavioral responses to heat stress. Behavioral responses in summer include shifting activity to cooler nights and using vegetation cover as a way to reduce thermal regulation (Dussault et al. 2004).

In regions near the southern edge of moose distribution mature forest cover can be used as a thermal refuge when ambient temperatures are high. In warmer periods during winter and summer cover types within home ranges have lower temperatures and reduced solar radiation (Black et al. 1976, Schwab and Pitt 1991, Demarchi and Bunnell 1993). Regions where temperatures frequently exceed 27°C during the summer do not support moose populations unless shaded areas, rivers, or lakes are present (Demarchi 1991).

The metabolic rates of captive moose began to increase when ambient temperatures exceeded 14°C and panting began when temperatures were > 20°C (Renecker and Hudson 1986). Moose have persisted for decades in northeastern Minnesota despite temperatures that consistently exceed the 14°C and 20°C thresholds in summer. In northeast Minnesota the average normal temperature in July is 17.5°C with an average daily maximum of 24.4°C (National Weather and Climate Center 2000). Temperature data loggers were used to measure thermal differences between forest cover

types and it was found that there was low variability in temperature among cover types, implying that cover types may not be thermal shelters (Lowe et al. 2010). Furthermore, cover type selection by moose in Ontario did not appear to be influenced by summer temperatures above the thresholds observed in captive moose.

The radiation balance of an animal is affected by availability of shade within local environments (Mader et al. 1999, Hahn et. al. 1970, Buffington et. al. 1981, Esmay 1982). Black globe thermometers measure the thermal environment by incorporating ambient temperature, wind velocity, and radiant energy (Bond and Kelly 1955). Solar radiation is likely more influential in causing differences in habitat use than wind in mature forests with closed canopies (Schwab and Pitt 1991). Canopies filter solar radiation, which causes the greatest difference in equivalent black body temperatures within different cover types (Schwab and Pitt 1991). Operative temperature is determined by a blackbody with the same convection conditions as its environment and produces a net heat flow similar to the heat flow on the surface of an animal (Bakken 1980). Increasing crown closure decreases operative temperature as summer thermal cover shelters animals from both heat and radiation. Conifer forests often have high levels of crown closure and have the highest degrees of thermal shelter (Demarchi and Bunnell 1993).

At the southern edge of moose range forest cover types were not thermal shelters and moose did not change habitat use when ambient temperatures exceeded the 14°C or 20°C thresholds (Lowe et al. 2010). However farther north in moose range in the boreal forest moose altered habitat use and activity rates with increasing summer and fall air

temperatures (Dussault et al. 2004). We measured black globe temperatures in four common forest cover types at the southern edge of moose range in northeast Minnesota. In addition to determining overall black globe temperature differences we compared temperatures among cover types on clear and cloudy days, cool and warm days, and determined when temperature differences were greatest throughout the day.

Study area

This study was conducted in Lake County in northeastern Minnesota. Lake County is in the arrowhead region of northeastern Minnesota and has a humid continental climate with severe winters and short, warm summers (Frelich 2002). Precipitation is moderate with an average of 25-30 inches throughout the spring, summer and fall. Average snowfall along the north shore of Lake Superior in northeast Minnesota is about 70 inches annually with snow cover usually present from December through April. Average July temperatures are about 17.5°C and January temperatures average -17°C (NOAA 2009). Topography of the region is relatively flat with elevation ranging from 1,500 to 2,000 feet above sea level.

Northeastern Minnesota has near-boreal forests extending down from Canada that are classified into five main forest stand types (Frelich 2002), 1) fir-birch (*Abies balsamea*, *Betula papyrifera*) forests found on good soils, 2) jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) on coarse, shallow soils, 3) red maple (*Acer rubrum*), aspen (*Populus tremuloides*), birch and fir in moist areas, 4) red pine (*Pinus resinosa*) on shallow rocky soils, and 5) birch and white pine (*Pinus strobes*) are found along lakes

and streams. Conifer swamps are also present and are dominated by tamarack (*Larix laricina*) and black spruce.

Methods

We measured temperature in four different forest cover types throughout the spatial extent of 95% kernel home ranges of VHF collared moose in northeast Minnesota (Moen *pers. comm.*, Lenarz et al. 2009, 2010). Random points along roads and trails were generated using ArcView with a 200 m buffer. Black globe temperature data loggers were placed > 25 m and < 200 m from road edges within the study area.

Black globe temperature data loggers were used to determine differences in radiant heat load of local environments. Black globes were constructed from 6 inch diameter copper bulbs painted matte black. HOBO[®] Pendant or Pro v2 Temperature/Relative Humidity Data Loggers were attached so sensors hung in the center of each globe. HOBO Pendant temperature data loggers measure air temperature with an accuracy of $\pm 0.47^{\circ}\text{C}$ at 25°C from -20° to 70°C , and can record and store approximately 29,000 samples per unit. HOBO Pro v2 temperature data loggers measure air temperature with an accuracy of $\pm 0.02^{\circ}\text{C}$ from 0° to 50°C , and record and store about 15,000 temperature samples.

Temperature data loggers were synchronized to begin taking temperature samples at six minute intervals for 120 days during summer. Stored temperature readings were downloaded every 30 days to ensure data loggers were working properly and that data was not lost.

ArcView 3.3 and Land Use Land Cover LANDSAT Thematic Mapper (TM) images were used to identify and locate forest cover types that potentially offered thermal relief within the home ranges of VHF collared moose. Land Use Land Cover (LULC) satellite imagery was used to estimate cover type frequency and distribution in the study area. LULC is a raster dataset with 30 m resolution, >95% classification accuracy, and 16 defined cover types (Minnesota Department of Natural Resources [MNDNR] 2007b). Mixed forest ($41 \pm 1\%$), wetlands ($18 \pm 2\%$), coniferous forest ($19 \pm 1\%$), and deciduous forest ($3 \pm 1\%$) composed $80 \pm 1\%$ ($8 \pm 1\%$) of the 95% kernel home ranges.

Forty temperature data loggers were placed within four cover types (10 per cover type), one at each of the random points generated using ArcView 3.3 (Figure 1). Black globes were secured to the trunk of a tree by a steel eye-bolt 75 cm above the ground; the approximate shoulder height of a moose while lying down. Black globe temperature data loggers extended 15 cm from the tree. Black globes were attached by the eye-bolt extending from the top of the black globe to the steel bolt extending from the tree. All globes were attached to the northeast side of the trees for standardization and to reduce the chance that direct sunlight would be shining on the black globes during the warmest parts of the day. Topographic and aspect variation were controlled for by placing black globes at flat locations within the defined cover types, though we did not make quantitative measurements.

We measured the amount of time when ambient temperatures exceeded 14°C and 20°C . We also defined a hot day when maximum ambient temperature reached or exceeded 24.4°C (National Weather and Climate Center 2000) to determine if there were

greater differences between cover types when ambient air temperatures exceed normal conditions experienced by moose in northeast Minnesota. Cloudy days were defined as days when the cloud cover index was ≥ 7 , while clear days were defined as days when the cloud cover index was ≤ 3 (MN State Climatologist 2010). Ambient air temperature and cloud cover data for the region was retrieved from NOAA and the MN State Climatology archived data for weather stations in northeast Minnesota.

Temperature data was analyzed with repeated measures ANOVA using Statistix (version 9, Analytical Software, Boca Raton, FL). Bonferroni comparisons were used to determine which cover types were different from one another. Significance levels were set at $P = 0.05$ for all tests. Sub-samples of the dataset were analyzed to determine the degree to which cover type temperatures differed due to time of day, season, and climatic events such as hot, cloudy, clear, and hot/clear days.

Results

Highest black globe temperatures were recorded in the afternoons with the greatest difference in temperature between conifer and deciduous cover types ($17.9 \pm 0.35^\circ\text{C}$ vs $19.6 \pm 0.35^\circ\text{C}$, $\bar{x} \pm \text{SE}$; $F_{3,39} = 4.47$, $p < 0.001$). Black globe temperatures in mixed and bog cover types were intermediate between deciduous and conifer cover types, with the bog cover type showing slightly cooler temperatures at night (Figure 2). Temperature differences between cover types were greater during the afternoons ($F_{3,39} = 4.59$, $p < 0.009$) (Figure 2).

From June 15 – October 15, 2009 ambient temperature exceeded 14°C 50% of the time at a weather station in Isabella, MN (Fig. 1). On days when ambient temperatures

exceeded 14°C, about 15.3 hours of each day was above 14°C. The temperature difference between cover types was greatest between deciduous and conifer cover types when ambient temperature was > 14°C (Table 1). The longest period above 14°C was 120 consecutive hours (5 days) during August. During those 5 days ambient temperature was > 20°C between 8:00-20:00 daily, with mean temperature of $23.4 \pm 0.45^\circ\text{C}$.

Ambient temperature exceeded 20°C for 33% of the study period. When ambient temperatures were above 20 °C average temperatures were $23.0 \pm 0.09^\circ\text{C}$ with the longest continuous time above 20°C being 18 hours. When temperatures were > 20°C there were 6.6 hours consecutive hours above that threshold.

As ambient temperature increased, differences in temperature between cover types were greater, with temperature differences from 1.1°C (above 14°C) to 2.1°C (above 24.4°C). During 3 separate 11 hour periods (2 in August, 1 in June) when ambient temperatures were above 24.4°C temperature differences between the deciduous and conifer cover types ranged from 1.5°C to 2.4 °C, with warmer periods resulting in larger differences in temperature. Deciduous and conifer cover types had the greatest differences in temperature (Table 1).

Differences in temperature between cover types were smaller on cloudy days compared to clear days. On clear days (cloud cover index <3) deciduous and bog cover types had the largest difference in temperature (Table 1). When we restricted the sampling to afternoon (12:00-15:00), the deciduous cover type again had the highest temperature while the conifer cover type had the lowest temperature (Figure 4, Table 1).

The difference was greatest during the afternoons of days when temperatures were > 24.4 °C and when there was no cloud cover (Figure 4, Table 1).

On cloudy days (cloud cover index >7) there were smaller differences in temperature between cover types though the deciduous cover type still had the highest temperatures and the conifer cover type had the lowest temperatures. When the sampling period was restricted to the afternoon, differences became greater once again (Figure 4, Table 1). Days when ambient temperature exceeded 24.4°C were not cloudy.

Discussion

During the warmest periods of the summer differences in temperature among cover types were at most 2°C . Small differences in temperature among forest cover types were also measured in Algonquin Provincial Park (Lowe et al. 2010). It seems likely that a 2°C difference among cover types is not biologically significant and moose would not use temperature as the driving factor in selecting a cover type in hot weather. However, temperature differences in cover types may be larger, as slope and aspect may also influence temperature. Slope and aspect were kept constant in this study but should be considered in the future. Changes in cover type use and activity time have been observed elsewhere in core moose range at high temperatures (Dussault et al. 2004).

Summer temperatures are predicted to increase $1.5\text{-}2^{\circ}\text{C}$ by 2025 (Union of Concerned Scientists 2003), and by $3\text{-}4^{\circ}\text{C}$ by 2100 (IPCC 2007). If average summer temperatures continue to increase, the likely result will be more and longer periods during which temperatures are continuously higher than the upper critical limit of moose. As in Ontario (Lowe et al. 2010), temperatures in northeast Minnesota frequently exceed

thresholds observed in captive moose (Renecker and Hudson 1986), yet moose in Ontario did not respond to warm temperatures by selecting specific cover types. Use of forest types with increased crown closure, especially conifers, has been documented with high temperatures, though there is not a consistent change in behavior as not every moose moved into conifer stands during warm periods (Dussault et al. 2004).

Given the small differences in black globe temperature among cover types, changes in moose behavior may be caused by other aspects of a cover type. Moose will bed in water as a means of reducing heat load (Renecker and Hudson 1990, Ackerman 1987). Use of cover types for bedding and the effectiveness of duff layers and soils as heat sinks should also be considered.

Even though summer temperatures are often greater than the 14°C and 20°C thresholds established in captive moose (Renecker and Hudson 1986), moose are resident in northeast Minnesota. Within the past two decades however, the northwest population has declined from about 4,000 to less than 100 animals and there is evidence of a decline beginning in the northeast population. Survival in both populations has been correlated to increasing temperatures. Increasing summer temperatures were correlated with the decline in the northwest Minnesota moose population (Murray et al. 2006). In contrast, high average January and late spring temperatures explained more of the variability in moose survival in northeast Minnesota (Lenarz et al. 2009). It is possible that cover types within moose range in Minnesota provided thermal relief, though not necessarily through moderation of air temperature.

This study provides information on the potential for available vegetation types in northeast Minnesota to serve as thermal cover. If moose at the southern edge of their range are encountering high temperatures at an increasing and prolonged rate, then their behavior should change. There also is a need to measure alternative cooling mechanisms, such as the potential heat sink which cool soils may provide while moose are bedded. Future research should concentrate on how cover types are used when temperatures are high and how they function to provide thermal relief.

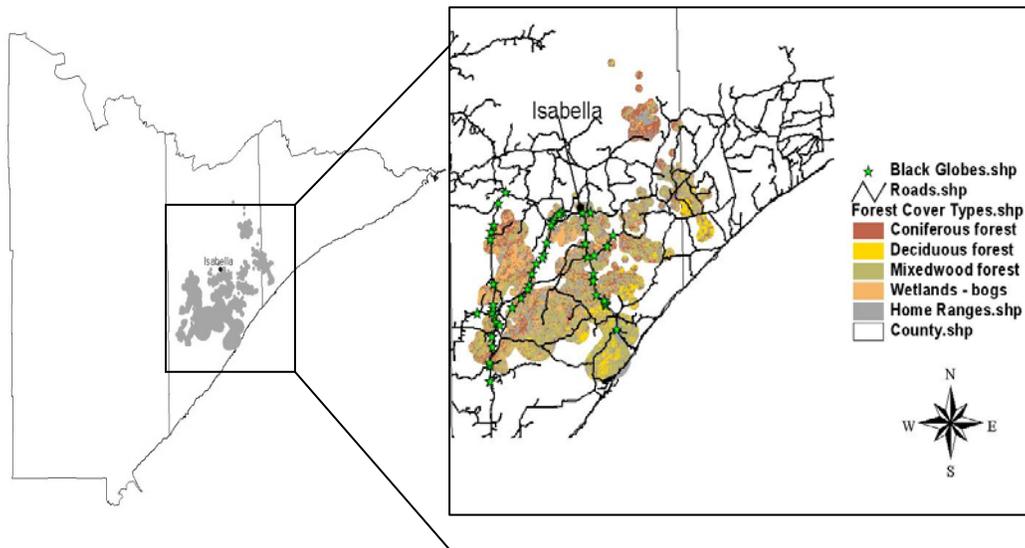


Figure 2.1. Temperature data logger locations. Darker gray areas indicate 95 kernel home ranges of VHF collared moose. Forest cover types are from LULC coverage classifications. Isabella, MN is the location of weather station data used to determine when ambient temperatures exceeded thresholds.

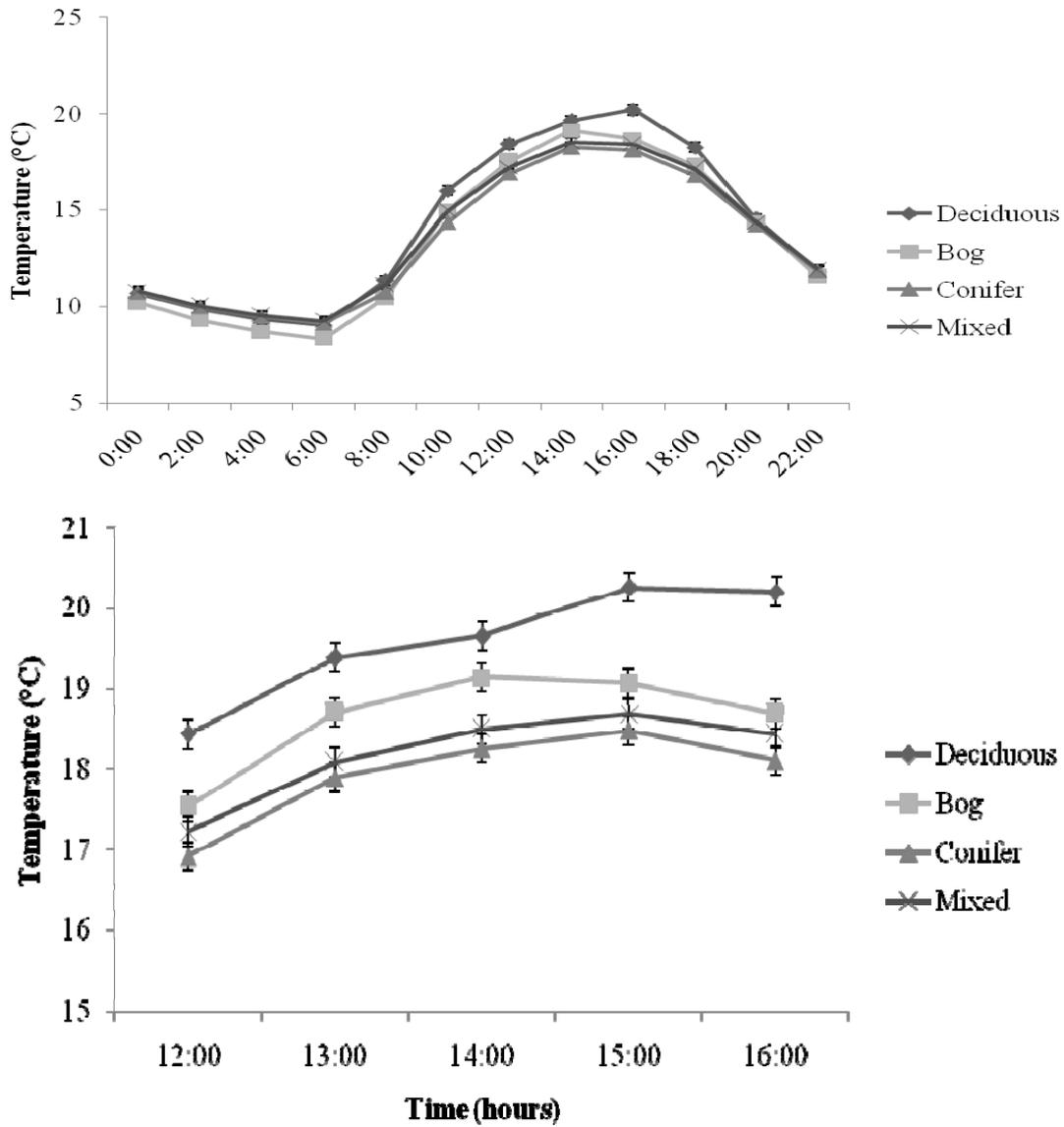


Figure 2.2. Average temperature of the 4 cover types over a 24 hour period (a).

Temperatures among cover types showed the greatest divergence during the afternoon (b), typically the warmest part of the day. Vertical error bars represent standard errors.

Table 2.1. Temperature differences between cover types under different climatic conditions and during afternoons. Letters indicate homogenous groups.

Cover types	Deciduous	Bog	Conifer	Mixed	<i>p-value</i>	<i>F</i> _{3,39}
>14°C	19.2 ± 0.04 <i>a</i>	18.4 ± 0.04 <i>b</i>	18.1 ± 0.03 <i>b</i>	18.3 ± 0.03 <i>ab</i>	0.011	4.33
>20°C	23.8 ± 0.06 <i>a</i>	22.7 ± 0.05 <i>ab</i>	22.0 ± 0.04 <i>b</i>	22.3 ± 0.04 <i>ab</i>	0.019	3.81
>24.4°C	26.6 ± 0.11 <i>a</i>	25.4 ± 0.08 <i>ab</i>	24.6 ± 0.08 <i>b</i>	24.8 ± 0.07 <i>b</i>	0.012	4.3
Clear days	15.8 ± 0.19 <i>a</i>	14.8 ± 0.18 <i>ab</i>	15.0 ± 0.18 <i>b</i>	15.2 ± 0.18 <i>b</i>	<0.003	5.87
Cloudy days	12.3 ± 0.17 <i>a</i>	12.0 ± 0.16 <i>a</i>	11.8 ± 0.16 <i>a</i>	12.0 ± 0.16 <i>a</i>	0.054	2.83
Cloudy afternoons	15.1 ± 0.16 <i>a</i>	14.5 ± 0.16 <i>ab</i>	14.0 ± 0.15 <i>b</i>	14.3 ± 0.15 <i>ab</i>	0.035	3.23
Clear afternoons	23.6 ± 0.44 <i>a</i>	22.4 ± 0.44 <i>ab</i>	21.6 ± 0.44 <i>b</i>	21.7 ± 0.44 <i>b</i>	0.012	4.29
Hot/Clear afternoons	26.6 ± 0.13 <i>a</i>	25.4 ± 0.10 <i>ab</i>	24.6 ± 0.10 <i>b</i>	24.6 ± 0.09 <i>b</i>	0.012	4.27

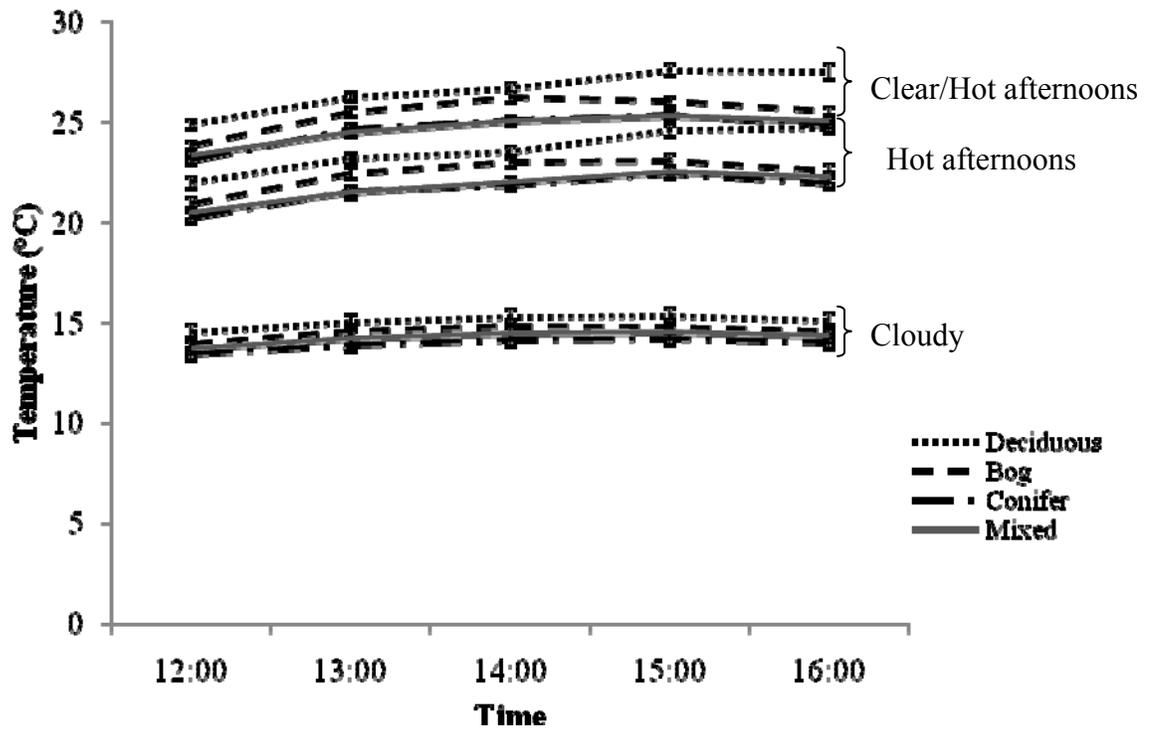


Figure 2.3. Average temperature of cover types during afternoons when ambient temperatures exceeded 24.4°C and there was no cloud cover, during hot afternoons, and during afternoons when there was cloud cover. Vertical error bars represent standard errors.

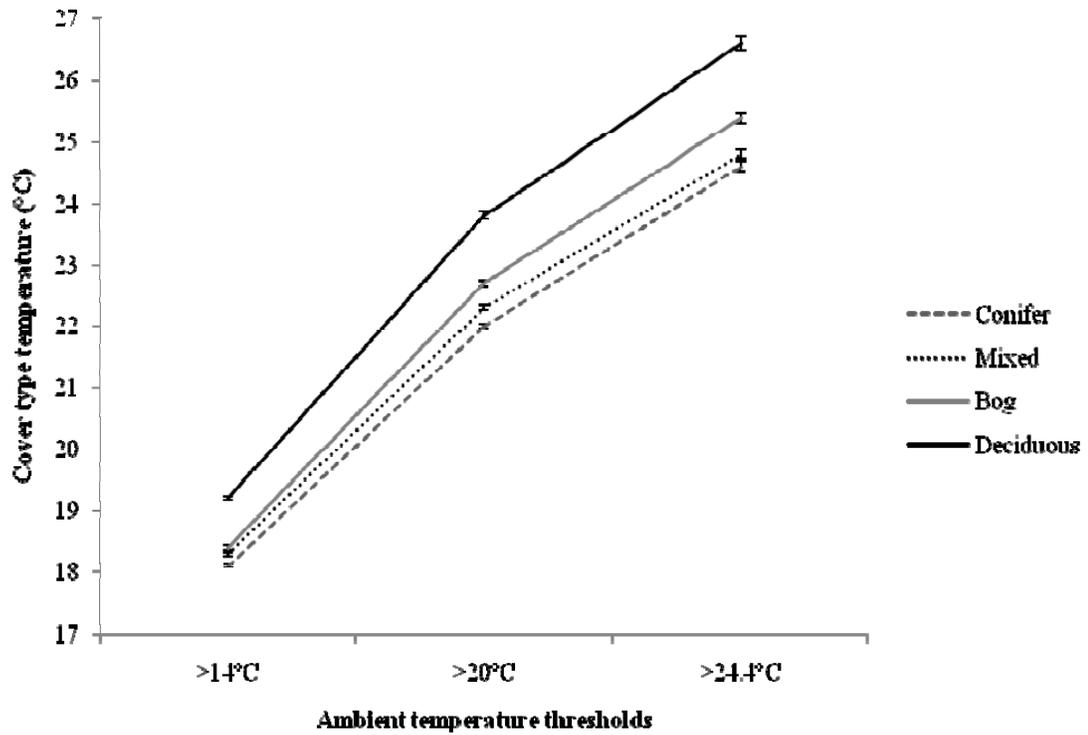


Figure 4. Temperature between cover types at threshold levels found for captive moose and average July maximums in northeast Minnesota. As ambient temperatures increased, differences in black globe temperature among cover types also increased.

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