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ECOLOGY AND POPULATION DYNAMICS OF BLACK BEARS IN MINNESOTA

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SUMMARY OF FINDINGS

During April 2012–March 2013, we monitored 30 radiocollared black bears (*Ursus americanus)* at 4 study sites representing contrasting portions of the bear's geographic range in Minnesota: Voyageurs National Park (VNP, northern extreme), Chippewa National Forest (CNF; central), Camp Ripley (southern fringe), and a site at the northwestern (NW) edge of the range. Most of the focus of this study has been in the NW site in recent years. Hunting has been the primary source of mortality in all areas; however, with a concerted effort to discourage hunters from shooting collared bears, and by clearly marking bears with large ear tags, no collared bears were killed by hunters in fall 2012. Reproduction was highest in the NW study site. Stable isotopic analysis of portions of hair samples was useful in distinguishing seasonal changes in bear diets, especially use of crops (corn and sunflowers) during fall. Crop use of individual bears, based on data from Global Positioning System (GPS)-radiocollars, was related to isotopic signatures of their hair samples. These analyses indicated that the enhanced reproduction of bears in NW Minnesota was due to the combined use of crops and an abundant supply of natural foods. Bears were especially attracted to grain corn and oilseed sunflowers, based on damage reported by farmers in the region. Farmers who had experienced more crop damage were less tolerant of bears and desired reduced local bear abundance.

INTRODUCTION

Intensive research on black bears was initiated by the Minnesota Department of Natural Resources (MNDNR) in 1981, and has been ongoing since then. Objectives shifted over the years, and study areas were added to encompass the range of habitats and food productivity across the bear range. For the first 10 years, the bear study was limited to the Chippewa National Forest (CNF), near the geographic center of the Minnesota bear range (Figure 1). The CNF is one of the most heavily hunted areas of the state, with large, easily-accessible tracts of public (national, state, and county) forests dominated by aspen (*Populus tremuloides, P. grandidentata)* of varying ages. Camp Ripley Military Reserve, at the southern periphery of the bear range, was added as a second study site in 1991. The reserve is unhunted, but bears may be killed by hunters when they range outside, which they often do in the fall. Oaks (*Quercus* sp.) are plentiful within the reserve, and cornfields border the reserve. Voyageurs National Park (VNP), at the northern edge of the Minnesota range (but bordering bear range in Canada) was added as a third study site in 1997. Soils are shallow and rocky in this area, and foods are generally less plentiful than in the other sites. Being a national park, it is unhunted, but like Camp Ripley, bears may be hunted when they range outside.

In 2007 we initiated work in a fourth study site at the northwestern edge of the Minnesota bear range (henceforth NW; Figure 1). This area differs from the other 3 areas in a number of respects: (1) it is largely agricultural (including crop fields, like corn and sunflowers, that bears consume), (2) most of the land, including various small woodlots, is privately-owned, with some larger blocks of forest contained within MDNR Wildlife Management Areas (WMAs) and a National Wildlife Refuge (NWR); (3) the bear range in this area appears to be expanding and bear numbers have been increasing, whereas most other parts of the bear range are stable or declining in bear numbers; and (4) hunting pressure in this area is unregulated (it is within the no-quota zone, so there is no restriction on numbers of hunting licenses).

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OBJECTIVES

1. Quantify temporal and spatial variation in cub production and survival;
2. Assess causes of bear mortality in different parts of the bear range;
3. Evaluate use of crops by bears living along the edge of the range;
4. Assess damage caused by bears to various crops along the edge of the bear range, and corresponding attitudes of farmers toward bears.

METHODS

We previously attached radiocollars with breakaway and/or expandable devices to bears either when they were captured during the summer or when they were handled as yearlings in the den with their radiocollared mother. We used VHF collars in CNF, Camp Ripley, and VNP, and GPS in the NW study site. We used both GPS "pods" (Telemetry Solutions, Concord, CA) that were bolted onto standard VHF collars, and GPS-Iridium collars (Vectronic Aerospace, Berlin, Germany). The latter collars uploaded location data to an Iridium satellite, which was then transmitted to us daily by email. The location data stored in the pods were retrievable only by physically connecting the pod to a computer when we handled bears in dens.

During December–March, we visited all radio-instrumented bears once or twice at their den site. We immobilized bears in dens with an intramuscular injection of Telazol, administered with a jab stick or Dan-Inject dart gun. Bears were then removed from the den for processing. We measured lengths and girths, body weight, body fat (using biolelectrical impedance analysis), and took blood and hair samples. We changed or refit the collar, as necessary. All collared bears had brightly-colored, cattle-size ear tags (7x6 cm; Dalton Ltd., UK) that would be plainly visible to hunters. Bears were returned to their dens after processing.

We assessed reproduction by observing cubs in dens of radiocollared mothers. We sexed and weighed cubs without drugging them. We evaluated cub mortality by examining dens of radiocollared mothers the following year: cubs that were not present as yearlings with their mother were presumed to have died.

We did not monitor survival of bears during the summer. Mortalities, though, were reported to us when bears were shot as a nuisance, hit by a car, or killed by a hunter. Prior to the hunting season (1 September–mid-October), hunters were mailed a letter requesting that they not shoot collared bears with large ear tags.

We plotted GPS locations downloaded from collars on bears in the NW study site. We used a Geographic Information System (GIS) overlay to categorize the covertypes of GPS locations, including types of crop fields. We compared the proportion of time that bears spent in cropfields to stable isotopic signatures of carbon (C) and nitrogen (N) in their hair (Colorado Plateau Stable Isotope Laboratory, Northern Arizona University, Flagstaff, AZ). We sectioned hair in two pieces representing two periods of growth: spring-summer (distal half) and fall. We collected various types of bear foods from the NW study site, including herbaceous vegetation, fleshy fruits, nuts, ants, deer, corn, soybeans, and sunflowers, and obtained their isotopic signatures for C and N (Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN). We used the Stable Isotope Analysis package in Program R (SIAR) to solve mixing models for the isotopic data within a Bayesian framework, and thereby generated distributions for the probabilities that different individual bears consumed and assimilated given proportions of certain types of foods.

We interviewed farmers in the NW study site to gauge the amount of bear-related damage to various crops, and whether their attitudes toward bears changed accordingly. Growers were asked to subjectively rate levels of bear damage to their crops based on a scale of 0 (no damage) to 5 (major damage). We asked how tolerant the grower was of bear-related damage to crops and asked if they would prefer fewer, the same, or more bears in the region. We also inquired about any attempted hunting of bears on their property either as a direct response to crop damage or as a means to reduce the general number of bears near the crop land. Initial interviews were conducted with growers who reported damage to local Minnesota Department of Natural Resources offices, as well as growers who owned fields in which GPS-collared bears were known to have visited. After these interviews, other interview subjects were added.

RESULTS AND DISCUSSION

Radiocollaring and Monitoring

Since 1981 we have handled >800 individual bears and radiocollared >500. As of April 2012, the start of the current year's work, we were monitoring 30 radiocollared bears: 5 in the CNF, 8 at Camp Ripley, 4 in VNP, and 13 in the NW (Table 1). We did not trap any new bears this year. We collared one additional bear whose den was found by a hunter near the western edge of the range, but the GPS unit failed shortly afterwards. One VHF collar also failed. Two bears dropped collars: 1 of these was not handled during the winter of 2011–2012, so the breakaway on the collar deteriorated and severed (as it should have); the other had an expandable device that expanded too much. We could not find 1 CNF bear.

Mortality

Legal hunting has been the dominant cause of mortality among radiocollared bears from all study sites (Table 2). However, no bears were shot by hunters during 2012, as they respected our request not to shoot them. One NW study bear was hit by a car, and a yearling collared in a den in VNP in March 2012 apparently died of natural mortality (we found its collar chewed by wolves). One adult female who was denned in an open nest with her yearlings died after drugging, despite a normal drug dose and the bear being in apparent good health.

The oldest bear on our study, a 39-year-old female in the CNF (as of January 2013) survived another year.

Reproduction

Eleven collared females gave birth to 28 cubs in 2013. Nearly all bears maintained a 2-year reproductive cycle. All 8 females that produced cubs 2 years ago produced cubs again this year; 1 female whose litter died last year produced a litter this year; and 2 females produced their first litters (1 at 3 years old, 1 at 4 years old).

Since 1982, we have checked 269 litters with 689 cubs ($\bar{x}$ = 2.6 cubs/litter), of which 52% were male (Tables 3–6). Mortality of cubs during their first year of life averaged 21%, with mortality of male cubs (26%) exceeding that of females (16%; $\chi^2 = 7.3$, $P < 0.01$). The timing and causes of cub mortality are unknown.

Reproductive rates were highest in the NW study area, and lowest in VNP (Figure 2). The reproductive rate (cubs/female 4+ years old) combines litter size, litter frequency, and age of first reproduction into a single parameter. Reproductive rate was higher for 7+ year-old bears than 4–6 year-old bears because many bears in this younger age group either had not yet reproduced or had their first litter, which tended to be smaller. Reproductive rates for 7+ year-old bears in the CNF and Camp Ripley were similar, although Camp Ripley bears tended to mature earlier (Figure 2). Litter size averaged ≥3.0 cubs only for 7+ year-olds in the NW.

Crop Use by NW Bears

We were able to separate stable isotope signatures of bear foods into 5 groups: natural vegetation (herbaceous, berries, and nuts), ants, deer, corn, and sunflowers (Figure 3). Isotopic signatures of portions of bear hair representing spring-summer growth clustered around natural vegetation and varying amounts of ants and deer; samples with enriched nitrogen indicated use of ants or deer (CIs for ants and deer overlapped so could not be readily distinguished). Some spring-summer samples also had enriched carbon, indicative of use of corn by some animals, likely obtained from unharvested fields or spillage during fall harvest. Portions of bear hair representing fall growth had more variation in C and N signatures due to varying use of corn and sunflowers. Males made the most extreme use of these crops, but a number of females also used crops in fall, based on enriched C and/or N (Figure 3). However, the relatively high reproductive rate of females in this area was not solely due to crop use, as this analysis showed that most of them fed mainly on natural vegetation; abundant hazelnuts (*Corylus americana, C. cornuta*) probably contributed largely to their high reproductive output. Extent of cropfield use by GPS-collared bears was related to isotopic signatures of their hair (Figures 4,5), thus confirming the use of stable isotopes to assess crop use.

Crop Damage by NW Bears

During 2009–2012 we conducted 38 interviews with growers (36) and apiarists (2) in the NW study area. Most were long-time residents of the area (average ~30 years). Growers reported differing amounts of bear damage among crops and crop varieties (Table 7). Among the 25 survey participants who had grown corn in recent years, 91% reported damage from bears. Those who grew hybrid/grain corn reported more bear-related damage than those who grew field corn for silage (Table 7). Among 19 sunflower growers, 16 had grown oil sunflowers (used for cosmetics, cooking, birdseed), 9 confection sunflowers (used for human consumption, birdseed) and 6 had experience with both varieties. The mean level of bear damage in oil sunflower fields was significantly higher than confectionary sunflower fields (Table 7). Bears are likely attracted to the black oilseed for its high fat content (Figure 6). Apiarists (2 of 2, but highly dependent on year) and oat growers (9 of 9) also reported significant amounts of bear damage. Of 25 growers of soybeans, the crop with the most areal coverage, only 1 reported bear damage (rated as minor). Those who grew wheat, canola, barley, alfalfa, sugar beets, and rye grass, grains, or hay reported low or no distinguishable bear damage.

Tolerance toward bear damage was largely related to the perceived level of past damage: 5 of 26 growers had not incurred any bear damage and all considered themselves tolerant of bears; among 21 respondents that had incurred bear damage, only 6 (29%) classified themselves tolerant, 8 (38%) had tolerance "contingent on level of damage" and 7 (33%) were classified as having no tolerance for bear damage. Accordingly, 5 of 7 (71%) growers who did not report any damage from bears had not killed or attempted to kill bears and 50% said they would prefer the same or more bears in the region. Conversely, of 16 growers who reported crop losses to bears, 10 (63%) had attempted nuisance killing or additional hunting pressure and 73% indicated that they would prefer fewer or no bears in the region.

ACKNOWLEDGMENTS

We thank the collaborators in this study: Brian Dirks, who conducted the fieldwork and provided all materials for the work at Camp Ripley; Dr. Paul Iaizzo at the University of Minnesota, and Dr. Tim Laske at Medtronic, Inc., who assisted with fieldwork and provided the GPS-Iridium radiocollars, and Spencer Rettler who assisted in isotope sample preparation and data entry. Agassiz NWR kindly provided use of their bunkhouse and assistance from staff during the winter fieldwork.

Table 1. Fates of radiocollared black bears in 4 study sites (Chippewa National Forest, Camp Ripley, Voyageurs National Park, and northwestern Minnesota), April 2012−March 2013.

	CNF	Camp Ripley	VNP	NW
Collared sample April 2012	5	8	4	13
Killed as nuisance				
Killed in vehicle collision				1
Killed by Minnesota hunter				
Natural mortality			1	
Dropped collar				2
Failed radiocollar				1
Lost contact[a]	1			
Died in den[b]				1
Collared in den				1
Collared sample April 2013	**4**	**8**	**3**	**9**

[a] Due to radiocollar failure, unreported kill, or long-distance movement.
[b] Due to handling.

Table 2. Causes of mortality of radiocollared black bears ≥1 year old in 4 Minnesota study sites, 1981–2012. Bears did not necessarily die in the area where they usually lived (e.g., hunting was not permitted within Camp Ripley or VNP, but bears were killed by hunters when they traveled outside these areas).

	CNF	Camp Ripley	VNP	NW	All combined
Shot by hunter	223	11	15	12	261
Likely shot by hunter[a]	8	1	0	4	13
Shot as nuisance	22	2	1	3	28
Vehicle collision	12	8	1	3	24
Other human-caused death	9	1	0	0	10
Natural mortality	7	3	5	0	15
Died from unknown causes	4	2	0	3	9
Total deaths	**285**	**28**	**22**	**25**	**360**

[a] Lost track of during the bear hunting season, or collar seemingly removed by a hunter.

Table 3. Black bear cubs examined in dens of radiocollared mothers in or near the Chippewa National Forest during March, 1982–2013. High hunting mortality of radiocollared bears severely reduced the sample size in recent years.

Year	Litters checked	No. of cubs	Mean cubs/litter	% Male cubs	Mortality after 1 yr[a]
1982	4	12	3.0	67%	25%
1983	7	17	2.4	65%	15%
1984	6	16	2.7	80%	0%
1985	9	22	2.4	38%	31%
1986	11	27	2.5	48%	17%
1987	5	15	3.0	40%	8%
1988	15	37	2.5	65%	10%
1989	9	22	2.4	59%	0%
1990	10	23	2.3	52%	20%
1991	8	20	2.5	45%	25%
1992	10	25	2.5	48%	25%
1993	9	23	2.6	57%	19%
1994	7	17	2.4	41%	29%
1995	13	38	2.9	47%	14%
1996	5	12	2.4	25%	25%
1997	9	27	3.0	48%	23%
1998	2	6	3.0	67%	0%
1999	7	15	2.1	47%	9%
2000	2	6	3.0	50%	17%
2001	5	17	3.4	76%	15%
2002	0	0	—	—	—
2003	4	9	2.3	22%	0%
2004	5	13	2.6	46%	33%
2005	6	18	3.0	33%	28%
2006	2	6	3.0	83%	33%
2007	2	6	3.0	67%	17%
2008	1	3	3.0	100%	33%
2009	1	3	3.0	33%	33%
2010	1	4	4.0	100%	50%
2011	1	4	4.0	25%	50%
2012	1	3	3.0	67%	**33%**
2013	1	3	3.0	67%	
Overall	**178**	**469**	**2.6**	**52%**	**19%**

[a] Cubs that were absent from their mother's den as yearlings were considered dead.

Table 4. Black bear cubs examined in dens in northwestern Minnesota during March, 2007–2013.

Year	Litters checked	No. of cubs	Mean cubs/litter	% Male cubs	Mortality after 1 yr
2007	2	6	3.0	33%	100%
2008	5	15	3.0	67%	22%
2009	1	3	3.0	33%	33%
2010	6	17	2.8	41%	13%
2011	2	4	2.0	75%	25%
2012	4	10	2.5	60%	10%
2013	3	9	3.0	67%	
Overall	**23**	**64**	**2.8**	**54%**	**28%**[a]

[a] Excludes the total loss of a 5-cub litter in 2007 (which was not within the designated study area).

Table 5. Black bear cubs examined in dens in or near Camp Ripley Military Reserve during March, 1992–2013.

Year	Litters checked	No. of cubs	Mean cubs/litter	% Male cubs	Mortality after 1 yr[a]
1992	1	3	3.0	67%	0%
1993	3	7	2.3	57%	43%
1994	1	1	1.0	100%	—
1995	1	2	2.0	50%	0%
1996	0	0	—	—	—
1997	1	3	3.0	100%	33%
1998	0	0	—	—	—
1999	2	5	2.5	60%	20%
2000	1	2	2.0	0%	0%
2001	1	3	3.0	0%	33%
2002	0	0	—	—	—
2003	3	8	2.7	63%	33%
2004	1	2	2.0	50%	—
2005	3	6	2.0	33%	33%
2006	2	5	2.5	60%	—
2007	3	7	2.3	43%	0%
2008	2	5	2.5	60%	0%
2009	3	7	2.3	29%	29%
2010	2	4	2.0	75%	25%
2011	3	8	2.7	50%	25%
2012	1	2	2.0	100%	0%
2013	6	14	2.3	50%	
Overall	**40**	**94**	**2.4**	**52%**	**21%**

[a] Blanks indicate no cubs were born to collared females or collared mothers with cubs died before the subsequent den visit to assess cub survival.

Table 6. Black bear cubs examined in dens in Voyageurs National Park during March, 1999–2013. All adult collared females were killed by hunters in fall 2007, so no reproductive data were obtained during 2008–2009.

Year	Litters checked	No. of cubs	Mean cubs/litter	% Male cubs	Mortality after 1 yr[a]
1999	5	8	1.6	63%	20%
2000	2	5	2.5	60%	80%
2001	3	4	1.3	50%	75%
2002	0		—	—	—
2003	5	13	2.6	54%	8%
2004	0		—	—	—
2005	5	13	2.6	46%	20%
2006	1	2	2.0	50%	0%
2007	3	9	3.0	44%	—
2008	0				
2009	0				
2010	1	2	2.0	50%	0%
2011	1	2	2.0	0%	0%
2012	1	2	2.0	0%	50%
2013	1	2	2.0	50%	
Overall	**28**	**62**	**2.2**	**48%**	**27%**

[a] Blanks indicate no cub mortality data because no cubs were born to collared females.

Table 7. Extent of black bear-related damage to cropfields in NW Minnesota perceived by interviewed farmers, 2009–2012. Growers were asked to subjectively rate levels of bear damage to their crops based on a scale of 0 (no damage) to 5 (major damage).

Crop	Number of interviewees	Bear damage rating	
		Mean	95% CI
Hybrid/grain corn	13	3.61	2.71 – 4.51
Silage corn	10	1.83	1.30 – 2.68
Oilseed sunflowers	15	2.20	1.17 – 3.23
Confection sunflowers	9	0.28	0.04 – 0.52
Oats	9	2.94	1.96 – 3.93

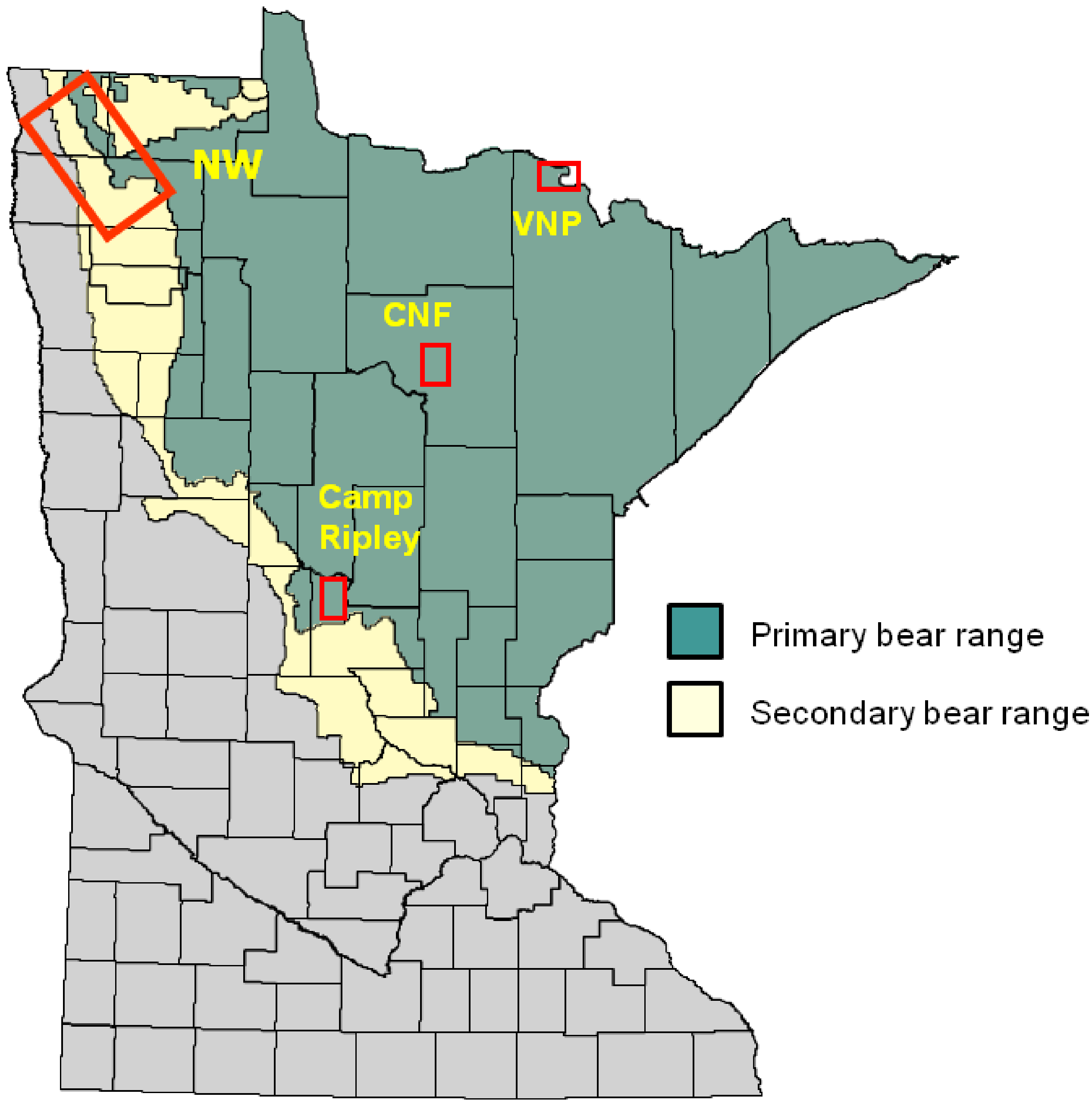

Figure 1. Location of 4 study sites within Minnesota's bear range: CNF (Chippewa National Forest, central bear range; 1981–2013); VNP (Voyageurs National Park, northern fringe of range; 1997–2013); Camp Ripley Military Reserve (near southern edge of range; 1991–2013); NW (northwestern fringe of range; 2007–2013).

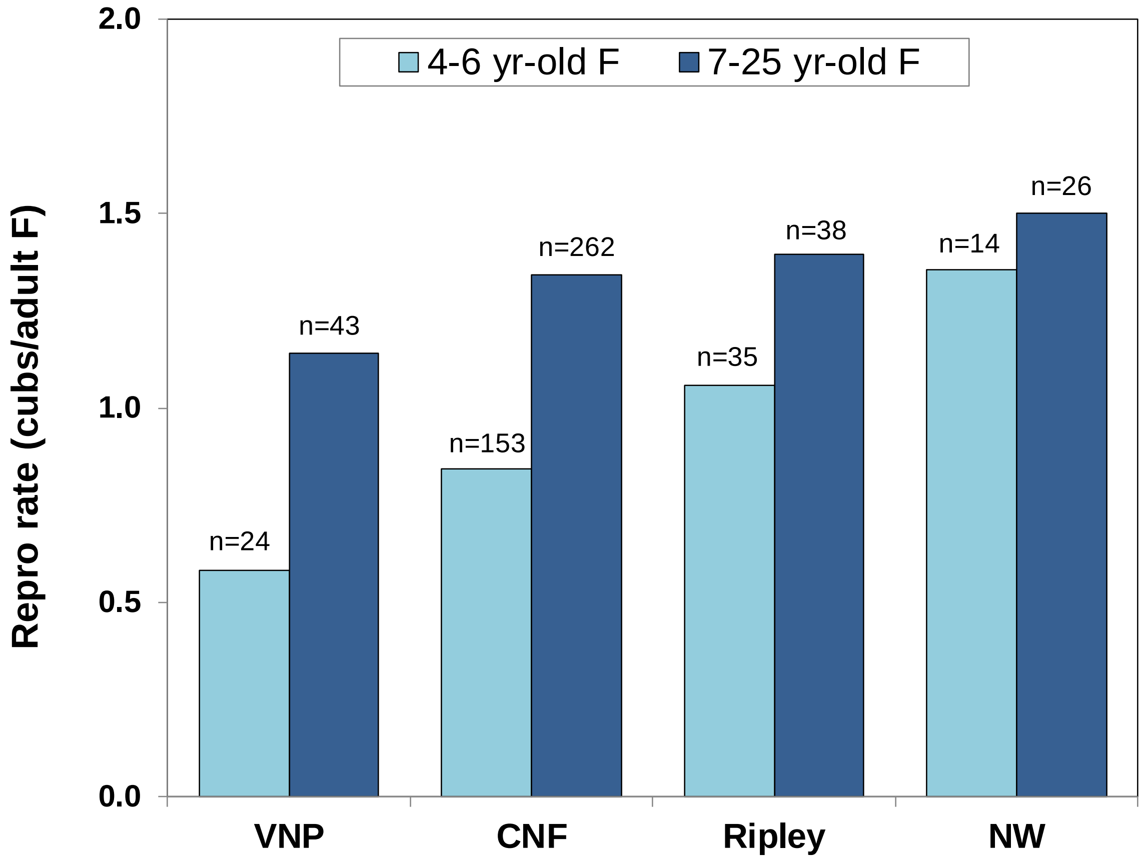

Figure 2. Reproductive rates of radiocollared bears within 4 study sites (see Figure 1) through March 2013. Sample sizes refer to the number of female bear-years of monitoring in each area for each age group. Data include only litters that survived 1 year (even if some cubs in the litter died). Some bears in CNF, Camp Ripley, and NW produced cubs at 3 years old, but are not included here.

Spring-summer

Fall

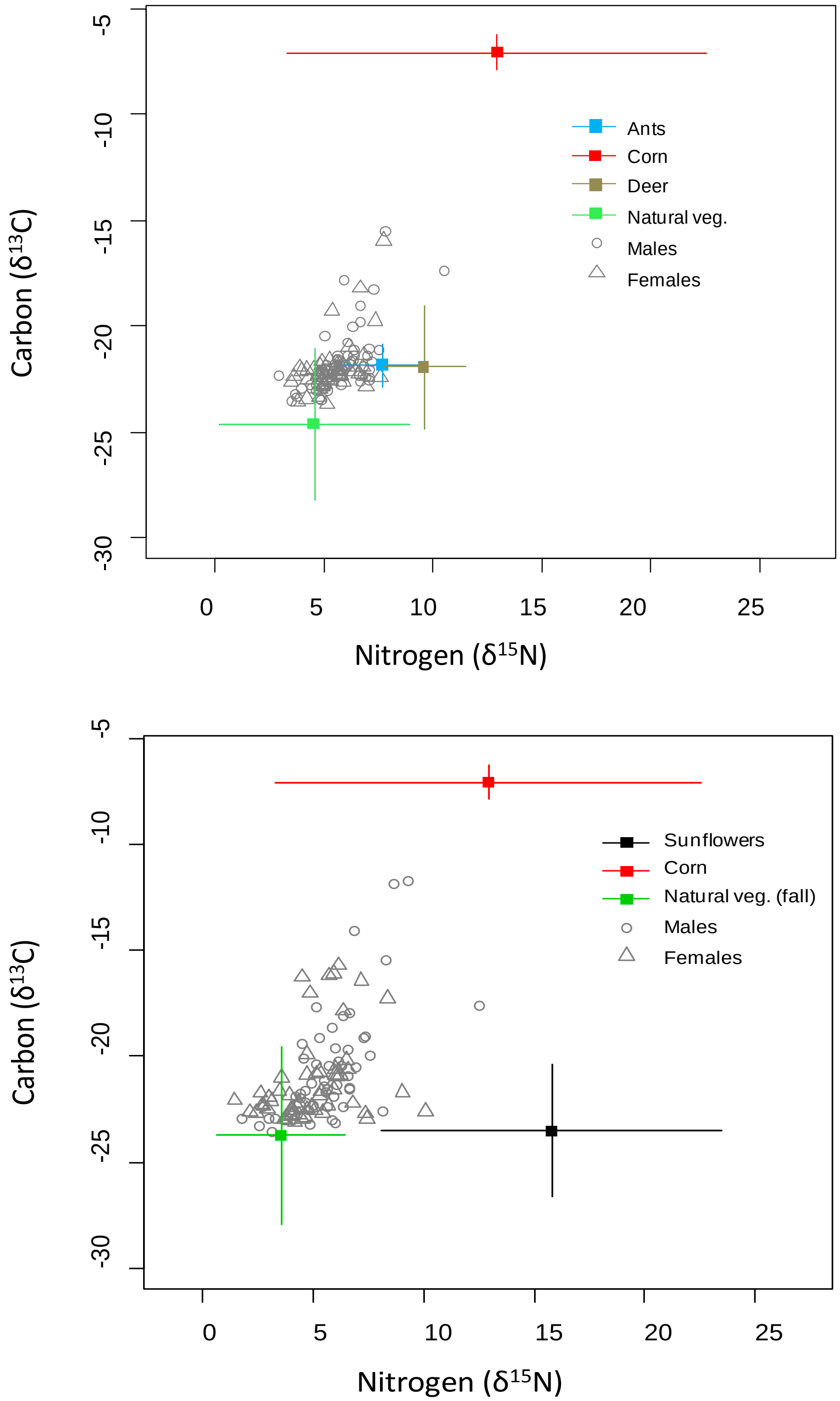

Figure 3. Stable isotope signatures obtained from hair samples of collared black bears in NW Minnesota, 2007–2012 (*n* = 58 female bear-years, 52 male bear-years; 21 different females, 30 different males) compared to mean isotope signatures (and 95%CI) of seasonal bear foods. Hair samples were divided into 2 sections representing spring-summer growth (assimilated diet during April–July; top panel) and fall growth (diet during August–denning; bottom panel). Samples with more enriched C and/or N in fall represent diets with increased use of corn or sunflowers. Corn in spring diet is from spillage and unharvested fields. Natural vegetation is season-specific (herbaceous plants and fleshy fruits in spring-summer; mainly nuts in fall).

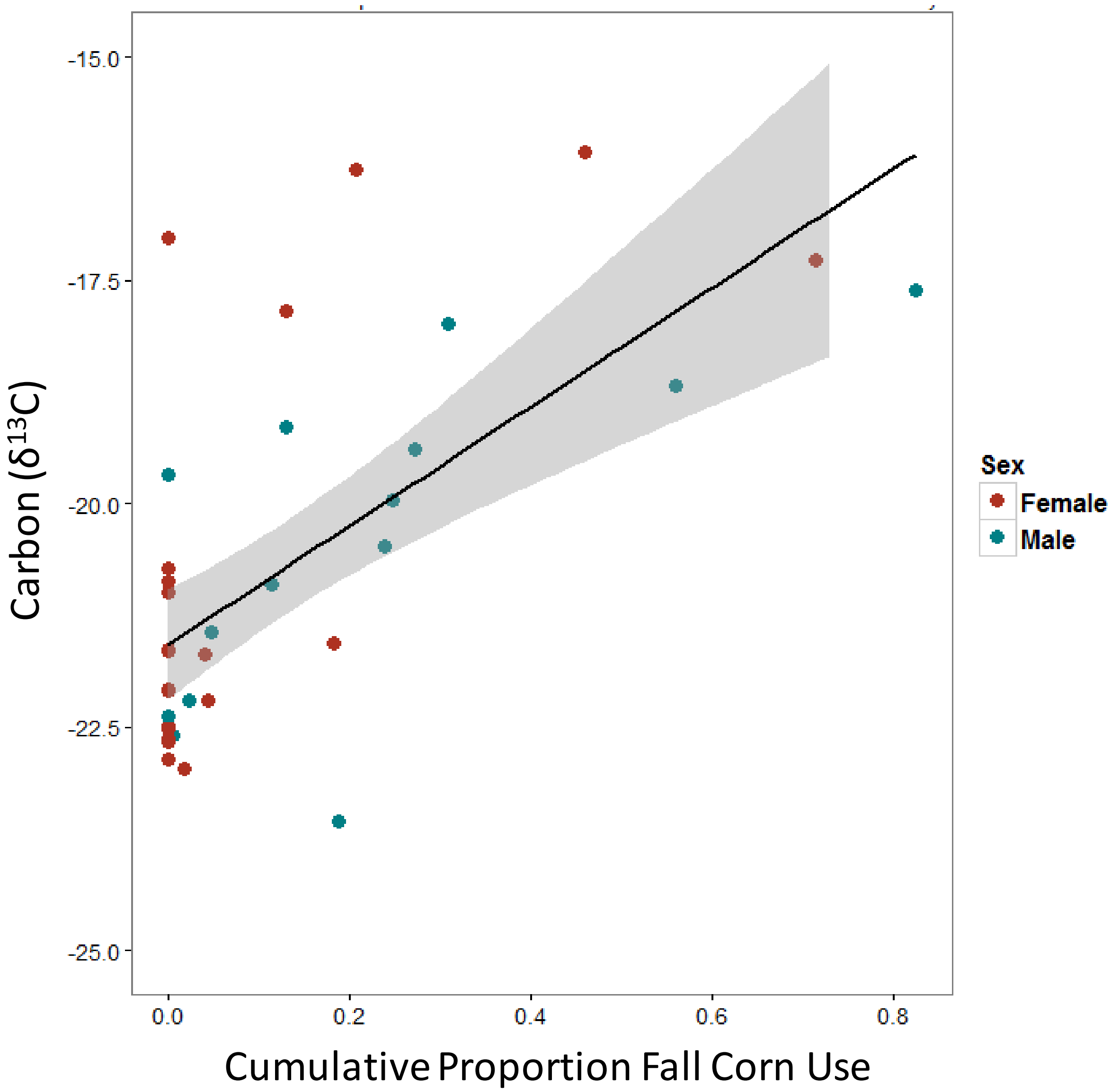

Figure 4. Isotopic values of carbon in fall growth of hair samples from GPS-collared black bears in NW Minnesota, 2007–2012 (*n* = 38 bear-years from 10 male and 12 female bears) compared to each individual's use of corn (measured as the summed proportion of GPS locations in cornfields each month, August-denning). Bears that spent more time in cornfields had more enriched carbon (r^2 = 0.434, P < 0.001; grey area represents ±SE of regression), indicating that stable isotope analysis portrayed the use of this crop.

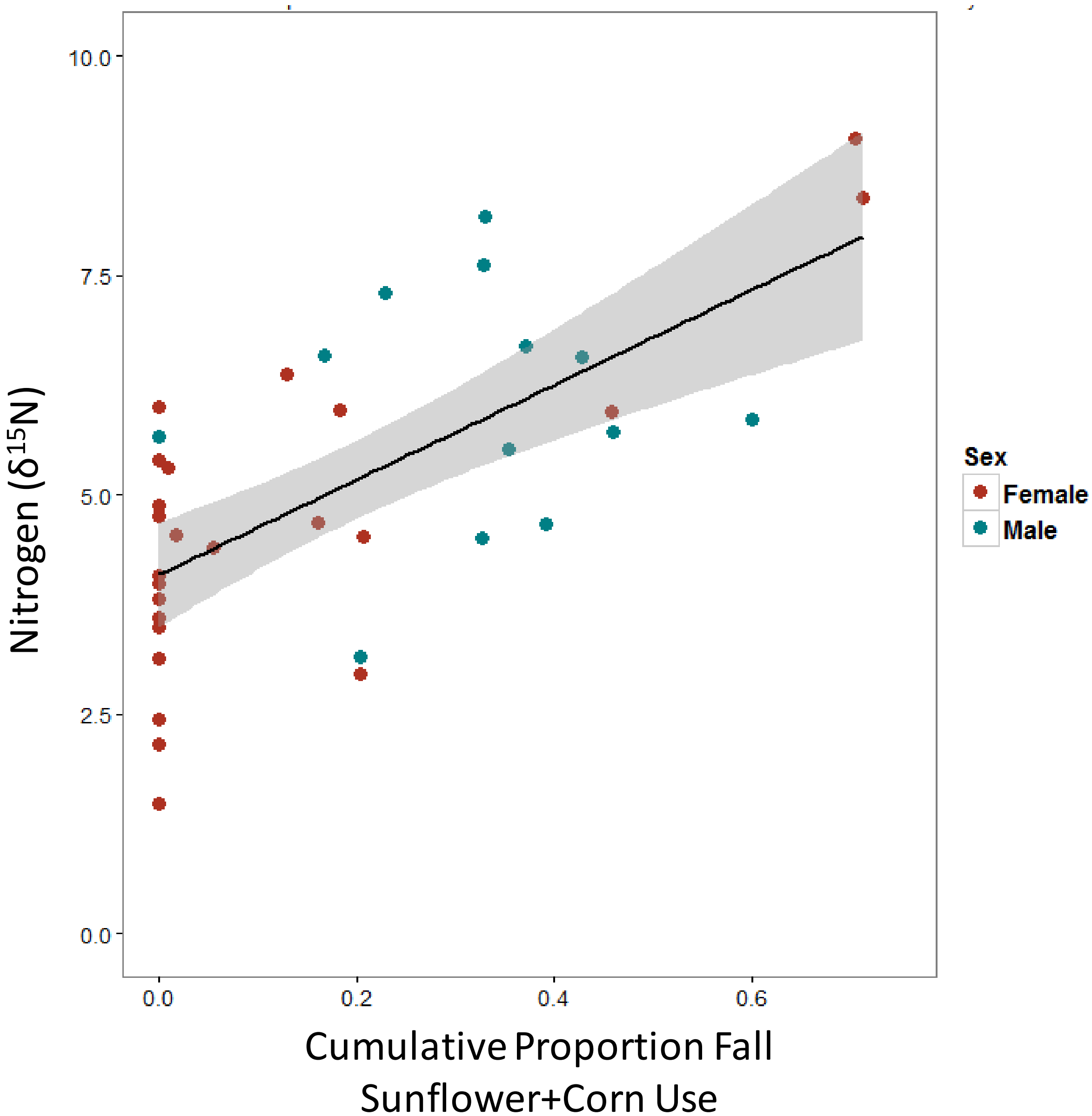

Figure 5. Isotopic values of nitrogen in fall growth of hair samples from GPS-collared black bears in NW Minnesota, 2007–2012 (*n* = 38 bear-years from 10 male and 12 female bears) compared to each individual's use of sunflowers and corn (measured as the summed proportion of GPS locations in these cropfields each month, August-denning). Bears that spent more time in sunflower and corn fields had more enriched nitrogen (r^2 = 0.554, P < 0.001; grey area represents ±SE of regression), indicating that stable isotope analysis portrayed the use of these crops.


Figure 6. Bears were especially attracted to oilseed sunflower fields. Fields like this one provide rich, abundant food for bears during the hyperphagic period prior to hibernation, as well as nearby cover and shade.

MEASURING THE APPARENT DECLINE OF A BEAR POPULATION IN THE CORE OF MINNESOTA'S BEAR RANGE

David L. Garshelis, Karen V. Noyce

SUMMARY OF FINDINGS

Bear abundance in the Chippewa National Forest (CNF) appears to have been declining for the past 2 decades, due to heavy hunting pressure. During the summer of 2012, we conducted a genetic capture–mark–recapture (CMR) estimate of abundance using hair snares to ascertain how much the population has declined. We will compare this estimate to CMR estimates from the 1980s and 1990s, which employed radiocollars as marks. We set 121 barbed wire hair snares in the same study site as used in the 1980s and 1990s. We checked snare sites 6 times, at 10-day intervals. Visitation by bears was high (55% of site-session checks), yielding 2784 hair samples, of which 1120 were submitted for genetic analysis. At the same time, we conducted a bait-station survey through the central study area, patterned after surveys conducted during the 1980s: bear visitation in 2012 was only 2%, compared to 35–70% during the 1980s. After completion of genetic analysis and computation of a population estimate we will learn whether the high visitation at hair traps represented a higher than expected abundance of bears, or a few bears visiting many traps.

INTRODUCTION

In 1981 we initiated a bear research project near the geographic center of the bear range, mainly within the Chippewa National Forest (henceforth CNF; Figure 1). A primary objective of this study was to monitor population dynamics in an area considered representative of much of the north-central part of the state in terms of habitat and hunting pressure. Radio-telemetry provided the central means of collecting population-related data on bears in the CNF during the 1980s. Population estimates were obtained through capture–mark−recapture (CMR), where marks were radiocollars (Garshelis 1992). Due to budgetary constraints, trapping was discontinued after 1989, at which time 7 population estimates had been obtained (1983−89); these suggested an increasing population trend (Figure 2). An upward trend also was observed for bears captured per unit effort, an index of bear density (Figure 2). We also conducted a bait-station survey through the middle of the study area in early July each year, consisting of 50 baits spaced at 0.5-mi intervals along dirt roads; the percent of baits taken by bears after 1 week was supposed to be another index of population size, but population trend gleaned from this survey did not match the trapping data (Figure 2).

A second series of population estimates was obtained in the mid-1990s (1994−1996), again using collared bears as marked animals, but instead of physical captures, we employed cameras (Noyce et al. 2001). These estimates were consistently lower than obtained in the late-1980s, suggesting that the population had declined (Figure 2).

Concurrent with these estimates, we observed a decline in the age of harvested female bears taken from the bear management unit (BMU) that contains the CNF study area, possibly indicating an over-harvest. These data were obtained from teeth submitted by hunters each year.

Periodic trapping during 2000−2005, while not sufficient to provide an estimate of density, indicated that the effort required to catch a bear in the CNF was 2−5x higher than it had been in the late 1980s (Figure 2). A bait-station survey conducted through the CNF in 2009 yielded a bear visitation rate of only 6%, <20% that of the late 1980s.

All of these indicators point to a population decline in the CNF resulting from an excessive harvest. Harvest is controlled by a quota, which was purposefully reduced during the past decade to lessen hunting pressure in response to a perceived population decline. Nevertheless, it appears that the population declined faster than expected, meaning that each year's reduced harvest may still be an over-harvest. Whereas collectively these data are strongly indicative of population trend, it is not possible to ascertain the true magnitude of population decline without an actual density estimate.

Since our work with physical CMR in the 1980s and camera-captures in the mid-1990s, a good deal of effort has gone into the development of genetic CMR approaches. The basic technique was first outlined by Woods et al. (1999). It involves stringing barbed wire around trees, thereby enclosing a small area. A scent lure and(or) suspended bait in the middle of the barbed-wire enclosure is used to entice bears to crawl under the wire, whereupon a clump of hair is plucked from their back; this hair is genetically analyzed to differentiate individuals. Many modifications of this basic procedure have been tried and compared (e.g., Boulanger et al. 2006, Tredick et al. 2007, Dreher et al. 2009, Robinson et al. 2009, Proctor et al. 2010, Pederson et al. 2012).

Genetic CMR has many advantages over marking bears through physical captures and radiocollaring. Because bears are not handled, checking hair traps requires a lower level of skill; more traps can be set because they do not have to be checked daily; and bears likely have less aversion to the traps, so are more likely to be recaptured; thus capture samples are apt to be larger and less biased. Moreover, radiocollaring necessitates later den checks to adjust or remove collars. For these reasons, we elected to employ genetic CMR to obtain a new population estimate on the CNF.

OBJECTIVES

1. Obtain an estimate of bear numbers on the CNF study site with sufficient precision to discern a decline of ≥50% during the past 20 years.
2. Obtain an estimate of bear density on the CNF with sufficient precision to guide management.
3. Obtain a reliable estimate of the sex ratio of bears on the CNF.

METHODS

The study area was same CNF study site where previous CMR estimates were obtained. It contains good access via 2 main paved roads, smaller unimproved roads, and forest roads. Ownership is mainly national and state forest, with additional county lands and private lands.

Hair traps were erected the third week of May, 2012, and removed the third week of July. We erected hair-snare traps using 2 strands of 4-pronged barbed wire wrapped around trees, 1 at 45 cm and 1 at 75 cm off the ground (Figure 3). We erected 1 trap in each square-mile section (121 mi^2). We set traps in what we perceived as good bear habitat to maximize visitation. We set traps at least 100m from main roads, but often along trails that we suspected bears would use.

We suspended a bag of bacon and a scent lure from a wire (above the reach of a bear) in the middle of each trap, and put bait and scent lure on a pile of brush in the middle of the enclosure (Figure 3). Baits and lures were refreshed at each trap visit. We added different types of lures at each trapping session to maintain novelty for the bears. We checked all traps 6x at intervals of 10 days. We did not move traps between sessions. At each trap check, all bear hair was removed from the wire. Each clump of hairs on a barb was collected in a separate envelope, and labeled as to proximity to other barbs with hair, trap number, and date (Figure 4). We coded barbs of hair that were adjacent (next to, or on the wire above/below) as being from the same cluster.

We set camera traps at some of the hair traps that were visited by bears to gauge whether cubs of the year left hair on wires, and to assess the responses of different bears to the wires and the baits.

During the first week of July, 2012, we conducted a bait-station survey, using the same technique and route through the study area as in our previous bait-station surveys. We wired 50 1-lb sacks of bacon to trees, spaced at 0.5-mile intervals, and checked them for visitation 1 week later.

RESULTS AND DISCUSSION

We checked all 121 hair traps 5 times (605 site-sessions), then dismantled 36 traps that were never visited by a bear, leaving 85 to be checked in session 6. Of 690 total site-sessions, 377 (55%) had bear hair (Table 1). Bear visitation was low in the first session (late May), then increased, possibly as bears became more accustomed to the traps and scents.

We collected a total of 2784 barbs of hair (Table 1). We did not collect hairs from barbs with fewer than 3 hairs because it would have been unlikely to yield enough DNA for genetic analysis. Our budget was not sufficient to analyze all collected hair samples, so we subsampled the collection. In subsampling we made an attempt to maximize the number of different bears that visited the sites. Thus, we initially chose (randomly) 1 barb from each of the 377 site-sessions with hair. We chose additional samples that, where possible, were not within the same cluster of barbs as the initial sample. We chose 737 samples from among the remaining 1265 clusters, yielding a total of 1114 samples for processing. Not all of these samples will yield sufficient DNA for genetic analysis.

We also submitted hair samples from 4 radiocollared bears and their current offspring living on the study area (collected during den visits) to determine whether they visited the hair traps.

Camera trap photos showed that individual bears visited traps multiple times within sessions, and also visited multiple traps. Individual bears entered and left traps at various locations along the wires, and different bears entered and left at some of the same locations (Figures 5,6). Thus, our presumption may not be correct that clusters of adjacent barbs are likely to be the same bear; also, some barbs may have collected hair from >1 bear. This will not affect the population estimate, as hairs from multiple bears on a single barb would be genetically discernible. Some photographed bears seemed reluctant to cross the wire (Figure 7), but we assume that most or all of these eventually did so, given the ease and frequency with which other identifiable bears entered the enclosure.

Camera traps also revealed that some bears learned how to reach the suspended bait, either by climbing nearby trees (Figure 8), or pulling down the string on which the bait was suspended. Despite consumption of this bait, the stations remained attractive to bears due to the lingering odors of the scents on the brush pile in the middle.

Only 1 of 50 baits on the bait-station survey was taken by a bear, 3 were taken by raccoons or fishers, yielding a bear visitation rate of 1/(50-3) = 2%. This is the lowest visitation rate ever measured in this area (Figure 2). This low rate of visitation appears inconsistent with the high visitation at the hair traps. The difference may have been due to (1) the location of hair traps in good bear habitat, distant from roads, and (2) the use of strong, attractive scents and more bait at hair traps. We will not know until after completion of genetic analysis and computation of a population estimate whether the high visitation at hair traps represented a higher than expected abundance of bears, or few bears visiting many traps.

ACKNOWLEDGMENTS

We sincerely thank the 2 volunteers who checked traps and meticulously collected hair: Chris Anderson and Chih-Chien (Jerry) Huang. We also thank the individuals who allowed us to set and check traps on their private land: Bradley Box, Mark Hawkinson, Dale Juntenen, Brad and Mary Nett, Jack Rajala, Scherer Brothers Lumber Company, and Thomas Schultz.

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Table 1. Bear hair collected at 121 barbed wire hair snares in the CNF during summer 2012.

Session	Dates	Number of snares with hair[a]	Number of barbs with hair	Number of barb clusters[b]
1	25 – 31 May	30	298	149
2	5 – 10 June	63	626	308
3	15 – 21 June	65	470	279
4	25 – 30 June	79	650	392
5	5 – 10 July	76	448	303
6	13 – 19 July	64	292	211
Total		**377**	**2784**	**1642**

[a] Each hair-snare was checked in each of sessions 1 – 5. Snares that were never visited by bears during that period (n = 36) were dismantled prior to session 6.

[b] Barbs with bear hair that were adjacent to each other, either on the same or different wires, were considered a cluster, possibly representing a single bear entering or leaving a hair snare.

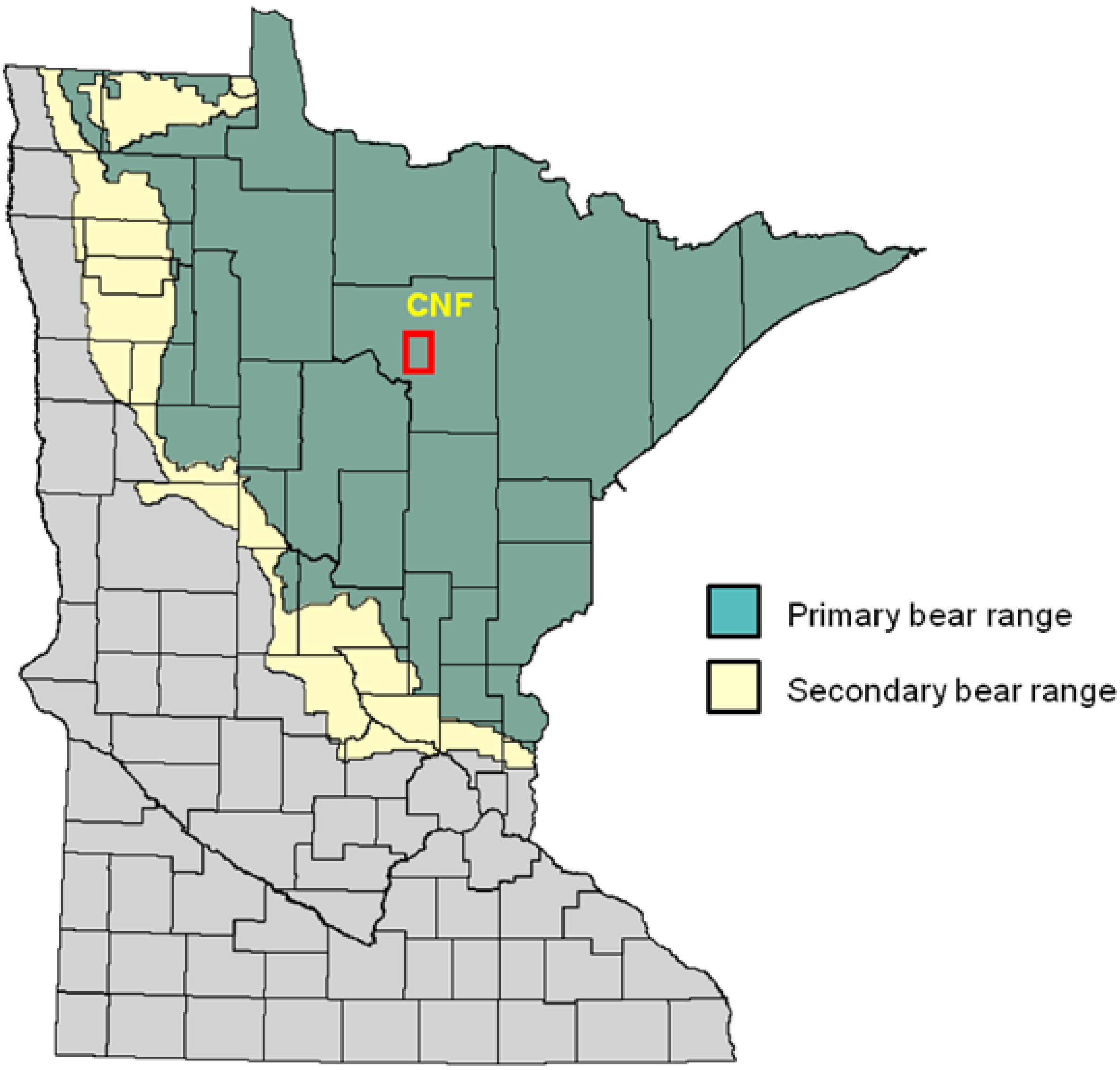

Figure 1. Location of study site in Chippewa National Forest, central bear range, 2012.

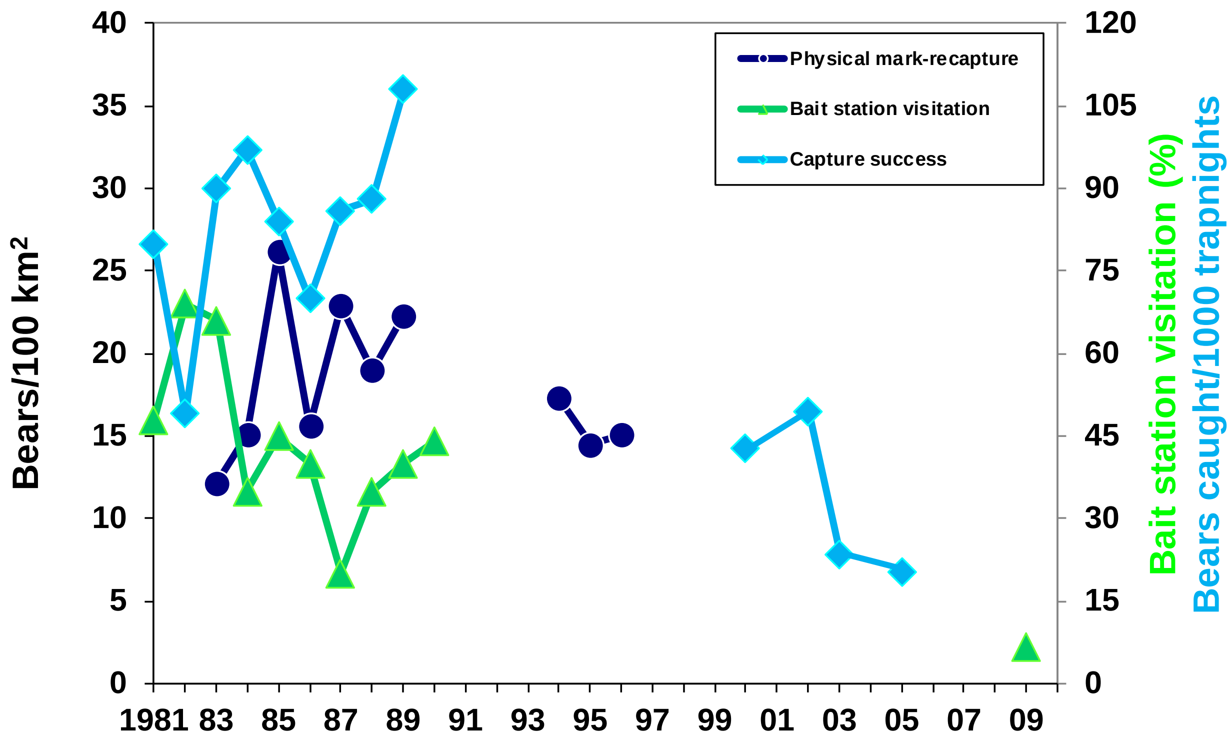

Figure 2. Indicators of bear population trend on the CNF study site, 1981–2009: density estimates derived from mark−recapture of radiocollared bears (physical captures in the 1980s, camera captures in the 1990s); bear visitation to baits on a standardized route through the study area; and bears caught (trapped) per unit effort.

Figure 3. Set-up of barbed wire hair snare, showing 2 strands of barbed wire, central pile of bait and scent, and suspended bait and scent cup.

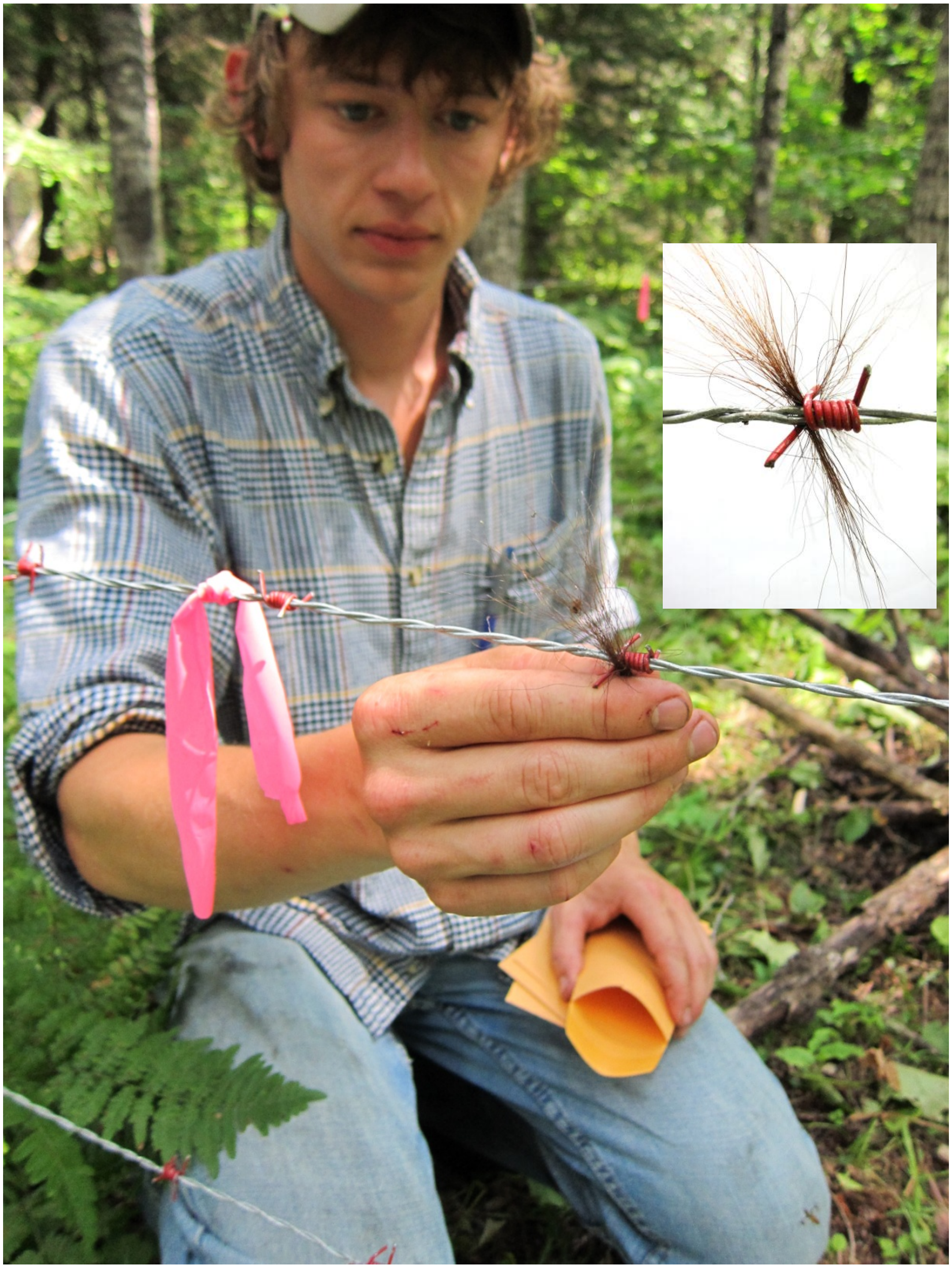

Figure 4. Volunteer Chris Anderson collecting bear hair from a barb. Each sample was placed in an individual envelope indicating the date, trap number, and location relative to other barbs with hair.

Figure 5. Radiocollared and eartagged adult female bear entering and then leaving hair snare at same site (1 minute apart), going between wires on 1 pass, and below lower wire on second pass. The other bears in the photos are her yearlings, 1 of which passed through the wires at the same spot as the mother.

Figure 6. Marked adult female bear, probably in estrus, followed under the same spot in the wire hair snare by an unmarked young male about 1 hour later. Prior to the arrival of this male, a much larger male was photographed consorting with this female inside the enclosure. That male exited a different way.

Figure 7. Some bears seemed deterred by the wire. This bear paced around the enclosure, but never entered. It is not known whether bears like this eventually entered a hair trap and were sampled.

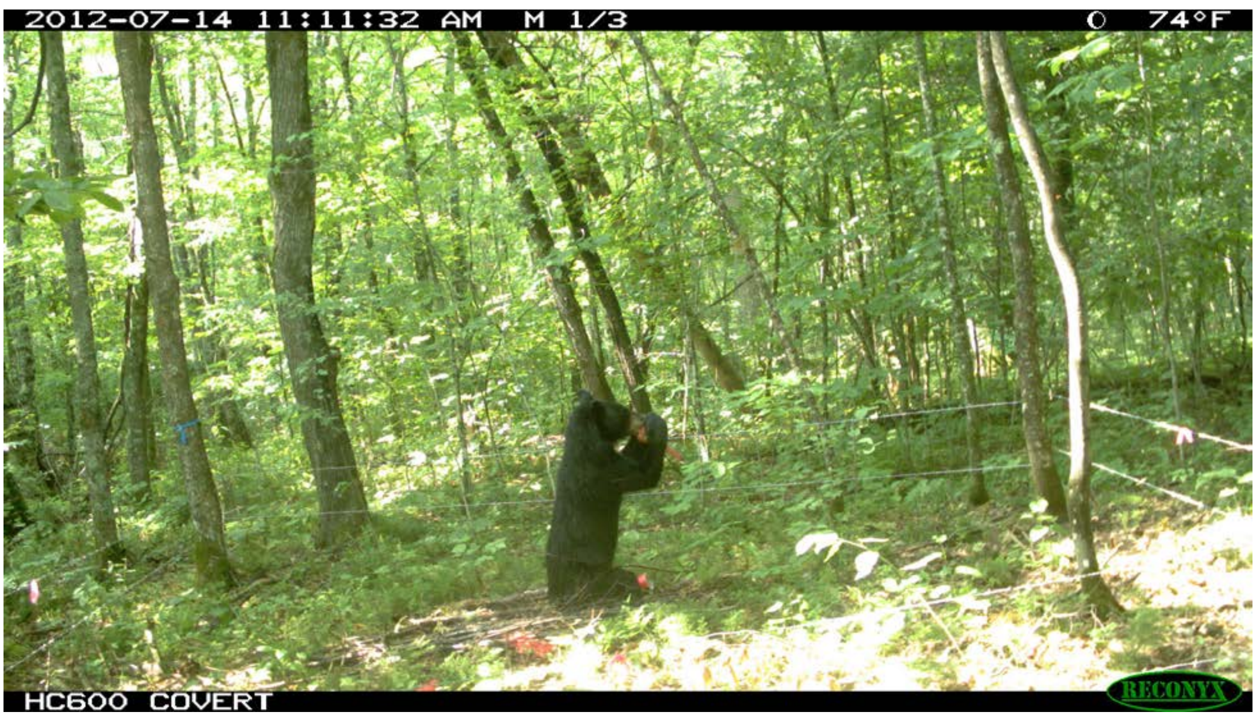

Figure 8. Some bears discovered clever ways of reaching the suspended "inaccessible" bait. The disappearance of this bait became increasingly common through the summer sampling period.

HELICOPTER CAPTURE OF NEWBORN MOOSE CALVES IN NORTHEASTERN MINNESOTA: AN EVALUATION

Glenn D. DelGiudice, William J. Severud, and Robert G. Wright[1]

SUMMARY OF FINDINGS

Important to our new study of moose (*Alces alces*) calf survival and cause-specific mortality in northeastern Minnesota, our objective here is to evaluate helicopter capture of newborn moose calves to better understand its value for fulfilling our primary research goal and to assess risks to the welfare of the captured calves. On 1 May 2013, we began monitoring the locations and movements of 52 pregnant global positioning system (GPS)-collared females to determine when they made their "calving move." We allowed an average of 54 hours of dam-calf bonding time before capture. We captured 49 (25 females, 24 males) newborn calves of 31 dams during 8-17 May 2013. Mean birth-date of captured neonates was 11 May 2013 and mean capture-date was 13 May. The overall twinning rate was 58% (18 of 31 dams). Mean rectal temperature, body mass, and hind leg length were 101.6^{o} F, 16 kg, and 46.2 cm, respectively. Capture operations yielded 38 GPS-collared calves suitable for studying survival and natural mortality. We unexpectedly documented a relatively high level of abandonment of calves by their dams during capture operations. Seven of a total of 31 dams abandoned 9 calves, possibly prompted most directly by the helicopter. Female calves were 2 times as likely to be abandoned as males (6 females, 3 males), but otherwise our examination of numerous factors revealed no relationships with the unpredictable abandonment behavior of the dams. We are discussing several considerations and ideas for attempting to reduce capture-related abandonment and mortality in the future.

INTRODUCTION

The moose population in northeastern Minnesota has been declining since at least 2005 from an estimated 8,160 moose to the current (2013) estimate of 2,760 (Lenarz et al. 2009, 2010; DelGiudice 2013). Annual aerial moose surveys have indicated an estimated decline of 52% from 2010 to 2013 (DelGiudice 2013). Climate change (i.e., warming temperatures) has been implicated in the population's decline, as well as for the population in northwestern Minnesota (Murray et al. 2006; Lenarz et al. 2009, 2010). In the latter, malnutrition and pathogens were identified as contributing factors to the population's diminution, but in the northeast associated specific causes of natural mortality remain largely unknown (Lenarz et al. 2009, 2010). Mean annual natural mortality rates of adults were similarly high in the northwest and northeast (21%, Murray et al. 2006, Lenarz et al. 2009), and currently remain elevated (R. A. Moen, Natural Resources Research Institute [NRRI], Duluth, MN, personal communication). Further, the long-term stochastic growth rate for the northeastern population was estimated at 0.85 and was most sensitive to estimated adult survival rates (Lenarz et al. 2010). These findings collectively have prompted the Minnesota Department of Natural Resources (MNDNR) to launch a new study focused on determining the specific causes of adult mortality (Butler et al. 2011).

Adult survival has a greater impact on ungulate population dynamics than that of juveniles; however, high annual variability in juvenile survival also can have a pronounced influence on a population's growth rate (Gaillard et al. 1998, 2000). Across much of moose range in Ontario, Canada, declining moose numbers and winter calf:cow ratios have been a cause for concern since the 1990s (Patterson et al. 2013). These authors reported that overall, natural causes

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were the leading mortality forces, primarily predation by black bears (*Ursus americanus*) and wolves (*Canis lupus*) in Algonquin Provincial Park, and malnutrition, exposure, and tick-related mortality in a Wildlife Management Area where hunting was permitted and accounted for 16% of calf mortality.

Average pregnancy rates have been relatively high (83%) in northeastern Minnesota, but annually it has been variable (range of 55-100%; Lenarz, unpublished data). Recently, Lenarz et al. (2010) reported an average annual survival rate of 0.40 for calves in the northeastern population. These crude estimates were based on fixed-wing flights conducted during May-June to determine whether radiocollared cows had newborn calves present, and again in April-May of the following year to determine if calves were still present. Further, based on the MNDNR's annual aerial moose survey conducted in January, the calf:cow ratio has declined from 0.52 in 2005 to 0.36 in 2012, and has been as low as 0.24 (2011, Lenarz 2012).

The average annual survival rate of northeastern Minnesota moose was consistent with estimates from moose populations elsewhere where black bears and wolves were common (Hauge and Keith 1981), yet black bear predation on moose calves can be highly variable across North America (see Ballard's 1992 review). Determination of cause-specific mortality of calves was not part of the Lenarz et al. (2009, 2010) study design, consequently very little is known about the specific causes or potential contributing factors.

The goal of our recently initiated moose calf research in northeastern Minnesota, a companion study to the MNDNR's adult moose study, is to enhance our understanding of the seasonal and annual survival of calves, specific causes of mortality and contributing factors, and to assess the potential quantitative impact of calf mortality on the declining trend of the population. The hazard, or instantaneous probability of death, for northern ungulates is highest at birth, and although it declines sharply during the first 12 months, it is markedly higher than during the subsequent prime years of its life (DelGiudice et al. 2002, 2006; Lenarz et al. 2010). Fulfilling the primary goal of the calf study requires 3 things, the ability to: 1) capture and GPS-collar a sample of newborn moose calves representative of the population in northeastern Minnesota, 2) closely monitor the movements and survival of moose calves, and 3) rapidly respond to calf mortalities to investigate and maximize our collection of site and carcass data and other evidence to most accurately determine the specific cause of death and assess the influence of contributing factors. To efficiently and cost-effectively obtain a sample size of 50 newborn calves during the spring of 2013, we opted for capture and handling by an experienced helicopter capture crew (Quicksilver, Inc., Fairbanks, AK, and Peyton, CO). Having captured more than 600 newborn moose calves, as well as neonates of numerous other ungulate species, this company is considered one of the leading helicopter capture outfits with respect to this type of work.

OBJECTIVE

1. To evaluate helicopter capture of newborn moose calves in northeastern Minnesota to better understand its value for fulfilling our primary research goal and to assess risks to the welfare of the captured calves. In a companion research summary (please see Severud, DelGiudice, and Wright), we describe and evaluate our process for monitoring the GPS-collared calves and their dams and rapidly responding to investigate mortalities.

STUDY AREA

The 6,068-km^2 study site for this calf research is the same as that of the Environmental and Natural Resources Trust Fund (ENRTF)-supported research addressing survival and cause-specific mortality of adult moose in northeastern Minnesota (Figure 1). This area has been classified as the Northern Superior Upland region (MNDNR 2007) and is characterized by a variety of wetlands, including bogs, swamps, lakes, and streams; lowland conifer stands, including northern white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), and tamarack (*Larix laricina*); and upland conifers of balsam fir (*Abies balsamea*) and jack (*Pinus banksiana*), white (*P. strobus*), and red pines (*P. resinosa*). Trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*) occur on the uplands, often intermixed with conifers. Open lands included lowland and upland deciduous shrub and sedge meadows. Potential predators of adult moose and their calves include gray wolves and black bears (Fritts and Mech 1981, Erb 2008, Lenarz et al. 2009, Garshelis and Noyce 2011, Patterson et al. 2013). White-tailed deer (*Odocoileus virginianus*) share most of the study area with moose; their pre-fawning densities are managed at ≤10 deer per square mile (MNDNR 2011).

The State moose hunt in northeastern Minnesota has been restricted to adult bulls-only since 2007 and accounts for 1.1-1.9% of the overall population (Lenarz 2011). A total of 87 licenses were purchased this year for the State moose hunt, and 46 adult bulls were harvested. Due to rapidly declining numbers, the State moose hunting season has been cancelled beginning in 2013 until further notice.

METHODS

Beginning 1 May 2013, we began monitoring closely the locations and movements of 52 GPS-collared (Iridium GPS collars, Vectronic Aerospace, Berlin, Germany) adult female moose, which were determined to be pregnant during winter capture by serum progesterone concentrations (≥2.0 ng/mL, Murray et al. 2006). Additionally, we similarly monitored 7 collared adult females not blood-sampled during winter capture and so assigned an "unknown" pregnancy status. Our primary monitoring objective was to record when and where individual pregnant females made their "calving move" (Bowyer et al. 1999; McGraw et al., in review). This is a variable but atypical, long distance move that often occurs an estimated 12 hours before calving, after which the dam's movements become very clustered or localized for up to 7-10 days.

We expected at least 80% of moose calving in northeastern Minnesota to occur during the middle 2 weeks of May (Patterson et al. 2013; Moen, unpublished data). Consequently, the Iridium collars of the adults were programmed to record an hourly fix during the month of May, rather than the normal 4-hour rate. Adult location fixes, and subsequently calf fixes, were transmitted 3-4 and 6 times per day, respectively, to our base station located about 59 km north of the Twin Cities, and we had continuous computer access to the base station. We had 3 sources of data and information for monitoring the hourly locations and movements of the dams, and subsequently of their GPS-collared calves. We have a shared network computer drive (M-drive) with the location coordinates and calculated hourly distances of all of the GPS-collared adult moose; the Vetronics website, which allowed us to observe the locations (and associated information) overlaid on GoogleEarth maps and aerial imagery at various scales; and an automated report produced by J. Forester (University of Minnesota, St. Paul), which plotted mean hourly distances moved for up to 10 days at a time and GPS coordinates of fixes and paths of movement for the most recent 5 days. This report was updated every 4 hours and provided locations and paths of movement for the past 24 hours overlaid on GoogleEarth coverage, as well as calculations of speed and displacement distance (see the research summary of Severud, DelGiudice, and Wright for additional details). Using fixes and hourly distances moved on our M-drive, we calculated and graphed the average hourly distance moved by cows by 3-hour intervals (R. A. Moen and A. McGraw, NRRI, Duluth, MN, personal communication), and identified times of the calving move and capture for estimating bonding time for individual dams and their calves (see example in Figure 2).

We began capture operations with a planning meeting involving the entire capture team (researchers and helicopter capture crew) the day before actually beginning calf captures to ensure that everyone was informed about safety, the monitoring process, criteria for targeting captures, limits on pursuit and handling time, capture-related abandonment and associated issues, and other logistical considerations. We operated our base station for calf captures out of the Ely Municipal Airport.

We assumed that once cows made their calving move, they calved within 12 hours. We then allowed an additional 24 hours for bonding between the dam and her calf or calves for an estimated minimum total bonding time of 24-36 hours. Once monitored females had calved and were allowed this bonding time with their newborn(s), the calves were identified as ready for capture and handling. Each morning our team provided the commercial capture crew with a list of females (ear-tag numbers, GPS collar number, and VHF radio frequency) and their most recent GPS coordinates.

The helicopter capture crew located the target dam from the air and then landed some distance away to allow the handler(s) to disembark and approach calves on foot. The calf handling protocol included slipping an expandable Globalstar GPS collar (440 g, Vectronic Aerospace, Berlin, Germany) over the head; fixing ear-tags; collecting 25 ml of blood by syringe from the jugular vein into 1 EDTA tube for hematology and into 2 serum tubes for laboratory analyses for chemistries, metabolites, electrolytes, and metabolic and reproductive hormones; weighing the calf to the nearest 0.5 kg; recording several morphological measurements (hind leg length, body length, girth, and neck circumference) and a rectal temperature (^oF); and a physical examination to record any noteworthy injuries or abnormalities. The calf collars were programmed to record a fix hourly. Time expended in attempting to capture a calf or calves for handling while dealing with an aggressive dam was to be limited to 10 minutes. Also, to minimize risk of abandonment, if a chase was necessary to capture a calf, it was limited to one attempt per calf. We planned the complete handling protocol to require about 5-6 minutes per calf to limit separation from the dam (Keech et al. 2011), and that in the case of twins, an attempt would be made to handle both calves. Our intention was to learn more about overall health at birth, survival, and cause-specific mortality by not excluding one of the twins. Further, extensive experience had indicated to the capture crew that handling both members of a twin set limited the risk of the dam abandoning the twin being handled with the one not being handled (M. A. Keech, Quicksilver, Inc., Fairbanks, AK, personal communication). An important field objective, when possible, was to capture, handle, and release twins together (Keech et al. 2011); ultimately the handling crew achieved this during our operations with 100% success. All captures and handling protocols followed requirements of the Institutional Animal Care and Use Committee for the University of Minnesota (Protocol 1302-30328A).

RESULTS AND DISCUSSION

Mean birth-date of captured neonates was 11 May 2013 (range = 5-15 May) and mean capture-date was 13 May 2013 (range = 8-17 May). Keech et al. (2011) reported a mean capture-date of 24 May during a 7-year study of newborn moose calves in western Interior Alaska. We captured 49 (25 females, 24 males) newborn calves of 31 dams. With only a few exceptions, dams were relatively non-aggressive during the capture and handling of their calves, particularly compared to dams of captured neonates in Alaska and Ontario (Keech et al. 2011, Patterson et al. 2013). Additionally, our process for monitoring and determining when GPS-collared dams had calved and met our minimum threshold of bonding time with their calves was very successful.

Our overall twinning rate was unusually high at 58% (18 of 31 dams); 11, 4, and 3 were female/male, female/female, and male/male sets of twins. Thirteen adult females had singletons (6 females, 7 males). Patterson et al. (2013) reported an overall twinning rate of 16.7% in a 4-year study of moose calves in central Ontario. Keech et al. (2011) observed an overall average twinning rate of 42% (24-52%) for collared cows ≥3 years old during their 7-year study. The long-term average annual twinning rate in northeastern Minnesota may be about 29% (Schrage, unpublished data), whereas in northwestern Minnesota, Murray et al. (2006) reported an average twinning rate of 19%. The high twinning rate we documented this year likely had much to do with beginning our capture of newborn calves early in the calving season, when the birthing of twins is most likely to occur. From 8 to 15 May, our twinning rate was 71.4%, but during 16-17 May, the twinning rate declined to 30% (70% singletons). An additional contributing factor to the elevated twinning rate may be that the mild winter of 2011-2012 may have allowed for a somewhat higher than normal proportion of cows to enter the rut (2012) in good body condition, increasing the probability that many would conceive twins (Schwartz 2007). This also suggests that a population is below carrying capacity (Gasaway et al. 1992).

Although the distance of the "calving move" was quite variable among individuals, average hourly movements prior to calving and the clustering of locations which occurred immediately following it, allowed us to identify this important behavior with a high degree of confidence (see Figure. 2). Further, having a time associated with "the move" allowed us to estimate dam-calf bonding time with a relatively high degree of certainty. Mean bonding time was 54 hours (n = 49, SE = 2.7, range = 31-116 hr), so on average, these calves were just over 2 days old at capture. Patterson et al. (2013) recently reported bonding times before capture of 9.5-58 hours (median = 19 hr) on their WMU49 site and <48 hours (48%) and 48-120 hours (52%) at Algonquin Provincial Park. In Interior Alaska, Keech et al. (2011) reported estimated mean age of newborns at capture (i.e., bonding times) of 2.6 days (62 hr) and a range of 0.5-11 days (12-264 hr). Typically, our handling time was 2-4 minutes per calf. Although the data did not indicate that handling time might be contributing to capture-related abandonment, after the first 2 cases, we limited our handling protocol to collaring, ear-tagging, measuring body weight, and recording rectal temperature.

Mean rectal temperature was 101.6^{o} F (n = 43, SE = 0.1, range = 99-103.4^{o}F). Apparently, these are the first rectal temperature data reported for free-ranging moose calves, and they are not dissimilar from rectal temperatures of free-ranging, adult white-tailed deer (*Odocoileus virginianus*, DelGiudice et al. 2005). Mean body mass of our captured calves was 16 kg (n = 43, SE = 0.3, range = 12.5-20.5 kg) and mean hind leg length (same as hind foot length) was 46.2 cm (n = 49, SE = 0.2, range = 42-49 cm). As adults, Minnesota moose (*Alces alces andersoni*) tend to be somewhat smaller than Alaskan moose (*Alces alces gigas*, Bubenik 2007); however, generally, body masses of the calves were unexpectedly similar (mean = 17.4 at <3 days old, Keech et al. 2011). In Ontario, mean body mass for calves <48 hours old was 15.4 kg (Patterson et al. 2013). Recording body mass of neonates can be of value to understanding their survival because generally neonates of the deer family at the low end of the birth-mass distribution may be more vulnerable to a variety of mortality factors (Thorne et al. 1976). However, presently such information for moose is sparse. We documented 2 cases of capture-related mortality not associated with dam abandonment. One neonate was accidentally stepped on by the dam, causing a head trauma. This was the smallest neonate (12.5 kg) of all 49. The second calf appeared healthy; however, it had the lowest rectal temperature (99^{o}F), had a relatively low body mass (14.0 kg), and a necropsy showed that its gastrointestinal tract contained no milk.

We unexpectedly documented a relatively high level of capture-related abandonment of calves by their dams during our operations. In these cases the dam would flee at the approach of the helicopter and/or handler(s) and not return for any length of time to the calf or calves. We observed 7 (23%) of 31 dams abandon 9 (18% of) calves, apparently prompted by capture-related activities. Female calves were 2 times as likely to be abandoned as males (6 females, 3 males), but otherwise there were no discernible patterns associated with abandonment events. Abandonment involved 2 cases of both calves of twins, 3 cases of 1 calf of twins, and 2 cases of singletons. All twins were captured, handled, and released together. This was exactly what we had hoped for because, according to the capture crew, this would minimize the risk of the dam abandoning a calf being handled with the one not being handled, even during the brief handling periods required. We examined a number of factors (birth-date, capture-date, bonding time, rectal temperature, calf body weight, and hind leg length) in an attempt to understand what might have influenced or prompted a dam to abandon her calf(ves), including an overall comparison to calves not abandoned and to calves which died from other causes, but there were no clear differences (Table 1). Additionally, we found no spatial pattern of the capture-related abandonments; they occurred throughout the study area. In the Alaskan study, researchers similarly used helicopters to capture 422 moose neonates and experienced 32 (7.6%) captured-related abandonments or mortalities (Keech et al. 2011).

The number of mortalities associated with capture-related abandonment was distributed as follows: May 10th (1), 12th (1), 15th (1), 16th (1), 17th (3), 19th (1), and 20th (1). Because this was the first study of free-ranging moose neonates fit with GPS collars, it permitted nearly continuous monitoring of the calves and their GPS-collared dams. Indeed, unlike in other studies employing VHF telemetry, there was almost no way abandonment could be underestimated unless the collars malfunctioned. Using VHF telemetry, Patterson et al. (2013) reported only 4 (4.6%) capture-related calf abandonments in a study which spanned 4 springs; all of their newborn calves were captured without the use of helicopters. They observed no relationship between body mass of the calves (indicative of their condition or development) and abandonment. Ground capture may limit the obtainable annual sample size of collared calves, but it also may at least partially account for the relatively low estimated number of abandonments in their study.

Movement behavior of dams which abandoned calves during and immediately post-capture/handling varied markedly. For example, in our study twin calves of dam number 12607 were captured on 14 May at 1216 hours. The dam made her first movement away from the calves about 15 hours later, moving about 2 km southwest. About 9.5 hours after that she made a 600-m move north, but was still more than 1 km from the calves. On 16 May at 0045 hours this dam made a large movement back to within 20-40 m of the calves, but then only about an hour later she moved 200 m west away from the calves, and then by 0255 hours she was about 1.5 km northwest of the calves. Finally, on 17 May (0215 hr), 12607 moved eastward again towards her twins, but only to within 200 m, and never actually returned. Shortly thereafter, she moved northwest and settled down about 1 km from her calves.

A second example involved dam number 12569, which also abandoned twins (captured/handled on 15 May at 1020 hr). This dam first moved about 500 m away from the calves at 1624 hours, but then made a 200-m move southwest and then a large movement back to the calves at 1830 hours to within 40 m. But then at 2143 hours the dam moved 700 m northeast away from the calves, followed by a movement that put her 1.5 km directly north of her calves. On 17 May (0225 hr), she moved back to within 100-200 m, but subsequently was located 2 km away from the calves. Finally, on 19 May the dam returned to the calves' location, but they had died on 17 May. These are just 2 examples of the 7 dams that abandoned their calves during capture operations, but the unpredictability of the timing and distance of their movements reflect the difficult challenge of deciding if, when, and how researchers should intervene.

Considerations for Future Capture Operations

Overall, this year's capture operations for newborn moose calves were successful in that they allowed us to better understand calf productivity at the population level and to learn about seasonal and annual survival and the primary natural mortality forces impacting this vulnerable age class. At the individual level, the operations were less successful as reflected by the unexpected high rate of dam abandonment (7 of 31) apparently associated with the capture operations, and possibly most specifically with the helicopter component. What we have learned from our preliminary examination of data from all 49 calf captures is that presently abandonment behavior is not at all predictable or well understood. Previous winter condition of the dams, assessed during their capture, was "normal" to "fat" for all but one "thin animal." Further, the development and condition of the calves as assessed during handling (e.g., body mass, hind leg length, and rectal temperature) did not appear to be influential factors. We hope to learn more from the ages of the 31 dams once those data are available from the analysis of last incisors extracted when they were captured during January-February 2013. It is conceivable that young or old dams may be most likely to abandon their newborns when disturbed, but presently this is unknown.

For next year's capture operations we will consider all the information gathered from our review of this year's data in an effort to markedly limit and minimize capture-related abandonments and mortalities. This may involve including a certain proportion of ground captures; higher-altitude approaches by the helicopter and greater landing distances from the dam and calves to be handled, with a 2-day capture protocol (one day for simply observing the location of a dam and its calf[ves] and planning a cautious approach and landing, and a second day for the actual capture); capture operations which span more of the calving period (later in May); and an abandonment response plan.

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Table 1. Comparison of capture-related factors (8-17 May 2013) which might influence dam abandonment of newborn calves, northeastern Minnesota (as of 2 July 2013).

	Mean (±95% CI)					
Group[a]	Birth-date	Capture-date	Bonding time (hr)	Rectal temperature (F)	Body mass (kg)	Hind leg length (cm)
Calves abandoned during capture	20130511 (2)	20130514 (2)	60 (9.2)	101.6 (0.6)	16.4 (1.0)	46.1 (1.4)
All others[a]	20130511 (1)	20130513 (1)	53 (6.4)	101.6 (0.4)	16.0 (0.8)	46.2 (0.6)
Survivors	20130510 (1)	20130512 (1)	62 (13.8)	101.7 (0.4)	16.6 (1.4)	46.3 (1.0)
Capture-related mortality[b]	20130511 (6)	20130513 (6)	43 (17.0)	99.0	13.3 (2.2)	44.5 (4.2)
Predator-killed	20130512 (1)	20130514 (1)	46 (6.0)	101.7 (0.4)	15.8 (1.0)	46.4 (0.8)
Other natural	20130508 (2)	20130511 (3)	65.7 (18.0)	101.8 (2.2)	14.3 (6.4)	45.7 (4.0)
Slipped collar	20130513 (3)	20130515 (3)	41 (4.2)	101.7 (1.0)	16.8 (2.4)	46.3 (0.6)

[a]Capture and handling circumstances did not always allow collection of all data for each calf; therefore sample sizes varied as follows: capture-related abandonment (8-9), "all others" (35-40), survivors (12-15), capture-related mortality (1-2), predator-kill (13-15), "other natural" (2-3), and slipped collar (4); the maximum was the total handled per group. [b]One calf, the smallest (12.5 kg) was fatally wounded by its dam during the capture process. A second calf, a singleton, appeared healthy during the capture and handling, but died 4 hours later of unknown causes. The handling was brief and largely uneventful, except this calf exhibited the lowest rectal temperature (99^{o}F) of all the neonates. The dam stayed close before, during, and post-capture, including when the carcass was recovered. Despite the dam's proximity, necropsy showed that the calf's gastrointestinal tract contained no milk. We are awaiting pathology results.

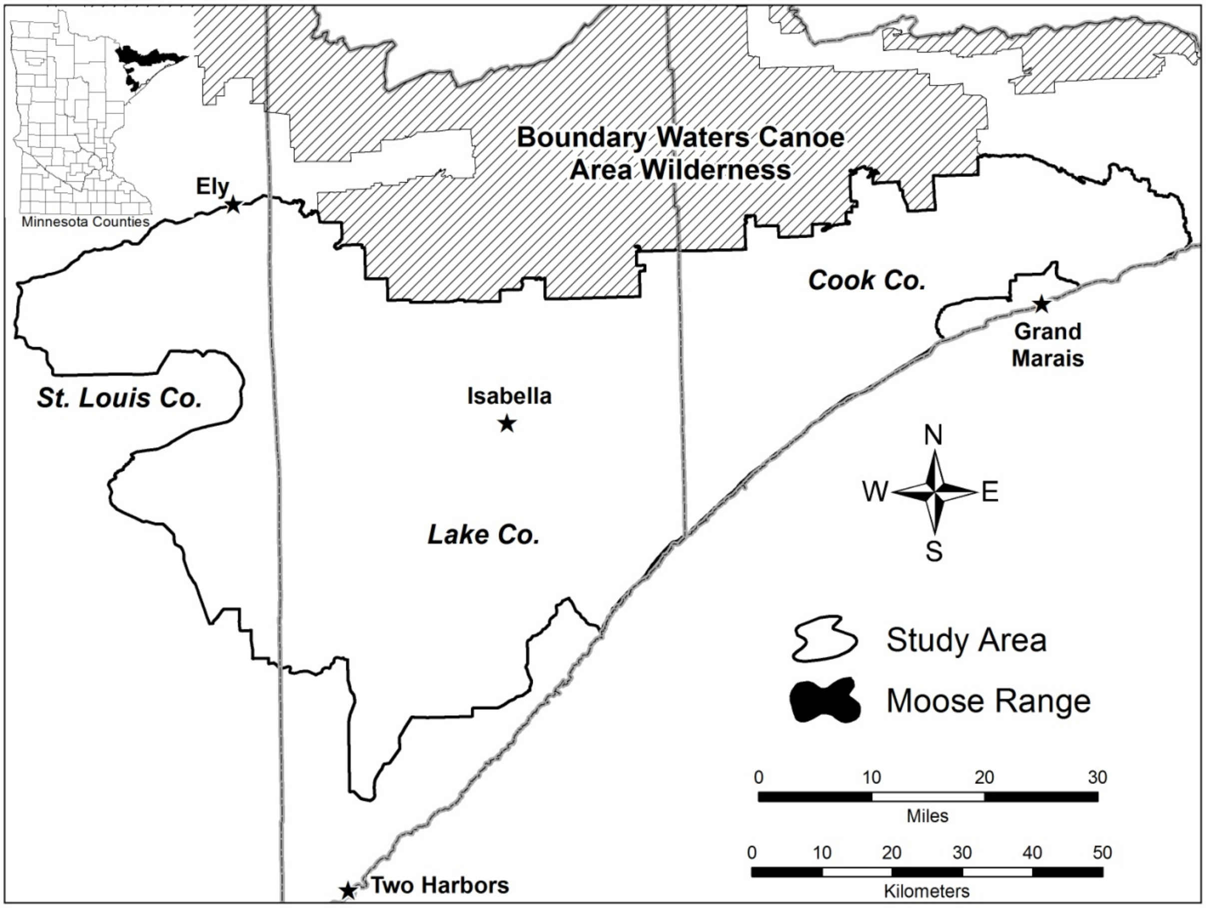

Figure 1. Study area for the study of moose calf survival and cause-specific mortality, northeastern Minnesota, 2013-2017.

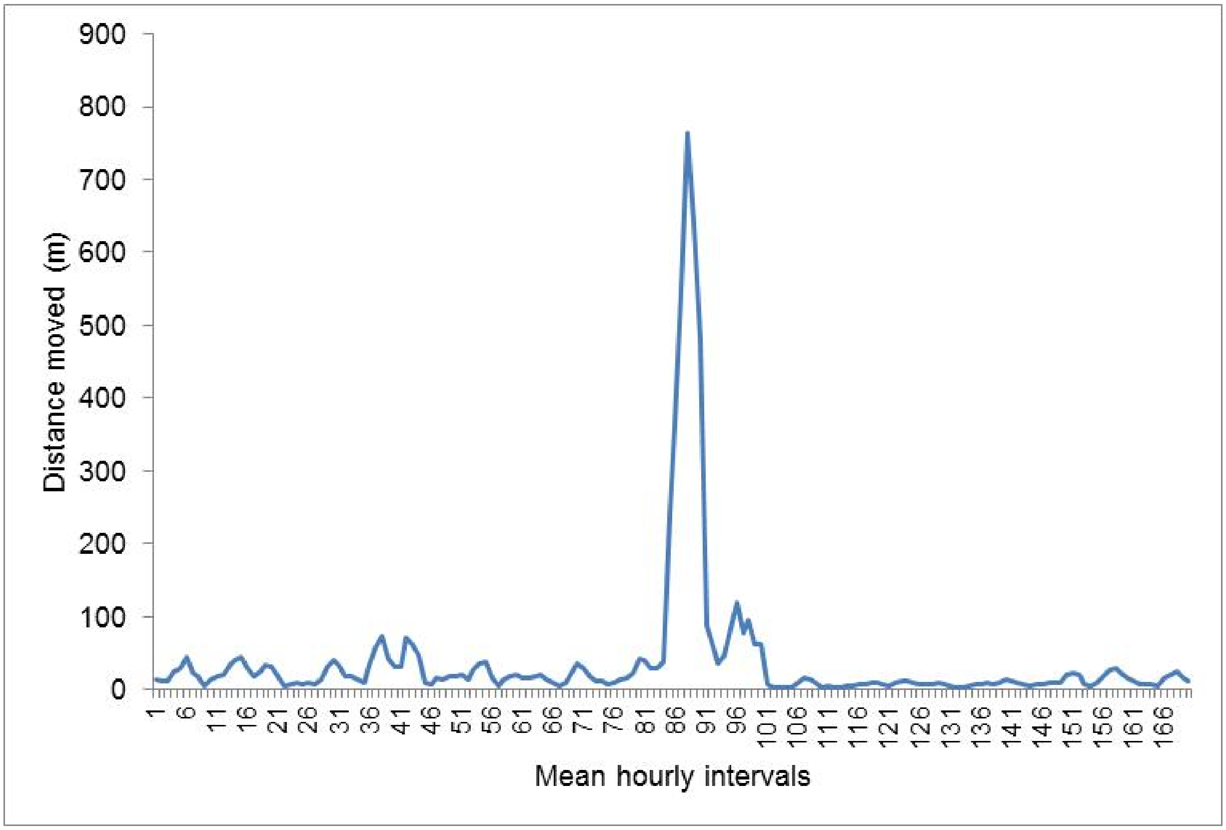

Figure 2. Calculated mean hourly distances moved by pregnant, adult female moose number 12500 from 12:04 am, 1 May to 1:42 pm, 8 May 2013. The elevated peak at Tick 88 represents the dam's primary "calving move" (about 800 m), but she didn't localize completely until after Tick 97. We used the latter as indicative of calving so as not to over-estimate bonding time, which was measured during the interval between then and capture time (Tick 172).

EVALUATING THE USE OF GPS-COLLARS TO DETERMINE MOOSE CALVING AND CALF MORTALITIES IN NORTHEASTERN MINNESOTA

William J. Severud, Glenn D. DelGiudice, and Robert G. Wright[1]

SUMMARY OF FINDINGS

Adult survival is an important driver of large herbivore population dynamics; however, low and variable recruitment also can have a strong influence on population trajectory. The northeastern Minnesota moose (*Alces alces*) population has been exhibiting a downward trend since 2005. Neonate and seasonal survival rates and specific causes of mortality (e.g., predation, undernutrition, disease) of calves are largely unknown. Our research is investigating survival rates and specific causes of mortality. We monitored 73 adult female moose fitted with global positioning system (GPS) collars (50 confirmed pregnant at capture by progesterone concentrations, 6 unknown, 17 not pregnant) beginning 1 May 2013, looking for long-distance pre-calving movements followed by localization. We confirmed the presence of calves with a helicopter capture crew for 31 of 38 cows suspected of calving. Of these 31 dams, 28 were confirmed pregnant by progesterone levels during winter adult capture, and 3 did not have blood drawn and were of unknown pregnancy status. Forty-nine neonates from 31 dams (58% twinning rate) were fitted with expandable GPS collars during May 2013 and are being tracked intensely throughout their first year. We are retrieving collars from calf mortalities and estimating proximate causes of mortality on site. Mean elapsed time between estimated time of death and mortality investigation ranges from 34 to 60 hours, dependent upon accessibility and functioning of individual collars. Thirty mortalities have occurred (with 4 slipped collars) during 8 May-2 July 2013, leaving 15 calves "on air" to date. After censoring 4 slipped collars, 9 capture-related abandonments, and 2 capture-related mortalities, 19 of 34 calves have died (56%). Natural abandonment (*n* = 2), abandonment of unknown cause (1), drowning (1), black bear (*Ursus americanus*)-kills (4), and wolf (*Canis lupus)*- or possible wolf-kills (11) are preliminary causes of death. Identifying specific causes of calf mortality and understanding their relations to various landscape and other extrinsic factors should yield insight into mechanisms contributing to the declining moose population in northeastern Minnesota and serve as a basis for an ecologically-sound management response.

INTRODUCTION

The moose (*Alces alces*) is an iconic species of northern Minnesota, which has afforded valuable hunting and viewing opportunities (Minnesota Department of Natural Resources 2012 [MNDNR]). In its most recent draft of proposed revisions to Minnesota's List of Endangered, Threatened and Special Concern Species, the MNDNR proposed moose for listing as a Species of Special Concern (http://files.dnr.state.mn.us/input/rules/ets/SONAR_all_species.pdf). Recently, the northwestern population declined precipitously to less than 100 moose due to a variety of natural factors (Murray et al. 2006). The northeastern moose population is in decline and is experiencing adult mortality rates similar to those of the northwestern population as it decreased (Lenarz et al. 2009, 2010).

Large herbivore population growth (λ) is most sensitive to variation in adult survival (Gaillard et al. 1998, 2000; Lenarz et al. 2010). Juvenile survival has less of an impact on overall population growth, but differences in temporal variation of juvenile survival may be important in accounting for between-year variation in λ (Gaillard et al. 2000). Fecundity and calf survival ultimately determine recruitment rates which are important to more fully understanding population dynamics (Van Ballenberghe and Ballard 2007). When viable populations of predators are present, predation can be a primary cause of mortality of temperate ungulate neonates (Linnell et al. 1995). Less is known about other specific ultimate or proximate sources of moose calf mortality or factors which may be contributing to predation

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and other sources of mortality. It also is unclear when predation is compensatory or additive to other sources of mortality (Franzmann et al. 1980, Linnell et al. 1995), although a recent study documented additive effects of predation in Alaska (Keech et al. 2011). The degree of predation's impact on calf survival depends on the extant predator guild and relative densities of predator and prey (Eriksen et al. 2011, Patterson et al. 2013).

Particularly after the calves' first summer, wolves (*Canis lupus*) can have a range of impacts on their survival (Patterson et al. 2013). Wolves are more adept at killing calves in deep snow (DelGiudice et al. 2009, Sand et al. 2012, Sivertsen et al. 2012), but wolves in an Alaskan study also were responsible for calf mortalities in fall (Keech et al. 2011). Typically, bear-caused (*Ursus* spp.) mortality of calves is greatest closer to parturition, more immediately following emergence from winter dens (Bastille-Rousseau et al. 2011). Once bears enter dens, their impact on calf mortality decreases dramatically (Garneau et al. 2008, Bastille-Rousseau et al. 2011). Cows in poor nutritional condition may defend calves less vigorously (Patterson et al. 2013). Further, risk of predation is not independent of maternal care and experience (Ozoga and Verme 1986, Gaillard et al. 2000). The importance of natural non-predatory causes of calf mortality likely vary during different times of the year, such as malnutrition and exposure in spring, or malnutrition and tick-related deaths in winter (Patterson et al. 2013). The extent to which diseases drive calf mortality is not well understood, although diseases have led to poor recruitment in moose (O'Hara et al. 2001, Murray et al. 2006). Juvenile animals are more predisposed to parasites than adults, and pathology related to parasite infection may be an important source of mortality for moose calves (Jenkins et al. 2001, Murray et al. 2006). Further, small calves may not be tall enough to efficiently nurse, leading to malnutrition (Murray et al. 2006). Drowning and climate have been known to affect moose calves more than predation in some regions (Crête and Courtois 2009). In winter, temperature and snow depth can be more important causes of mortality than predation (Keech et al. 2011).

Pregnant cow moose tend to move long distances (mean = 6 km) prior to localizing to give birth (McGraw et al., in review). These distances are typically much longer than movements between foraging and bedding sites. Following a long movement, calving localizations as measured by global positioning system (GPS) collars, resemble mortality localizations. A cow and calves may stay within a 1.2-ha area for up to 4 days.

Expandable GPS collars have until now not been fitted to moose neonates, and have only recently been used on other ungulate neonates (white-tailed deer [*Odocoileus virginianus*], Long et al. 2010; fallow deer [*Dama dama*], Kjellander et al. 2012). Observable fine-scale movement patterns and habitat use of moose calves, made possible by GPS collars, will enable us to examine landscape factors important for calf survival, and to closely track calves and their dams so we can quickly investigate mortality events to assign proximate causes and gather evidence for ultimate causes and contributing factors. Having dam and calf(ves) fitted with GPS collars also allows us to study the importance of proximity of dam and offspring to juvenile survival.

OBJECTIVES

1. Evaluate monitoring of movement behavior of GPS-collared adult female moose to determine timing and location of calving; and
2. Evaluate remote tracking of GPS-collared calves and dams to determine and investigate calf mortalities and to assign cause.

METHODS

Our study area is the same as that of the Environmental and Natural Resources Trust Fund (ENRTF)-supported study focused on survival and cause-specific mortality of adult moose in northeastern Minnesota (see Figure 1, research summary of DelGiudice, Severud, and Wright). As part of the companion adult moose mortality study, 111 adult moose (84 females, 27 males) were captured and fitted with Iridium GPS collars (Vectronic Aerospace, Berlin, Germany) during January 2013 (Butler et al. 2011). Blood was collected and tested for pregnancy; ≥2.0 ng/mL was the progesterone concentration threshold indicative of pregnancy. We monitored cow movements during pre-parturition and calving, with particular attention afforded to pregnant cows. We looked for movement patterns indicative of calving, including a long-distance movement followed by localization (Bowyer et al. 1999; McGraw et al., in review).

We began monitoring 73 collared adult female moose (50 confirmed pregnant at capture by progesterone concentrations, 6 unknown, 17 not pregnant) on 1 May 2013. Cow collars were programmed to collect hourly locations during May and transmit these locations 3-4 times per day. An automated R program (J. D. Forester, University of Minnesota, Twin Cities, unpublished data) generated emailed reports 6 times daily (0400, 0800, 1200, 1600, 2000, 2400 hr), which contained a document (pdf format) displaying various movement and location metrics for each collared cow, and table (csv format) and map (kml format) files with all recent locations of each animal. The .pdf reports contained a rough map of northeastern Minnesota with all cows displayed and a summary table of all animal locations and distances moved in the last 24 and 48 hours. The metrics for each cow included the date and time of the last location, movement path of the last 5 days, movement path of the last 24 hours overlaid on Google Earth imagery, a plot showing 3-hour average distances moved, and each cow's data on a single page (Figure 1). The distance plot showed peaks in movements that we then monitored for possible dampening of movements. If the cow moved <100 m over 36 hours after making a long-distance movement (dam-calf bonding time), the program flagged that cow as "localized," and that cow was put on the eligible list for visitation by the helicopter capture crew. When a cow was eligible for capture, we also checked her movement path on the Vectronic website (https://www.vectronic-wildlife.com; Figure 2). As a third way to check that the cow's movements were restricted, we plotted distances between fixes using data directly from the satellite base station using Excel (see Figure 2 in research summary of DelGiudice, Severud, and Wright). After capture, dams and calves were paired for the automated reports, and an additional plot was included (proximity between dam and calf, Figure 3). This plot was monitored for possible abandonments. Calves also were added to the report and had a page similar to that of the cows displaying their location and movement metrics.

Once a cow was identified at a calving site, a capture crew (Quicksilver, Inc., Fairbanks, AK) searched for the pregnant cow and calf(ves) by helicopter (see research summary of DelGiudice, Severud, and Wright). Each captured calf was fitted with an expandable Globalstar GPS collar (440 g; Vectronic Aerospace, Berlin, Germany) and 2 ear-tags, and was weighed (kg). Collars were programmed to take a fix hourly. Twins each received a collar and ear-tags. As feasible relative to the dam's behavior, the crew also made morphometric measurements (neck circumference, girth, total body length, hind leg length), collected blood, and measured a rectal temperature. All captures and handling protocols followed requirements of the Institutional Animal Care and Use Committee for the University of Minnesota (Protocol 1302-30328A) and were consistent with guidelines recommended by the American Society of Mammalogists (Gannon et al. 2007).

We will monitor each collared calf daily until mortality or until its collar drops off (designed to be about 400 days). We relied upon the collars to send mortality alert notification to cell phones via text message (i.e., SMS) when mortalities occurred, but after several mortalities went unnoticed (see below), we began using the Vectronic website and GPS Plus X software to check if calf collars were far from dam collars or in mortality mode. Each morning all dam and calf groups are checked and monitored closely throughout the day if separated by >100 m.

When we receive a mortality alert or determine a mortality may have occurred, we dispatch a necropsy team to collect the collar and carcass remains and to determine the cause of death (Ballard et al. 1979). To avoid possible investigation-induced abandonment, investigations are delayed if the dam is still in the area, especially if she is with a twin. Our primary field objective is to recover the entire carcass and deliver it to the University of Minnesota's Veterinary Diagnostics Laboratory (VDL) for necropsy. If the carcass cannot be extracted and transported, we perform a detailed field necropsy. If scavenged, fresh organ and tissue samples are collected and shipped to the VDL as feasible (Butler et al. 2011). Care is taken to haze off predators and scavengers when approaching the mortality site; bear repellent spray and firearms are available as a last resort for protection, but their use is not necessarily anticipated (Smith et al. 2008, 2012). We postpone the investigation when predators are sighted on the carcass; return is dependent on the age and size of the carcass as an indication of how long the predator or scavenger may feed.

Once we begin a thorough investigation of the site, we are careful not to disturb potential evidence. We photograph tracks and scat and collect scat when identification is uncertain. We note the presence of puncture wounds on the neck, skull, or hind quarters and claw marks across the body and take photographs of all wounds. When the hide is present, we note if it is inverted, which may indicate a bear was feeding on the carcass. We document the consumption of viscera, the rumen, or its contents. Wolves may chew on ribs and ends of long bones, whereas bears are more likely to cache pieces of the carcass. To determine if the calf was alive or dead when consumed, we look for subdermal hemorrhaging or sprays of blood on the collar or on broken or matted vegetation. We take note of the position of the carcass (lateral or sternal), and the distribution of body parts (scattered or near the carcass). An odor of decomposition or many fecal pellets in the area may indicate scavenging versus predation.

If we found a GPS collar without a carcass or other evidence of predation, we backtracked to the last known locations of the calf and its dam to examine a larger area in an expanded search. The Iridium collars are more accurate than the calf collars, so we use the cow's locations from the approximate time of death of the calf to look for a kill-site or evidence of the cause of mortality. We determined a collar to be slipped rather than a possible mortality if the breakaway section was frayed and/or the bolts holding the breakaway section were loose, coupled with both an absence of blood on the collar and lack of evidence within a 30-m radius of the collar.

RESULTS

We deployed 49 expandable GPS collars on the first neonates observed and captured from 31 dams (58% twinning rate) during 8-17 May 2013 (Figure 4; see research summary of DelGiudice, Severud, and Wright for additional details). Of the 31 dams, 28 were confirmed pregnant by progesterone, and 3 were unknown. Once we deployed 49 collars, we ceased capture operations, so it is not known whether the remaining cows calved or not. We visited 7 cows (4 pregnant, 3 not pregnant) which exhibited movement patterns indicative of calving, yet no calf was observed. We visited 4 dams more than once because no calf was observed during the first visit, yet the dam was behaving as if a calf was near, or she remained localized following the first visit. During a subsequent visit the helicopter crew observed and captured a calf or twins with each of these 4 dams.

As of 2 July 2013, we have documented 30 mortalities (Figure 5) and 4 slipped collars; 15 collared calves remain "on air." Capture-related activities accounted for 11 mortalities (see research summary of DelGiudice, Severud, and Wright). Of the remaining 19 mortalities, there were 2 natural abandonment (dam and calf were together after capture activities for 2-3 days before abandonment), 1 abandonment of unknown cause, 1 drowning, 4 bear-kills, and 11 wolf- or possible wolf-kills. Histological and disease-screening results from the VDL are pending. After censoring the capture-related mortalities and slipped collars, 19 of 34 calves have died (56%) as of 2 July 2013, with 15 of those preyed upon by wolves or bears.

Of the 28 mortalities we have investigated on site, 11 of the collars failed to send a mortality alert text message. Three of these collars were buried and never transmitted a mortality message to the satellite base station (and stopped sending GPS fixes); 1 was on a drowned animal in slightly flowing water (causing collar movement); 5 sent mortality transmissions to the base station, but the base station did not send an email or text alert; and 2 simply did not send a mortality transmission to the base station. It is unknown whether the collars that never sent a mortality transmission to the base station were in VHF mortality mode, because this was not checked in the field in these instances.

Mean elapsed time between estimated time of death and mortality investigation was 59 hours (range = 0-577 hr, n = 34). A collar that was inaccessible for 24 days (located on an island with the surviving twin and dam) was an extreme outlier at 577 hours. With this outlier excluded the mean time to investigation was 44 hours. The mean response-time was 60 hours (range = 10-577 hr, *n* = 20) when we received a mortality alert text message. With the island collar omitted, the mean was 34 hours (range = 10-80, *n* = 19).

DISCUSSION

Tracking GPS-collared cow movements was a highly reliable way to estimate whether or not a cow had calved. Of the 38 dams suspected of calving and subsequently visited, 31 were with a calf (82% success rate). We do not know for certain whether the 7 dams observed without calves had given birth. The calves may have been stillborn, abandoned, or preyed upon before we visited. Our study objective was to fit GPS collars to 50 newborns. We decided to track cows during May to look for movement patterns indicative of *calving* rather than fit vaginal implant transmitters (VITs) to pregnant cows for several reasons. Fitting VITs would have required determining pregnancy status during winter captures, which would have added significant expense and time to the handling of the adult females. Monitoring pregnant cows (determined later in the lab by serum progesterone concentration) for a "calving move" did not limit us to only those 50 pregnant females which would have been fitted with a VIT; the latter also would have required the expense of monitoring from a fixed-wing aircraft. Finally, twinning, unknown at adult capture, would mean that ultimately we would not be collaring neonates from all 50 cows fitted with a VIT. Indeed, this year's high twinning rate (58%) meant that newborns of only 31 dams were captured and collared; so the expense, time, and effort of fitting and monitoring VITs in 19 of the dams would have been wasted relative to calf capture operations. Monitoring calving movements will be invaluable next year as we plan to capture calves from collared cows that we will not need to recapture during winter to determine pregnancy.

We observed and handled many sets of twins at the beginning of calving, but over half of our singletons were handled the last 2 days of captures. To more accurately represent the northeastern population next year we will attempt to spread out capture efforts throughout the calving season. In northeastern Minnesota, mean calving date was 14 May (range 3-27 May), with 70% of births happening 9-20 May (McGraw et al, in review). We will need to balance attempting to catch later-born calves with loss of visibility due to leaf-out (see research summary of DelGiudice, Severud, and Wright).

To date we have had 4 collars slip off. In each instance the breakaway section of the collar was frayed and bolts were loose. There was no tearing or blood on the collars or sign of a struggle at the collar location. This may be a design flaw that will need to be addressed before next year's captures.

When collars did not send mortality alert text notifications, our response-time increased from 35 to 45 hours. Some collars were not sending text messages after calf release, consequently, we began to closely monitor cow and calf(ves) proximities and GPS Plus X software to alert us to possible mortalities rather than relying only on text messages. Bears caching collars or calves drowning and remaining in flowing water may either keep the collars from transmitting or keep the collars in normal mode due to movement. Similarly, predators or scavengers may "play" with the collar and keep it in normal mode long after mortality has occurred. These all will be considerations next year for how we monitor the calves and their dams from the beginning of capture operations.

ACKNOWLEDGMENTS

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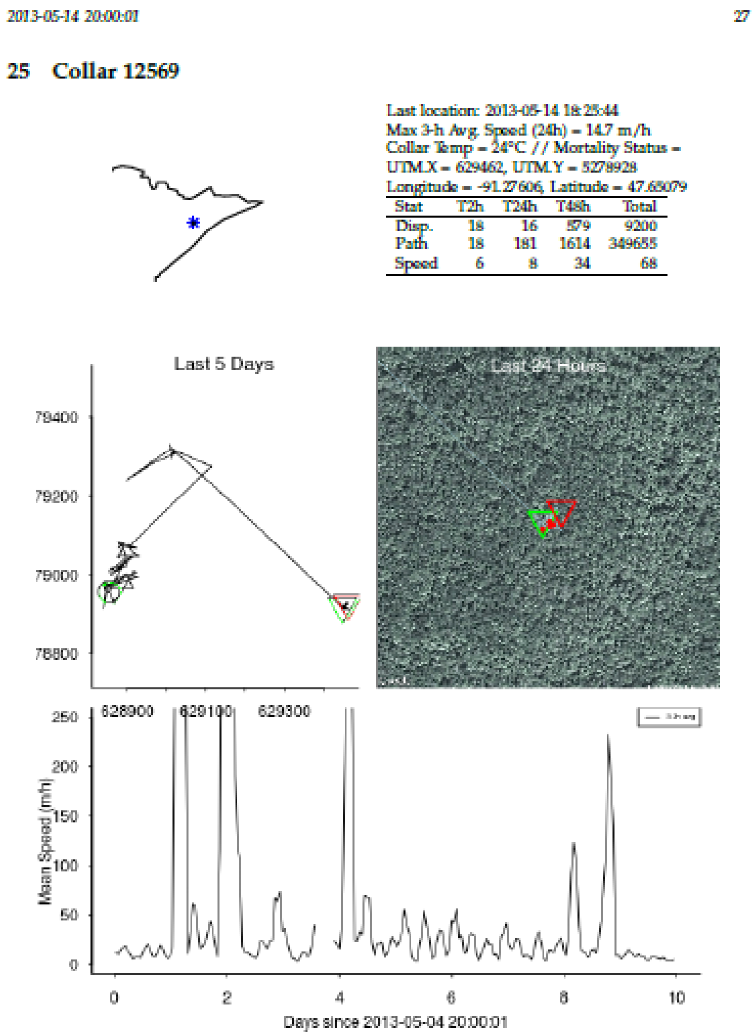

Figure 1. Example report for adult female moose number 12569 from 20:00 hours, 14 May 2013, northeastern Minnesota, showing movement paths for the last 5 days and 24 hours, and 3-hour average hourly distances moved. Green circle represents the start of the 5-day period, green triangle the start of the 24-hour period, and red triangle the most recent location. Red dots indicate location when the collar was "localized." We visited this cow at 7 days since 4 May (12 May), but she had not yet calved. She made a "calving move" ~9 days after 4 May 2013 (14 May) and then localized. She was visited on 15 May and her twins were collared.

Figure 2. Vectronic website (https://www.vectronic-wildlife.com) map interface showing the path of adult female moose number 12569, 12–14 May 2013, northeastern Minnesota. The green square represents the start of the interval, and the red square depicts the end of the interval. The cow's movement pattern in the southwestern corner of the map indicates typical bedding and foraging, whereas the cluster in the southeastern corner of the map indicates a tight localization which followed a long-distance movement. This cluster is likely the calving ground.

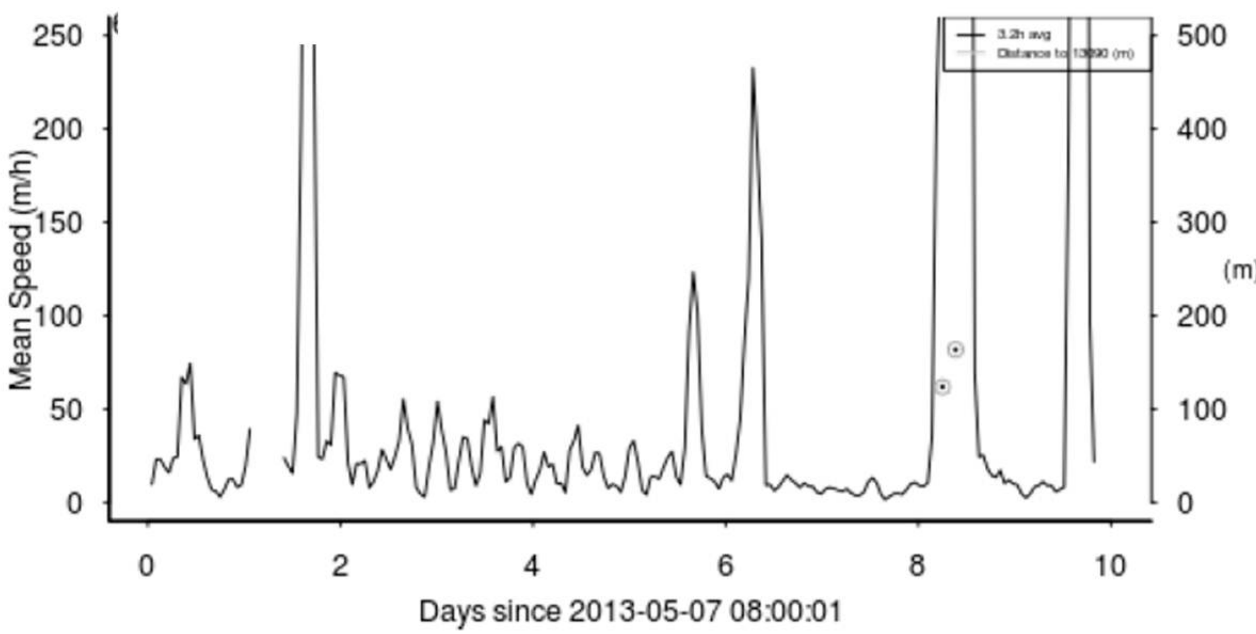

Figure 3. Distance plot displaying both 3-hour average distance moved and proximity of adult female moose number 12569 to calf number 13090, northeastern Minnesota. Line displays the distance the dam has moved; dots with circles represent the distance between the dam and calf collar.

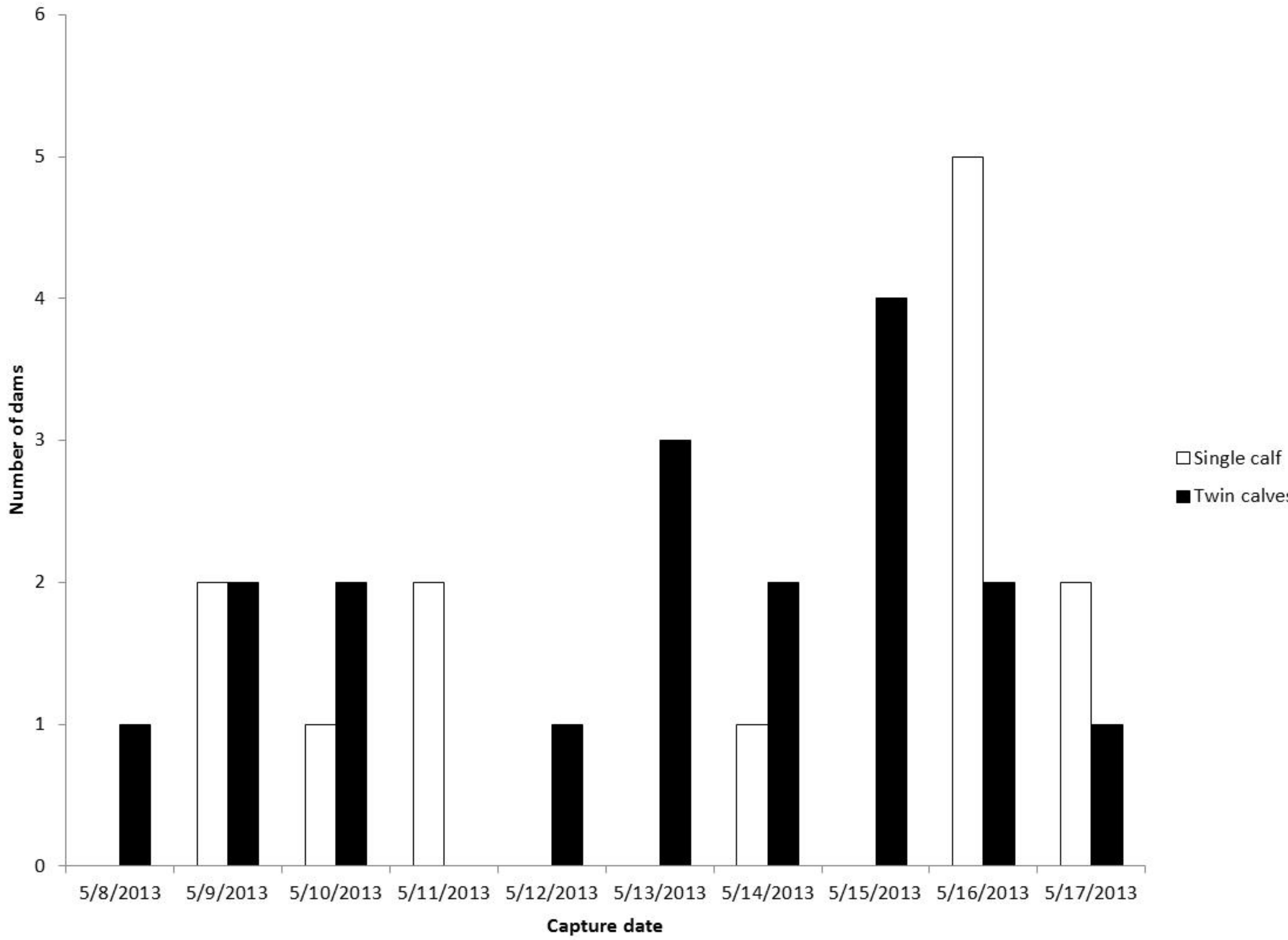

Figure 4. Number of moose dams with single and twin calves captured and handled, 8-17 May 2013, northeastern MN.\

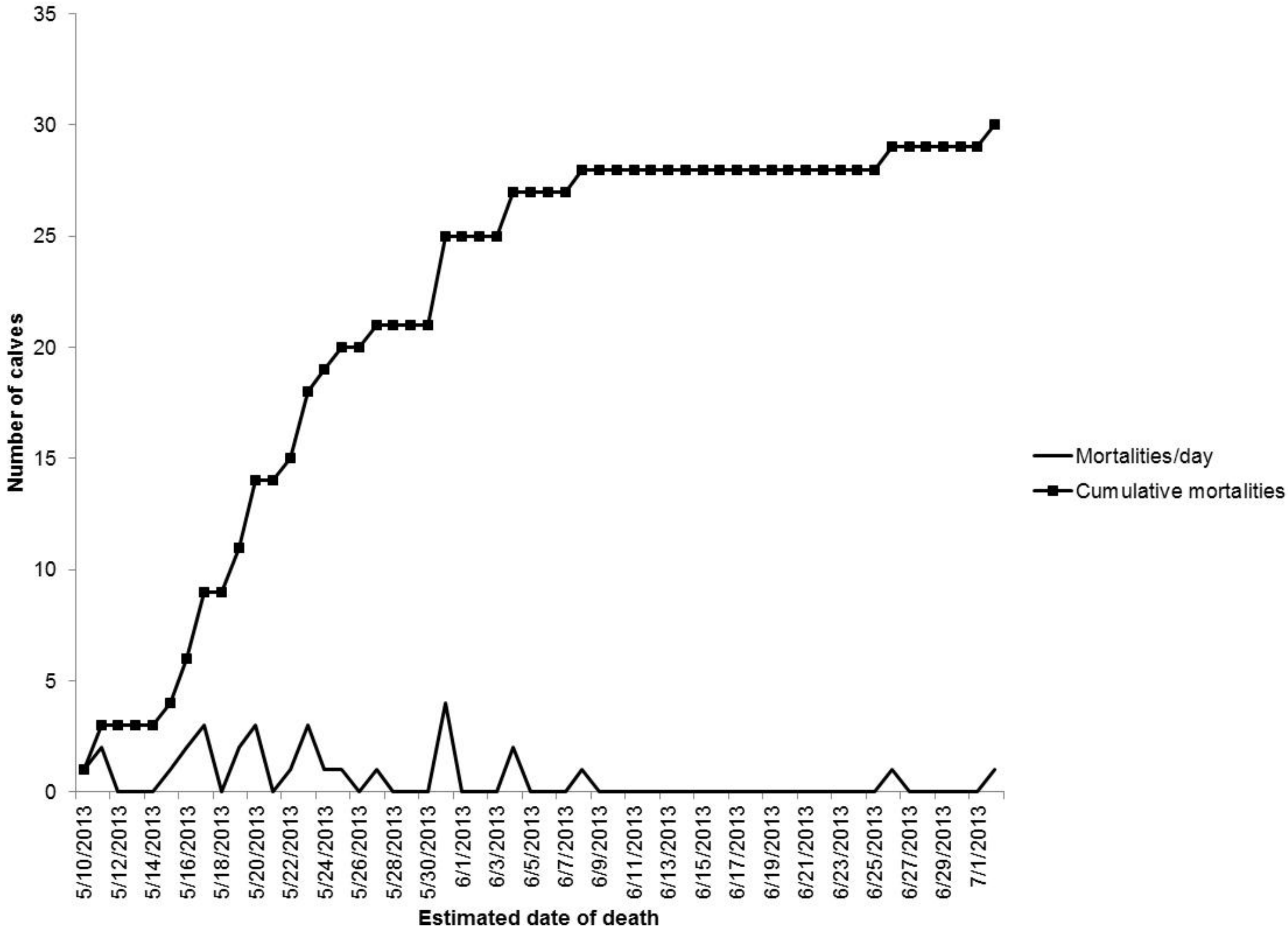

Figure 5. Number of moose calf mortalities by day and cumulative mortality by day, 10 May – 2 July 2013, northeastern MN.

ASSESSING NUTRITIONAL RESTRICTION OF MOOSE IN NORTHEASTERN MINNESOTA, WINTER 2013: A PILOT

Glenn D. DelGiudice, Erika Butler, Michelle Carstensen, and William J. Severud

SUMMARY OF FINDINGS

The moose (*Alces alces*) population in northeastern Minnesota has declined an estimated 66% since 2005. As in northwestern Minnesota, a number of factors, such as malnutrition, pathogens, and predation may be contributing to this recent dramatic decline. Nutrition is centrally related to all other aspects of an animal's ecology. Winter nutritional restriction of moose and other northern ungulates may be physiologically assessed by serial collection and chemical analysis of fresh urine in snow (snow-urine). Urinary urea nitrogen:creatinine (UN:C) ratios have shown the most potential as a metric of winter nutritional status and have been associated with changes in the moose population on Isle Royale. Serial collection and chemical analysis of moose snow-urine in northeastern Minnesota during winter 2012-2013 served as a pilot study for assessing nutritional restriction and to better understand the feasibility of the associated logistics. Our prediction was that winter nutritional restriction would be relatively severe in this declining population. During 23 January-25 March, 124 snow-urine samples of moose were collected randomly during 5, 2-week sampling intervals. During 13 February-25 March, 112 specimens were collected from 35 (31 females, 4 males) target Global Positioning System (GPS)-collared moose; each individual was sampled during 1-3, 2-week sampling intervals. According to our random sampling, overall, the mean UN:C ratio for the entire winter was 3.7 mg:mg (SE = 0.4, n = 123), and the percentage of snow-urine specimens collected with UN:C ratios indicative of severe nutritional restriction (≥3.5 mg:mg) of moose was 32%. Mean urinary UN:C ratios indicated that nutritional restriction on average was "normal" or modest during late January, but was severe throughout February and early March, and still moderately severe during late March. Overall, about 41% of the UN:C values of total snow-urine specimens collected tracking target moose indicated moose were experiencing moderately severe (21.4%) to severe (20.0%) dietary restriction; the remaining 58.6% reflected normal or modest winter restriction. From late February through late March, the percentage of snow-urine specimens reflecting normal restriction was stable at about half (53.8-57.7%); however, the percentage of samples indicative of severe restriction doubled from late February (19.2%) to late March (38.5%), and those reflecting moderately severe restriction decreased from 28.0 to 7.7%. The random sampling approach involved specimens from a large number of moose during each 2-week sampling interval and should be continued as part of the adult moose mortality study in northeastern Minnesota. Beginning sampling during early December (rather than January) when moose are in relatively peak condition should be an important consideration for future assessments. Monitoring the nutritional status of these animals long-term at the population level should facilitate a better understanding of important relationships to other aspects of their ecology, including movements, habitat use, and population performance.

INTRODUCTION

Since 2005, when the aerial moose (*Alces alces*) survey in northeastern Minnesota was more completely standardized and a sightability model included, the population has decreased 66% (from 8,160 to 2,760 moose; Lenarz et al. 2009, 2010; DelGiudice 2013). The decreasing trajectory has been similar to that documented recently for the moose population in northwestern Minnesota (Murray et al. 2006, Lenarz et al. 2009). This poses a complex and immediate management challenge, which must rely largely on relatively new accumulating research findings to expedite effective responses. As in northwestern Minnesota, the recent decline is likely attributable to a number of factors. Climate change (i.e., warming temperatures) has been implicated in the decline of both populations (Murray et al. 2006; Lenarz et al. 2009, 2010). In northwestern Minnesota, malnutrition and pathogens were identified as contributing factors to the population's decrease, whereas in the northeast specific causes of natural mortality have been largely unknown (Lenarz et al. 2009, 2010), but currently are being investigated aggressively (Butler et al. 2011). Mean annual natural mortality rates of adults were similarly high in the northwest and northeast (21%) and have the strongest impact on population growth rates (Murray et al. 2006, Lenarz et al. 2009). Currently, these adult mortality rates remain elevated in northeastern Minnesota (R. A. Moen, unpublished data; Butler et al., unpublished data).

"Knowledge of wildlife nutrition, as a component of both wildlife ecology and management, is central to understanding the survival and productivity of all wildlife populations…" (Robbins 1993). Whereas current investigations may discover that a number of factors, such as disease, parasites, or predation are contributing significantly to the decline of moose in northeastern Minnesota, there also is little doubt that seasonal nutrition may be playing a key role. For northern ungulates, winter dietary restriction due to natural reductions of forage abundance, availability, and quality reflects the most apparent annual nutritional bottleneck with which they must contend, but generally have adapted (DelGiudice et al. 1989, Robbins 1993, Schwartz 2007). Moose and other members of the deer family may withstand losses of 33% of their peak fall body mass while they rely heavily on all of their fat reserves and up to 33% of their endogenous protein (mostly as lean body mass) to compensate for natural dietary restriction and attempt to fulfill their energy and protein requirements. However, severity of nutritional restriction of ungulates may be mediated by a variety of environmental factors, including diet composition, disease, parasites, and density of the target species (DelGiudice et al. 1997, 2001, 2010; Schwartz 2007).

Winter nutritional restriction of moose and other northern ungulates may be physiologically assessed by serial collection and chemical analysis of fresh urine samples in snow (snow-urine; DelGiudice et al. 1988, 1997, 2001, 2010; Moen and DelGiudice 1997, Ditchkoff and Servello 2002). Urea nitrogen (UN) is one of many chemistries investigated for its potential value as an indicator of nutritional restriction, and it has shown the most promise in studies of white-tailed deer (*Odocoileus virginianus*), moose, elk (*Cervus elaphus*), and bison (*Bison bison*). Its value is related to its role as an end-product of protein metabolism, both dietary crude protein and endogenous protein, and how its values change in response to diminishing intake of crude protein and digestible energy and accelerated catabolism of endogenous protein as dietary restriction becomes increasingly serious and fat reserves are depleted.

On Isle Royale winter nutritional restriction of moose was assessed by collection and analysis of snow-urine for 7 years. Urea N:creatinine (UN:C) ratios were strongly related to winter tick (*Dermacentor albipictus*) infestation and population change of moose, including significant declines and historic high numbers. Collection and chemical analysis of snow-urine also elucidated relationships between winter nutritional restriction, winter severity, and mortality rates of deer in northern Minnesota and Maine, and elk and bison in Yellowstone National Park (DelGiudice et al. 1989, 1997, 2001, 2010; Ditchkoff and Servello 2002).

This year's (winter 2012-2013) field effort served as a pilot study for assessing nutritional restriction of moose by serial collection and chemical analysis of fresh snow-urine and to better understand the challenges of the associated logistics. Our prediction is that winter nutritional restriction is relatively severe in the declining moose population in northeastern Minnesota.

OBJECTIVE

1. To estimate the proportion of the northeastern moose population experiencing severe nutritional restriction during winter 2012-2013 as indicated by urinary UN:C ratios >3.5 mg:mg.

STUDY AREA

The 6,068-km^2 study site for this research is the same as that of the Environmental and Natural Resources Trust Fund (ENRTF)-supported research addressing survival and cause-specific mortality of adult moose in northeastern Minnesota (Figure 1). This area has been classified as the Northern Superior Upland region (MNDNR 2007). Additional details are provided in the research summary of DelGiudice, Severud, and Wright, also included in this issue.

METHODS

We collected fresh snow-urine specimens of moose during 23 January-25 March 2013. We began snow-urine sampling according to a random design then transitioned (beginning 13 February) into targeting known Global Positioning System (GPS)-collared moose, while continuing the random sample collections. Our field team drove (by truck or snowmobile) a 201-km (125-mile) route designated for wolf (*Canis lupus*) scat and moose snow-urine collections. The route was divided into 4 legs to distribute the sampling throughout the study area; the team was not restricted to this route. Our field team used handheld GPS units loaded with several land coverages (R. Wright, Minnesota Information Technology @ Minnesota Department of Natural Resources, Section of Wildlife), a Superior National Forest map (U. S. Forest Service), and the Vectronic Aerospace website (https://www.vectronic-wildlife.com/index.php) with GoogleEarth to locate and navigate to target GPS-collared moose for sampling.

To be able to associate urine chemistry data of randomly collected snow-urines and nutritional assessments with specific temporal windows, sampling generally was conducted within 7 days of a fresh snowfall, but most often within 2-4 days. Upon observing fresh moose sign (e.g., tracks, pellets), the team tracked the individual(s) on foot as necessary until they came to a fresh specimen(s). The primary objective for the random collections was to sample adult (>1 year old) moose (indicated by track and bed size), because once capture operations were completed, our expanded sampling included GPS-collared adults.

After the first week of sampling known or target GPS-collared adult moose and being more aware of the logistical challenges involved, we concentrated our efforts on sampling adult females, because they have a greater potential impact on population dynamics through nutritional effects of the dam on reproductive success. We focused primarily on the adult age class to maximize sample sizes (i.e., they are more abundant) and to facilitate optimum comparability of data. Typically juveniles begin winter with far less fat reserves than adults, thus their physiological (urinary UN:C) data are less likely to occur on a temporal scale comparable to that of adults, which could confound interpretations at the population level. Recent GPS locations of target collared moose were used to locate areas where relatively fresh snow-urine specimens might be located. Multiple known locations were used to increase confidence that a sample was from the target individual. Snow-urine specimens of target individuals were not always collected with 100% certainty based on the evidence (e.g., GPS locations, sets of tracks, beds, number of individuals in a group). The estimated degree of certainty was recorded. When the sampling team encountered multiple fresh specimens which could have been voided by the target moose or other moose traveling closely with the target, and distinguishing between them was not 100% certain, all were collected and analyzed. When sampling target individuals, additional random specimens (i.e., not associated specifically with the GPS-collared moose) were collected opportunistically and data were included with those of the other specimens collected randomly.

Specimens were collected and handled as described by DelGiudice et al. (1991, 1997). A GPS waypoint was recorded for each snow-urine specimen collected. Date of the most recent snowfall and comments describing the presence of moose and "other" sign in the area also were recorded.

Snow-urine specimens were analyzed for UN (mg/dL) and C (mg/dL) by a Roche Cobas Mira autoanalyzer (Roche Diagnostics Systems, Inc., Montclair, NJ) in the Forest Wildlife

Populations and Research Group's laboratory. One specimen from random sampling and 1 from sampling target GPS-collared moose were excluded, because UN or C concentrations were below the threshold of sensitivity of the autoanalyzer due to dilution by snow. Data are compared as UN:C ratios to correct for differences in hydration, body size, and dilution in snow (DelGiudice 1995, DelGiudice et al. 1988).

The winter collection period (23 Jan-25 Mar) was divided into 5, 2-week sampling intervals (15-31 Jan, 1-15 Feb, 16-28 Feb, 1-15 Mar, and 16-31 Mar). Sample sizes for the random snow-urine collections varied by interval due to variability of weather conditions, equipment availability, logistical challenges, and ease of finding samples. Mean (± SE) UN:C values are reported by sampling intervals for snow-urine specimens collected randomly. Additionally, based on past work, urinary UN:C values were assigned to 1 of 3 levels of nutritional restriction: modest or "normal," 0.5-2.9 mg:mg; moderately severe, 3.0-3.5 mg:mg; and severe, ≥3.5 mg:mg (DelGiudice et al. 1997, 2001, 2010). Because sampling of known GPS-collared moose began rather late in winter and access to areas where these animals occurred was often quite challenging, the number of snow-urines per individual was limited to 1-3 specimens for the winter.

RESULTS AND DISCUSSION

During 23 January-25 March, 124 snow-urine samples of moose were collected randomly during all 5, 2-week sampling intervals using our designated route and by opportunistically collecting additional random specimens while sampling target individuals. During 13 February-25 March, 112 specimens were collected from 35 target GPS-collared moose, 1-3 times each (i.e., 1-3, 2-week sampling intervals), for a total of 69 known individual-sampling interval combinations. Forty-three of these specimens were collected with 100% certainty that they were voided by the target individual for a 62% success rate. Specimens associated with the remaining 26 target-sampling interval combinations were collected with a reasonable amount of confidence (≥50%). When multiple specimens were collected for a target moose within a sampling interval and location with less than 100% certainty, the mean UN:C ratio of the specimens was used to represent that individual.

According to our random sampling, overall, the mean UN:C ratio for the entire winter was 3.7 mg:mg (SE = 0.4, n = 123), and the percentage of snow-urine specimens collected with UN:C ratios indicative of severe nutritional restriction (≥3.5 mg:mg) of moose was 32%. Mean urinary UN:C ratios indicated that nutritional restriction was normal or modest (0.5-2.9 mg:mg) during late January, but was severe (≥3.5 mg:mg) throughout February and early March, and still moderately severe (3.0-3.4 mg:mg) during late March (Figure 2). As severe nutritional restriction of individuals progresses with winter, they may be under-sampled as they urinate less to conserve water and electrolytes or begin to succumb. Percentage of samples with urinary UN:C ratios indicative of severe nutritional restriction was relatively high throughout winter (Figure 3). These very elevated values (≥3.5 mg:mg) were associated with starvation or fasting in controlled nutrition studies of white-tailed deer and free-ranging elk, bison, and moose (DelGiudice et al. 1987, 1991, 1997, 2001). The percentage of snow-urine specimens with UN:C ratios indicative of moderately severe to severe nutritional restriction throughout the winter was 45.9%.

The greatest value of the mean UN:C values from randomly sampled snow-urines and the percentage of specimens indicative of moderately severe to severe nutritional restriction comes from our comparison to data from previously studied Isle Royale moose (DelGiudice et al. 1997). During that 7-year study, mean annual UN:C ratios of several winters hovered at about 3.0 mg:mg were associated with severe winter tick infestations and a significant 26% population decline from winters 1988 to 1990. Additionally, our nutritional assessment showed that restriction was markedly more severe on the east side of the island, which was dominated by balsam fir (*Abies balsamea*); the west end was characterized by more diverse woody browse. As the Isle Royale moose numbers steadily recovered to a new estimated historic high (1,880) during winter 1992-1993, and remained elevated during winter 1993-1994 (1,770), mean annual

UN:C ratios were stable at about 2.0 mg:mg, (see Figure 4 in DelGiudice et al. 1997). During the 3 winters of the Isle Royale moose decline, the percentage of snow-urine samples with UN:C ratios indicative of severe nutritional restriction varied between 50 and 60%, but during the subsequent years of recovery, ≤ 12% were indicative of severe restriction. The percentage of snow-urine samples collected randomly with UN:C ratios indicative of severe nutritional restriction also was significantly related (r^2 = 0.52, P = 0.013) to percent winter mortality of white-tailed deer during a long-term study in north-central Minnesota (DelGiudice et al. 2010) and to elevated winter mortality of elk and bison during a severe winter immediately following historic (300-year) fires which had burned much of their winter range (DelGiudice et al. 2001).

We sampled 35 target GPS-collared adult moose (31 females, 4 males) 1 to 3 times each from mid-February to late-March (Table 1). Overall, about 41% of the UN:C values of total snow-urine specimens collected while tracking target moose indicated moose were experiencing moderately severe (21.4%) to severe (20.0%) dietary restriction; the remaining 58.6% reflected normal winter restriction. During early February, 100% of the UN:C ratios of target moose were indicative of normal restriction, but the sample size of snow-urines was small (n = 4) as we began transitioning to sampling target moose. From late February through late March, the percentage of snow-urines reflecting normal restriction was stable at about half (53.8-57.7%); however, during those 3 sampling intervals, the percentage of samples indicative of severe restriction doubled from late February (19.2%) to late March (38.5%).

Of the 35 target moose sampled 1-3 times for fresh snow-urine from early February to late March (including moose numbers 12577 and 12486 traveling together and considered 1 target animal for 1 sampling), 19 (54.3%) were represented by at least 1 specimen with a UN:C ratio indicative of moderately severe to severe nutritional restriction. Nine of these (25.7% of total 35 targets) were restricted severely during at least 1 sampling (Table 1).

At capture, 10 (31.3%) of the 32 adults assessed by body condition scoring (3 were not assessed at capture) were classified as “thin” or “very thin” (Butler and Carstensen, unpublished data) (Table 1). Of these 10 adults, 8 yielded at least 1 snow-urine specimen indicative of moderately severe nutritional restriction subsequent to capture and release (Table 1); a ninth moose sampled only once, had a UN:C value (2.9) just below the moderately severe threshold. Five (50%) of the 10 thin or very thin moose had UN:C values reflecting severe undernutrition later during winter. Of the 22 moose classified at capture as being in normal condition (21) or fat (1), 13 (59.0%) yielded snow-urine specimens during all 1-3 sampling intervals with UN:C ratios indicative of normal dietary restriction (i.e., none of their samples indicated moderately severe or severe restriction as winter progressed, Table 1). Only 2 (9.1%) of the 22 moose in normal condition yielded at least 1 snow-urine sample with a UN:C value indicating the animal was experiencing severe restriction at some point subsequent to capture, whereas 7 (31.8%) of these moose went on to experience moderately severe dietary restriction during at least 1 of the 2-week intervals in which they were sampled.

Seven of the adult moose captured during late January-early February subsequently died from a variety of causes (Butler and Carstensen, unpublished data) during April-July 2013. Three and 1 of these adults yielded at least 1 snow-urine UN:C value indicative of severe and moderately severe winter nutritional restriction, respectively (Table 1).

At the individual level, UN:C ratios in fresh snow-urine of moose have value in distinguishing whether an individual moose is experiencing modest to severe nutritional restriction at a given point in time. Clearly, collecting 1-3 specimens from an individual over time is not going to allow us to reliably predict whether that individual is going to be in poor, average, or good condition by late winter. However, if we can sample target moose once per week or biweekly throughout the winter, then our ability to relate their nutritional status to environmental conditions (e.g., severity of weather, habitat types) or to estimate physical condition by physiological modeling would be greatly enhanced. Accomplishing this would also allow us to examine relationships of specific pregnant females to calf productivity, reproductive success, and calf survival; however, the daily logistical challenges and intermittent inefficiency experienced with accessing these specific target individuals to collect their urine specimens prompts us to afford additional consideration to the feasibility of this approach in the field.

At the population level, random sampling and chemical analysis of snow-urine of moose and other ungulates serially throughout winter has repeatedly demonstrated significant value in relating nutritional assessments to winter severity, winter tick infestations, major fire disturbances, temporally and spatially to distinctly different ranges, and to mortality rates (DelGiudice et al. 1989, 1997, 2001). The random sampling approach involved specimens from a large number of moose during each 2-week sampling interval, is more feasible compared to individual-level sampling, and should be continued as part of the adult moose mortality study in northeastern Minnesota. This population approach should continue to generate data amenable to application of our physiological model for condition assessments which can then be related to survival and pregnancy rates, calf productivity, and reproductive success. Importantly, concentrating greater resources would allow sampling to begin during early December (rather than January) when moose are in relatively peak condition. The longer we can monitor the nutritional restriction and condition of these animals at the population level, the better we will come to understand relationships to their habitat and other aspects of their ecology.

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Table 1. Assessment of nutritional restriction of known Global Positioning System (GPS)-collared moose by serial collection and chemical analysis of fresh urine in snow (snow-urine), northeastern Minnesota, February-March 2013.

Moose ID[a]	Sex[b]	Condition at capture[c]	2-week interval[d]	Sampling date	Urinary UN:C (mg:mg)[e]
12479	F	Thin	3	28-Feb	4.1
			4	13-Mar	2
12485	F	Thin	3	1-Mar	3.5
			4	13-Mar	3.3
12486	F	Thin	5	22-Mar	3
12489	F	Normal	3	21-Feb	3.9
			4	8-Mar	2.2
			5	22-Mar	4.7
12490 (Mort)	F	Very thin	3	21-Feb	6.8
			4	8-Mar	3.2
			5	25-Mar	6.4
12495 (Mort)	F	Normal	3	19-Feb	2.5
			4	11-Mar	1.9
12497	F	Normal	4	11-Mar	2.4
			5	25-Mar	2.4
12499 (Mort)	F	Normal	3	18-Feb	2.5
			4	6-Mar	2.1
			5	21-Mar	1.9
12503	F	Normal	3	26-Feb	2.8
			4	15-Mar	2.9
12553	F	Normal	2	15-Feb	2.6
			4	14-Mar	2
12560	F	Thin	4	8-Mar	3.8
			5	22-Mar	4.8
12563 (Mort)	F	Normal	3	18-Feb	2
			4	6-Mar	2.5
			5	21-Mar	2.2
12564 (Mort)	F	NR	3	22-Feb	2.9
			4	6-Mar	3
			5	21-Mar	4.7
12567	F	Normal	3	18-Feb	3
			4	6-Mar	3.2
			5	20-Mar	2.9
12569	F	Normal	3	22-Mar	2
12572	F	Normal	3	26-Feb	2
			4	15-Mar	2.6
12573	F	Fat	3	1-Mar	3.2

Table 1 (cont.)

			4	13-Mar	3
12574 (Mort)	F	Thin	3	25-Feb	4
			4	12-Mar	4
12577	F	Normal	5	22-Mar	2.6
12587	F	Thin	2	15-Feb	2.9
12605	F	Normal	3	26-Feb	1.7
			4	15-Mar	2.5
12609	M	Normal	2	14-Feb	2.7
12615	M	Thin	3	18-Feb	1.5
12618	M	Normal	3	19-Feb	3
12619 (Mort)	F	Normal	2	13-Feb	1.9
			3	26-Feb	1.6
			4	15-Mar	3.2
12624	M	Normal	3	19-Feb	3.1
12625	F	NR	3	18-22 Feb	2.1
			4	6-Mar	2.6
			5	20-Mar	2.2
12628	F	Normal	3	28-Feb	2.3
			4	13-Mar	3.5
12629	F	Thin	3	22-Feb	2.6
			4	6-Mar	3.9
			5	20-Mar	4.1
12634	F	Normal	4	11-Mar	2.1
			5	25-Mar	2.6
12635	F	Normal	3	25-Feb	2.7
			4	12-Mar	2.6
12636	F	Normal	4	8-Mar	2.8
			5	22-Mar	3.4
12658	F	Normal	3	28-Feb	2.8
			4	13-Mar	3.3
12659	F	Thin	3	28-Feb	3.4
12577/12486	F	Normal/ Thin	3	21-Feb	3.3

[a]These are GPS-collared adult moose captured and collared during late January-early February 2013. “(Mort)” indicates that the associated moose died during April-July 2013. Moose numbers 12577 and 12486 were traveling together so closely that it was difficult to associate the 3 snow-urine specimen collected with 1 or the other individual. The UN:C value of 3.3 represents the mean of the 3 specimens.

[b]F = female and M = male.

[c]Physical condition at capture was assessed by body condition scoring (1-4), and adults were classified as very thin, thin, normal, or fat. On a number of occasions time did not allow scoring and so a score was not recorded (NR).

[d]Two-week intervals were 15-31 January (1), 1-15 February (2), 16-28 February (3), 1-15 March (4), and 16-31 March (5).

[e]UN:C = urinary urea nitrogen:creatinine ratio.

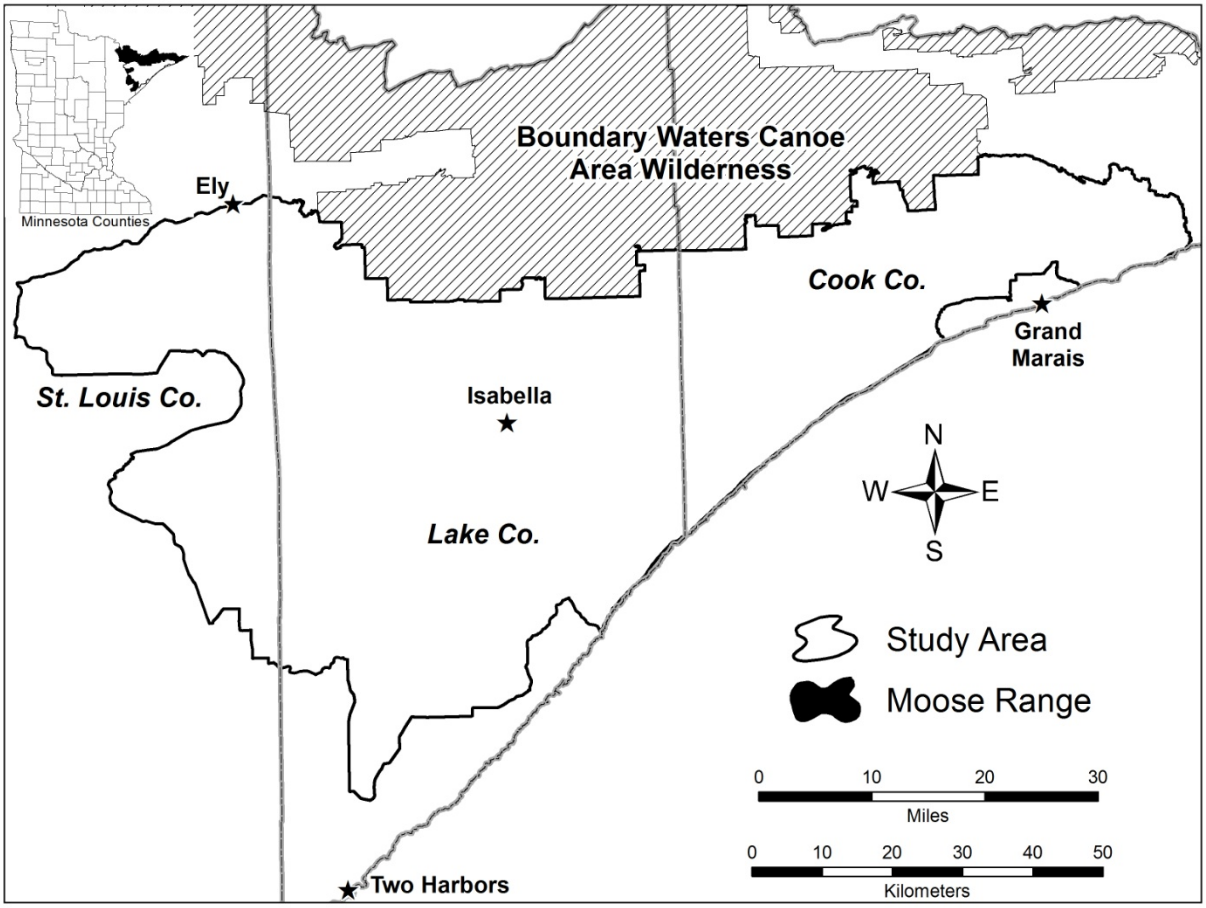

Figure 1. Study area for assessing nutritional restriction of moose by serial sampling and chemical analysis of urine voided in snow (snow-urine), northeastern Minnesota, late January-March 2013 (5, 2-week sampling intervals). (This includes all randomly collected samples and specimens from "known" GPS-collared moose.)

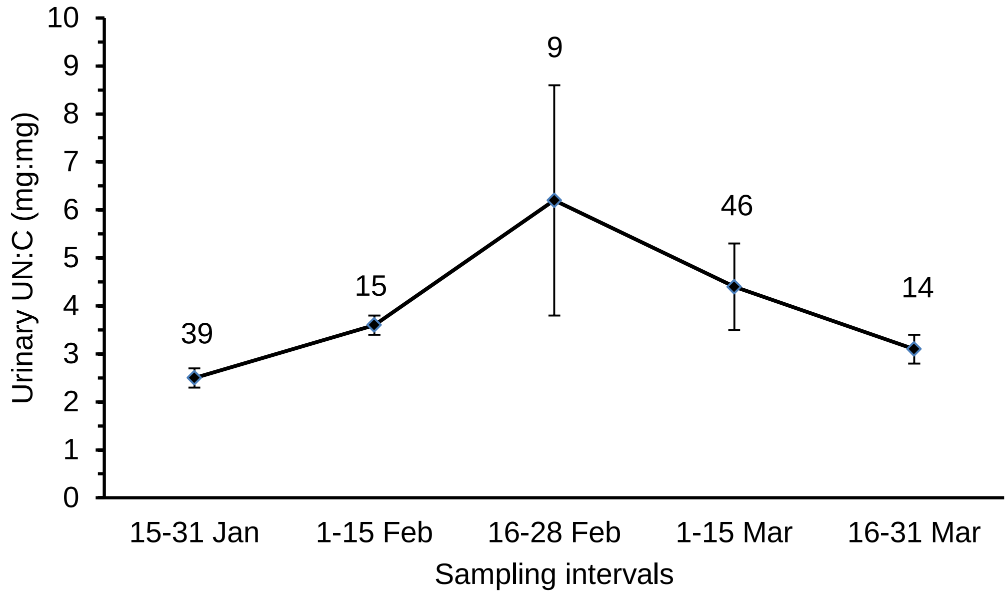

Figure 2. Mean (± SE) urinary urea nitrogen:creatinine (UN:C) ratios in snow (snow-urines) sampled randomly from moose in northeastern Minnesota, January-March 2013. Urea N:C ratios of 3.0-3.4 and ≥3.5 mg:mg are indicative of moderately severe and severe nutritional restriction, respectively (DelGiudice et al. 1987, 1991, 1997).

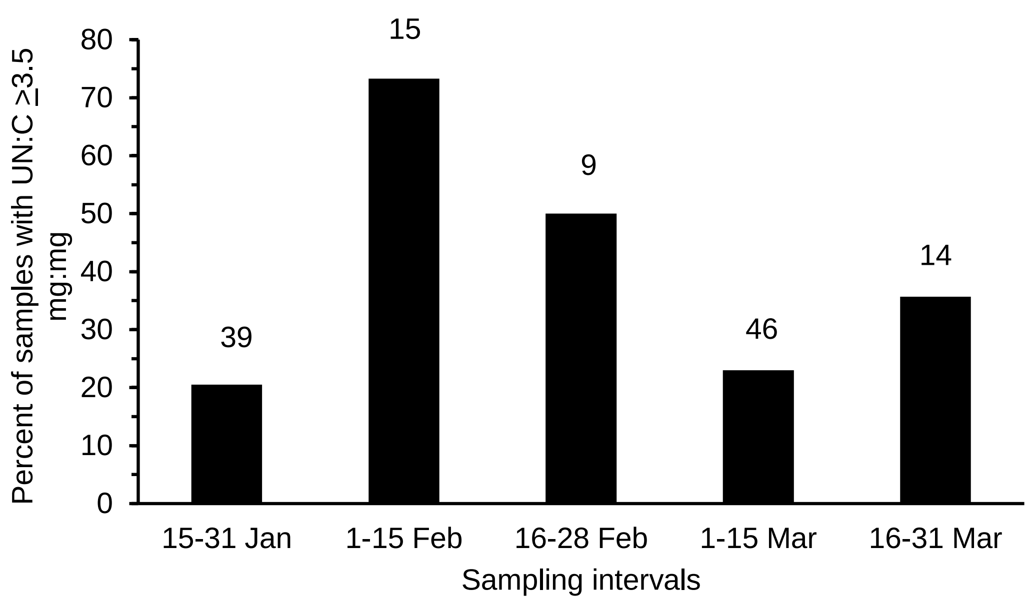

Figure 3. Percentage of randomly sampled urine specimens in snow (snow-urines) from moose with urea nitrogen:creatinine (UN:C) ratios indicative of severe nutritional restriction, northeastern Minnesota, January-March 2013.

A LONG-TERM ASSESSMENT OF THE EFFECT OF WINTER SEVERITY ON THE FOOD HABITS OF WHITE-TAILED DEER[1]

Glenn D. DelGiudice, Barry A. Sampson, and John H. Giudice

ABSTRACT

Nutrition is a critical link between environmental and population variation in northern populations of free-ranging white-tailed deer (*Odocoileus virginianus*). Yet, there are few studies of winter food habits of northern free-ranging deer and all of these were short-term studies (1-2 winters). Consequently, little information is available on the effect of inter-annual variation in winter severity on browse availability and diet composition of free-ranging deer. We describe winter browse use by white-tailed deer on 4 study sites in northern Minnesota during 1991-2005. We also tested several *a priori* predictions about how browse use and availability would change as a function of winter severity. We collected browse data from 1,028 feeding trails and recorded 38 available browse species or species groups. The 4 most common browse species (beaked hazel [*Corylus cornuta*], mountain maple [*Acer spicatum*], trembling aspen [*Populus tremuloides*], and speckled alder [*Alnus incana]*) accounted for 76% of total available stems, and beaked hazel and mountain maple accounted for 68% of total used stems. As expected, browse use and availability distributions were very similar (i.e., deer utilized many of the available browse resources). Mean number of browse species used did not increase (decreased selection) with snow depth. However, mean browse rate (functional response) increased with increasing snow depth, and use of speckled alder ("starvation food") increased when snow depth exceeded 40 cm. In addition, the number of browse species along feeding trails declined and stem abundance increased, on average, with increasing snow depth. Deep snow and increased use of dense conifer cover in northern Minnesota may restrict deer to greater use of lower quality feeding sites. In landscapes where this may occur, habitat management should attempt to minimize over-browsing on feeding sites in proximity to dense conifer cover by maximizing browse abundance and availability, particularly for beaked hazel and mountain maple. Managers also should consider enhancing alternative early winter feeding sites.

[1]Abstract from paper accepted by the *Journal of Wildlife Management*

A LONG-TERM ASSESSMENT OF THE VARIABILITY IN WINTER USE OF DENSE CONIFER COVER BY FEMALE WHITE-TAILED DEER[1]

Glenn D. DelGiudice, John R. Fieberg, and Barry A. Sampson

ABSTRACT

Backgound: Long-term studies allow capture of a wide breadth of environmental variability and a broader context within which to maximize our understanding of relationships to specific aspects of wildlife behavior. The goal of our study was to improve our understanding of the biological value of dense conifer cover to deer on winter range relative to snow depth and ambient temperature.

Methodology/Principal Findings: We examined variation among deer in their use of dense conifer cover during a 12-year study period as potentially influenced by winter severity and cover availability. Female deer were fitted with a mixture of very high frequency (VHF, n = 267) and Global Positioning System (GPS, n = 24) collars for monitoring use of specific cover types at the population and individual levels, respectively. We developed habitat composites for four study sites. We fit multinomial response models to VHF (daytime) data to describe population-level use patterns as a function of snow depth, ambient temperature, and cover availability. To develop alternative hypotheses regarding expected spatio-temporal patterns in the use of dense conifer cover, we considered two sets of competing sub-hypotheses. The first set addressed whether or not dense conifer cover was limiting on the four study sites. The second set considered four alternative sub-hypotheses regarding the potential influence of snow depth and ambient temperature on space use patterns. Deer use of dense conifer cover increased the most with increasing snow depth and most abruptly on the two sites where it was most available, suggestive of an energy conservation strategy. Deer use of dense cover decreased the most with decreasing temperatures on the sites where it was most available. At all four sites deer made greater daytime use (55 to >80% probability of use) of open vegetation types at the lowest daily minimum temperatures indicating the importance of thermal benefits afforded from increased exposure to solar radiation. Date-time plots of GPS data (24 hr) allowed us to explore individual diurnal and seasonal patterns of habitat use relative to changes in snow depth. There was significant among-animal variability in their propensity to be found in three density classes of conifer cover and other open types, but little difference between diurnal and nocturnal patterns of habitat use.

Conclusions/Significance: Consistent with our findings reported elsewhere that snow depth has a greater impact on deer survival than ambient temperature, herein our population-level results highlight the importance of dense conifer cover as snow shelter rather than thermal cover. Collectively, our findings suggest that maximizing availability of dense conifer cover in an energetically beneficial arrangement with quality feeding sites should be a prominent component of habitat management for deer.

[1]Abstract from published paper: DelGiudice, G. D., J. R. Fieberg, and B. A. Sampson. A long-term assessment of the variability in winter use of dense conifer cover by female white-tailed deer. PLoS ONE 8(6):e65368. Doi: 10.1371/journal.pone.0065368