Section 7: Muskoxen

Patricia E. Reynolds, Kenneth J. Wilson, and David R. Klein

Dynamics and Range Expansion of a Reestablished Muskox Population

Muskoxen (*Ovibos moschatus*) disappeared from Alaska in the late 1800s, but returned to the Arctic National Wildlife Refuge when animals were reestablished into areas of former range in 1969-1970 (Klein 1988). Released at Barter Island (Kaktovik) and the Kavik River, muskoxen initially moved into regions that encompassed the 1002 Area on the coastal plain of the Arctic Refuge. From 1974 to 1986 the muskox population grew rapidly. By 1987, however, numbers declined in the regions that they had first occupied (Reynolds 1998*a*).

Petroleum exploration and development could occur in muskox habitat in the 1002 Area of the Arctic Refuge. Status of the muskox population and factors related to trends in local abundance need to be determined if changes resulting from natural processes are to be separated from those that might result if industrial development is permitted in the Arctic Refuge.

We developed a study with the following objectives to understand the dynamics of the muskox population in and near the 1002 Area of the Arctic Refuge: 1) determine abundance and rates of population increase, production, and survival; 2) document changes in population distribution over time; and 3) evaluate factors associated with changes in the number of muskoxen.

Numbers of muskoxen seen during annual censuses in 1982-2001, combined with data from earlier studies, were used to estimate animal abundance and population trends of muskoxen in the 1002 Area (regions first occupied) and adjacent areas to the east and west (regions occupied later) (Reynolds 1998*a*). *Rates of successful calf production* (defined as calves:100 females >2 years old present in late June), survival of calves and yearlings, and long term reproduction patterns by marked female muskoxen were determined from annual sex and age composition counts made from the ground in 1983-2001.

Radio-collared adult muskoxen were relocated 6 times/year from 1982 to 1994 to determine seasonal and annual variability in population distribution and to document adult mortalities. Locations were determined from the air with a global positioning system (GPS) or were plotted on 1:63,360-scale maps. The adaptive-kernel technique within the computer program CALHOME (Kie et al.1996) was used to delineate the size and locations of regions used by mixed-sex groups of muskoxen in 1969-1981, 1982-1985, 1986-1989, and 1990-1993. *Core areas of use* (70% adaptive-kernel contour) and *total range* (95% contour) were used to document changes in distribution and range expansion over time.

Locations of muskoxen seen during seasonal muskox surveys in the Arctic Refuge, as well as locations of mixed-sex groups seen during other studies, were used to document the continued expansion of the population distribution from 1994-2001. Reconstructed models of the population estimating maximum and predicted population growth were used to evaluate how changes in calf production, survival, and emigration affected local abundance of muskoxen.

The Arctic Refuge's reestablished population of muskoxen grew slowly for a few years and then increased rapidly for more than a decade (Reynolds 1998*a*). Between 1977 and 1981, the population grew at $r = 0.24$, a rate approaching maximum growth. In 1986, 368 muskoxen were counted in the 1002 Area, but after 1986, numbers of muskoxen declined (Fig.7.1). The rate of increase slowed to 0.14 in 1982-1986 and to <0.00 in 1987-1995.

The rate of population growth ($r = 0.14$) in 1972-1996 (Reynolds 1998*a*) was similar to rates recorded for other expanding populations of muskoxen in Alaska and Canada (Spencer and Lensink 1970, Gunn et al. 1991). An introduced population of muskoxen in Greenland was still irrupting 25 years after release, but those animals were in an area of abundant high-quality forage with no predation and low snowfall (Olesen 1993).

In 1996-2001, numbers of muskoxen counted in the 1002 Area ranged from 168 to 212 (P. E. Reynolds, U.S. Fish and Wildlife Service, unpublished data) and indicate that muskox abundance is still declining slowly (Fig. 7.1).

Factors affecting changes in the number of muskoxen in the 1002 Area of the Arctic Refuge included changes in rates of successful reproduction and survival as well as changes in animal distribution.

Calf production was the only source of increase in this reestablished population; a lack of adjacent populations

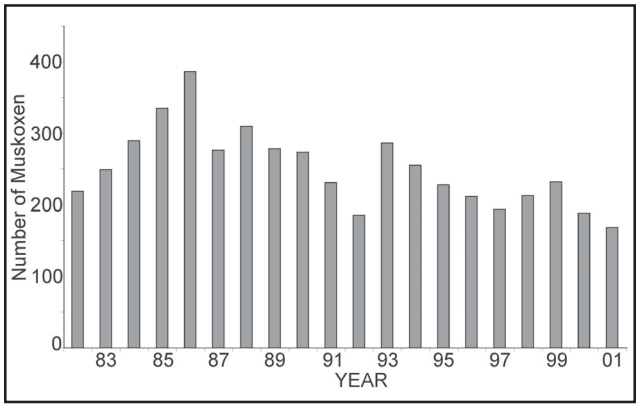

Figure 7.1. Number of muskoxen observed in the regions first occupied after reintroduction — the 1002 Area, Arctic National Wildlife Refuge, Alaska, USA, during spring censuses, 1982-2001

of muskoxen precluded immigration. Growth of the population during its most rapid increase was due to high rates of reproduction and survival of muskoxen in newly occupied habitats. In the 1002 Area, indices of successful calf production reached a maximum between 1977 and 1980 (87 calves:100 females >2 years old) during years when successful reproduction by some 2-year-old females and 100% reproduction among females >2 years old occurred in some groups (Jingfors and Klein 1982).

Calf production declined between 1983 and 2001 (Fig. 7.2). In 1983-1986, as the rate of population increase began to slow, calf production in the 1002 Area averaged 61 calves:100 females >2 years old compared with 49 in 1987-1990, 41 in 1991-1994, and 28 in 1995-1999 (Reynolds 1999). In June 2000 and 2001, very few calves (<5 calves per 100 females >2 years old) were seen. Because calves were counted several weeks after birth, we could not determine if changes in the production of muskox calves were due to lower fecundity or increased neonatal mortalities.

Reproductive patterns of radio-collared females in the 1002 Area showed similar trends. Mean *reproductive intervals* (number of years between successful reproductive events in a 3-year period) increased significantly ($r^2 = 0.95$, $n = 6$, $P = 0.0009$) between 1982 and 1999. By 1991-1993, most marked females successfully reproduced at intervals of 2 to 3 years, rather than every year (Reynolds 2001). Percentages of marked females without calves for 3 or more consecutive years were 0% in 1982-1987, 15% in 1988-1990, and 25% in 1994-1996 (Reynolds 2001). In summer, body weights of 8 lactating muskoxen (mean = 223 kg, range = 188-254 kg) were not different ($t = 2.2$, df = 10, $P = 0.167$) from 8 non-lactating females (mean = 196 kg, range = 136-254 kg) and were similar to weights of female muskoxen in other wild and captive populations (Reynolds and Reynolds 1999).

Unlike calf production, which declined in 1983-1995 ($r^2 = 0.75$, $P < 0.001$), calf and yearling survival did not decline over time (calf survival: $r^2 = 0.01$, $P = 0.71$; yearling survival: $r^2 = 0.01$, $P = 0.82$). Annual variability in young animal survival followed the same annual trends as calf production and was related to snow depth and the length of the snow season (Reynolds 1998*a*).

Between 1983 and 1999 the percentages of radio-collared muskoxen dying each year were variable but showed an increased trend (Reynolds 1999). Sources of mortality included kills by predators, including humans.

Legal hunting of muskoxen in the Arctic Refuge began in 1982. Over time, the number of permits issued each year increased from 5 males only to 12 males and 3 females. The season was expanded from 2 to 8.5 months. An average of 7 muskoxen was killed in 1985-1989 compared with an average of 10 in 1995-1999. About 3% of the muskox population in the Arctic Refuge was harvested annually from 1990-1999 (P. E. Reynolds, U.S. Fish and Wildlife Service, unpublished data).

Kills or scavenging of muskoxen by grizzly bears (*Ursus arctos*) in and near the Arctic Refuge increased significantly between 1986 and 2001 ($\beta = 0.504$, df = 18, $P < 0.001$) (Fig. 7. 3). Known kills of muskoxen by grizzly bears ranged from 0-2 deaths per year before 1993, 1-4 deaths per year in 1993-1996, and 5-10 deaths per year in 1997-2001 (Reynolds et al. 2002).

Forty-seven deaths of adult or sub-adult muskoxen from known grizzly bear predation occurred between 1982-2001. Of these, 28 muskoxen died during 10 incidents of multiple kills in which bears killed more than one muskox from a group. Most of these kills (79%) took place between May 1998 and June 2001 (Reynolds et al. 2002).

Grizzly bears likely also killed muskox calves and caused other mortalities of young calves that were

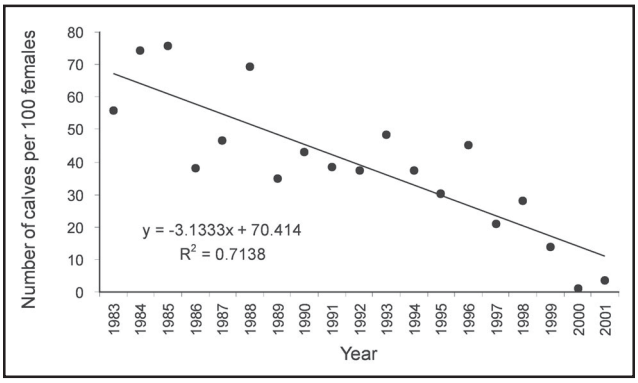

Figure 7.2. Changes in rates of successful production of muskox calves in the regions first occupied after reintroduction – the 1002 Area, Arctic National Wildlife Refuge, Alaska, 1983-2001. Successful calf production was measured by counting the number of calves per 100 females >2 years of age in late June.

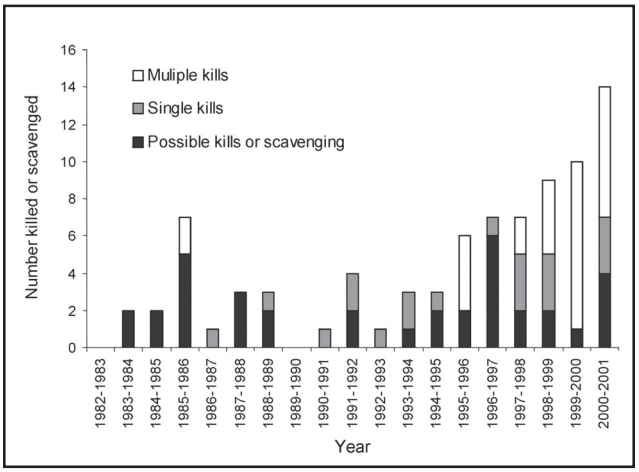

Figure 7.3. Number of muskoxen killed or scavenged by grizzly bears from April 1982 through June 2001 in northeastern Alaska, USA. (*from* Reynolds et al. 2002)

deserted during predation events. Multiple kills of calves were observed in Canada (Clarkson and Liepins 1993). The increase in kills by grizzly bears suggests that predation may have been one factor that resulted in very low numbers of calves in late June of 2000 and 2001. Deep snow and a prolonged winter season in 2000 and 2001 also likely contributed to the low numbers of calves seen in those years and may have exacerbated the number of predation events (Reynolds et al. 2002).

Shifts in distribution and emigration also affected numbers of muskoxen in the 1002 Area of the Arctic Refuge. Following their release in 1969 and 1970, most muskoxen became associated with 1 of 3 mixed-sex groups in 3 regions of the Arctic Refuge. The regions first occupied were located between the Canning and Aichilik Rivers within the boundaries of the 1002 Area (Fig. 7.4*a*) (Reynolds 1998*a*). After 1986, muskoxen in mixed-sex groups colonized new regions east and west of the 1002 Area (Fig. 7.4*c,d*) (Reynolds 1998*a*).

In 1995, about 800 muskoxen were counted in the entire range of the population (Table 7.1), which had expanded westward to the Itkillik River, Alaska, and eastward to the Babbage River in northern Yukon Territory, Canada (Reynolds 1998a). In 1998-2001, mixed-sex groups of muskoxen continued to expand their range west to the Colville River, southwest along the Sagavanirktok River, and south and east of the Babbage River in northwestern Canada. During these years, <700 muskoxen were counted throughout the total range of the population (Table 7.1) (P. E. Reynolds, U.S. Fish and Wildlife Service, unpublished data, E. A. Lenart, Alaska Department of Fish and Game, unpublished data, and D. A. Cooley, Yukon Renewable Resources, unpublished data).

Differences between the observed and predicted abundance in the 1002 Area, based on reconstructed population projections, suggest that changes in muskox calf production and animal survival caused most of the decline in the rate of population growth (Reynolds 1999). Density dependent factors as well as annual variability in snowfall and increasing rates of predation all likely influenced observed changes in calf production and animal survival.

Emigration of mixed-sex groups of muskoxen also reduced the number of muskoxen in the 1002 Area (Reynolds 1998*a*, 1999). In 2000 and 2001, the additional emigration of mixed-sex groups containing marked animals and the low rates of successful calf production (<5 calves per 100 females > 2 years old) contributed to the declining trend in numbers of muskoxen in the 1002 Area (P. E. Reynolds, U.S. Fish and Wildlife Service, unpublished data).

Although muskoxen are continuing to expand into their former range in northern Alaska and northwestern Canada, numbers of muskoxen in the 1002 Area are not likely to increase from their present level of <250 animals in the near future.

If exploration and extraction of petroleum resources are permitted in the Arctic Refuge coastal plain, associated industrial activities could further reduce the number of muskoxen in the 1002 Area either through induced dispersal or decreased productivity and survival. Muskoxen are year-round residents of the 1002 area, which heightens their vulnerability. In addition, their small numbers make it less likely that the muskoxen can recover from perturbations.

Status and distribution of muskoxen in and near the 1002 Area should continue to be monitored to document future trends.

Seasonal Strategies of Muskoxen: Distribution, Habitats, and Activity Patterns

Seasonal shifts in distribution, habitat use, and activity are means by which animals maximize energy intake and avoid conditions that risk their survival. The muskox is an energetically conservative species (Klein 1992) and its seasonal habitat use and energy budgets influence its reproduction and survival (White et al. 1989). Limited forage availability and energy constraints in winter as well as potential cumulative effects of disturbance contribute to its susceptibility.

As year-round residents of the coastal plain of the Arctic Refuge, muskoxen are vulnerable to human activities in both winter and summer. Information is needed about their seasonal patterns of distribution and activity to evaluate and minimize potential effects associated with oil and gas exploration and development proposed for the Arctic Refuge's 1002 Area.

Our study to determine seasonal patterns of muskoxen on the coastal plain of the Arctic Refuge had the following objectives: 1) compare distribution and habitat use of muskoxen in different seasons, and 2) determine seasonal movements and activity patterns of muskoxen.

In the Arctic Refuge, snow is present from 8-9 months each year (September - May). Five seasons were defined for muskoxen based on ecological and biological conditions: *calving* (late March to mid-June), *summer* (late June to mid-September), *early winter* (late September to mid-November), *mid-winter* (late November to mid-January), and *late winter* (late January to mid-March).

To identify population distribution in different seasons, 19-25 radio-collared muskoxen were monitored and 4 to 6 radio-relocation surveys were flown each year from 1982 to 1995. Locations of groups of muskoxen, both marked and unmarked, were determined using a global positioning system or were plotted on 1:63,360 scale maps.

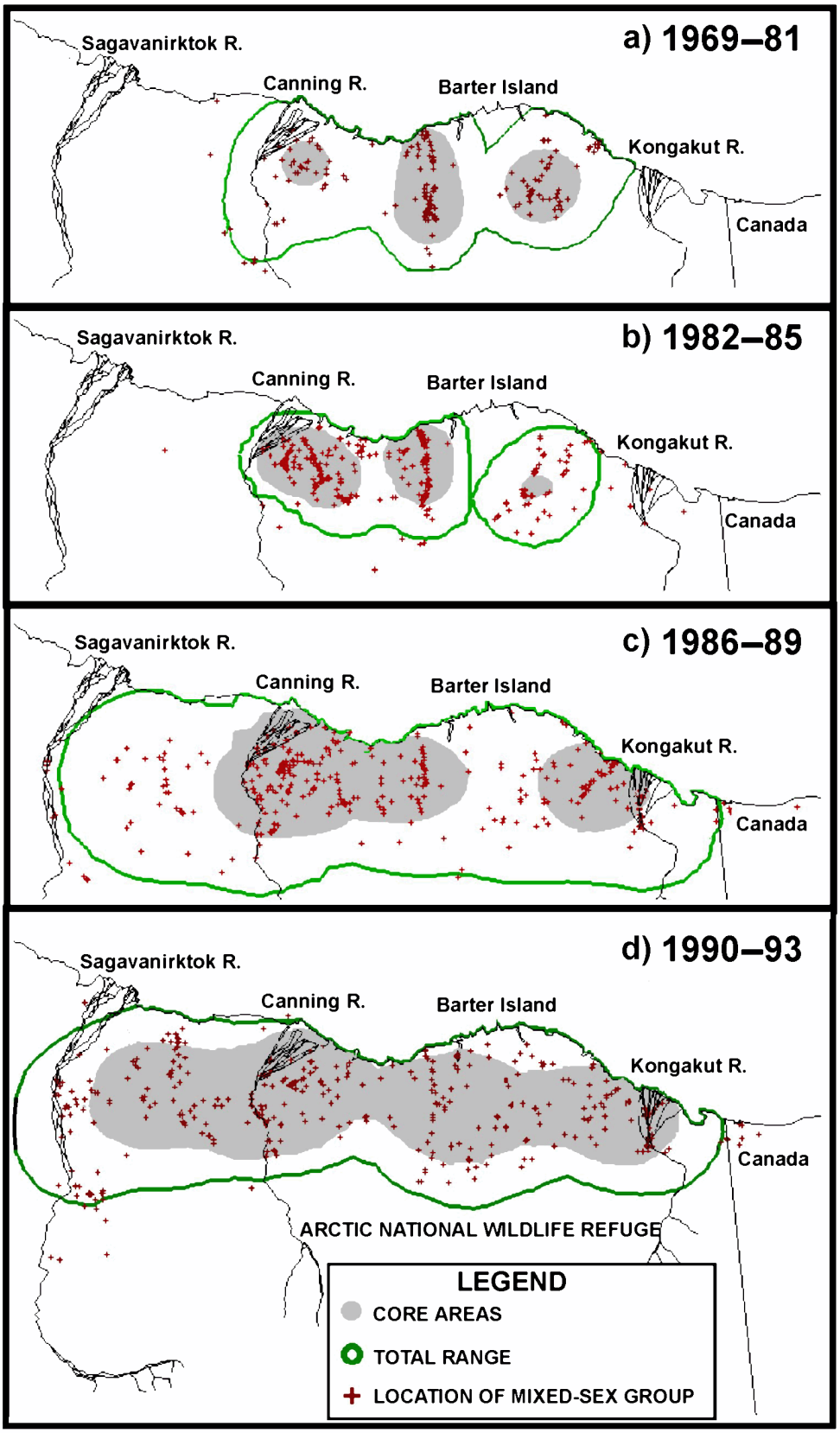

Figure 7.4. Range expansion of muskoxen in mixed-sex groups in and near the Arctic National Wildlife Refuge, Alaska, 1969-1993. *Total ranges* were defined by 95% adaptive kernel contours. *Core areas* were defined by 70% adaptive kernel contours. (*from* Reynolds 1998*a*)

Table 7.1. Number of muskoxen seen in different regions in northeastern Alaska, USA, and northwestern Canada in 1982-2000 during pre-calving surveys. *GMU 26B* and *26C* are State of Alaska game management units. The muskox population originated from animals released adjacent to the Arctic National Wildlife Refuge, Alaska, in 1969 and 1970. The muskoxen began to disperse into new regions east and west of the Arctic Refuge by 1986 (Reynolds 1998*a*).

Year	West of the Arctic Refuge: Itkillik River to Canning River (GMU 26B)[a]	1002 Area in the Arctic Refuge: Canning River to Aichilik River[b]	All Arctic Refuge: Canning River to Canada (GMU 26C)	East of the Arctic Refuge in northern Yukon Territory, Canada[c]	Arctic Refuge + west + east
1982		219	219		219
1986	9	386	399	23	431
1990	122	273	332	41	495
1995	330	228	321	146	797
1998	207	213	331	136	674
2000	277	189	246	146	669

a data source: E. A. Lenart, Alaska Department of Fish and Game, Fairbanks, Alaska, USA
b regions first occupied; numbers included in Arctic Refuge numbers
c data source: D. A. Cooley, Department of Renewable Resources, Yukon Territories, Canada

Seasonal distribution and movement rates were determined from 15 female muskoxen fitted with *satellite collars* (ultra-high frequency platform transmitter terminals that were relocated by satellite) (Reynolds 1989). Three to 5 animals carrying satellite collars were monitored yearly from October 1986 through March 1992. These collars transmitted information about animal location and activity every second or third day for 6 hr/day (Reynolds 1998*b*).

Seasonal distribution of the population and seasonal home ranges of satellite-collared muskoxen were delineated with an adaptive-kernel technique and the program CALHOME (Kie et al. 1996). Seasonal differences in population distribution were compared as the overlap of *core areas* (70% contour), distances between core-area centers, and core-area sizes.

Mean movement rates (km/day) for each season and each month were calculated from distances moved by satellite-collared muskoxen. Distances were calculated between consecutive locations at 40-55 hr intervals. Mean activity indices for each season and each month were derived. Activity counts from 5 satellite-collared muskoxen with >10 days of activity counts per month were used to estimate mean activity (Reynolds 1998*b*).

Land-cover and terrain types, extracted from a land-cover map derived from Landsat-Thematic Mapper data (Jorgenson et al. 1994), were used to determine seasonal differences in habitat use at a landscape scale. Selection ratios of 6 land-cover classes and 5 terrain types were based on proportions present in core areas (habitats used) divided by proportions in the entire study area (habitats available) (Reynolds 1998*b*).

The average size of core areas used by muskoxen carrying satellite collars was significantly larger ($P < 0.05$) in summer (223 km^2) than in calving season or the 3 winter seasons (27-70 km^2) (Reynolds 1998*b*). The size of core areas was highly variable in summer, but means differed by almost an order of magnitude between summer and other seasons. The minimum size of core areas used in summer was >4 times larger than minimum core areas occupied in winter or calving.

Muskoxen were conservative in their daily movements throughout the year. Most (95%, $n = 2314$) movements made by satellite-collared muskoxen were <5 km/day (Reynolds 1998*b*). Of these, 46% were <1 km/day. Moderate movements of 5-10 km/day took place primarily between June and September (77 of 108). Only 1 (<1%) moderate movement of 5-10 km/day was recorded between January and April. Movement rates >10 km/day, resulting in relatively long moves, were rare (18 of 2314); 16 (89%) movements >10 km/day occurred in July.

Mean daily movements in summer (2.6 km/day) were greater ($P < 0.05$) than in other seasons (1.1–1.4 km/day) (Reynolds 1998*b*). Mean rates of movement were significantly higher ($P < 0.05$) in July than in other months (Fig. 7.5). Activity counts/minute from satellite-

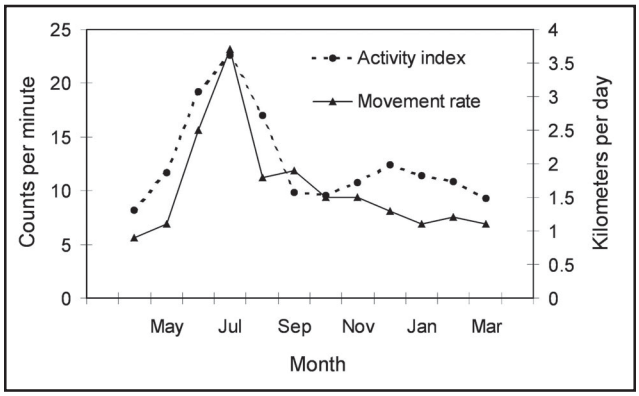

Figure 7.5. Seasonal changes in rates of movement and activity counts of satellite-collared female muskoxen in and near the Arctic National Wildlife Refuge, Alaska, 1986-1992. (*from* Reynolds 1998*b*)

collared muskoxen were also greater in summer ($P < 0.001$) than in other seasons. Activity counts differed among months ($P = 0.001$) and were highest in July and lowest in April during the onset of the calving season.

Seasonal home ranges occupied by females with satellite-collars overlapped less ($P = 0.01$) between calving and summer than between early winter and mid-winter and between mid-winter and late winter (Reynolds 1998*b*). This reflected the sedentary nature and small home range size of the muskoxen in winter. Distances between seasonal home ranges were also small. The distribution of the population of muskoxen occupying the coastal plain of the Arctic Refuge showed little change between seasons.

At a landscape scale, muskoxen used riparian cover along river corridors, floodplains, and foothills in all seasons. Moist sedge was selected in late winter and calving; tussock tundra was avoided in late winter. Wet sedge was used in proportion to availability in summer and early winter but avoided in other seasons. Upland shrub was selected only during the calving season and avoided in other seasons. Bare cover (including bare ground, water, and ice) was selected in all seasons except spring. Mountain terrain was avoided in all seasons (Reynolds 1998*b*).

Ground-based studies (Wilson 1992) provided more information at regional and local scales (*see next subsection on winter habitat use*). Locations of mixed-sex groups of muskoxen during summer and winter surveys demonstrated the importance of river corridors and adjacent uplands to this population (Fig. 7.6).

The small seasonal shifts in distribution and low movement rates observed in this study confirmed that muskoxen are energetically conservative throughout the year (Jingfors 1980, Thing et al. 1987) and that they have a high fidelity to geographic regions. Seasonal changes in movements, activity, and habitat use were related to

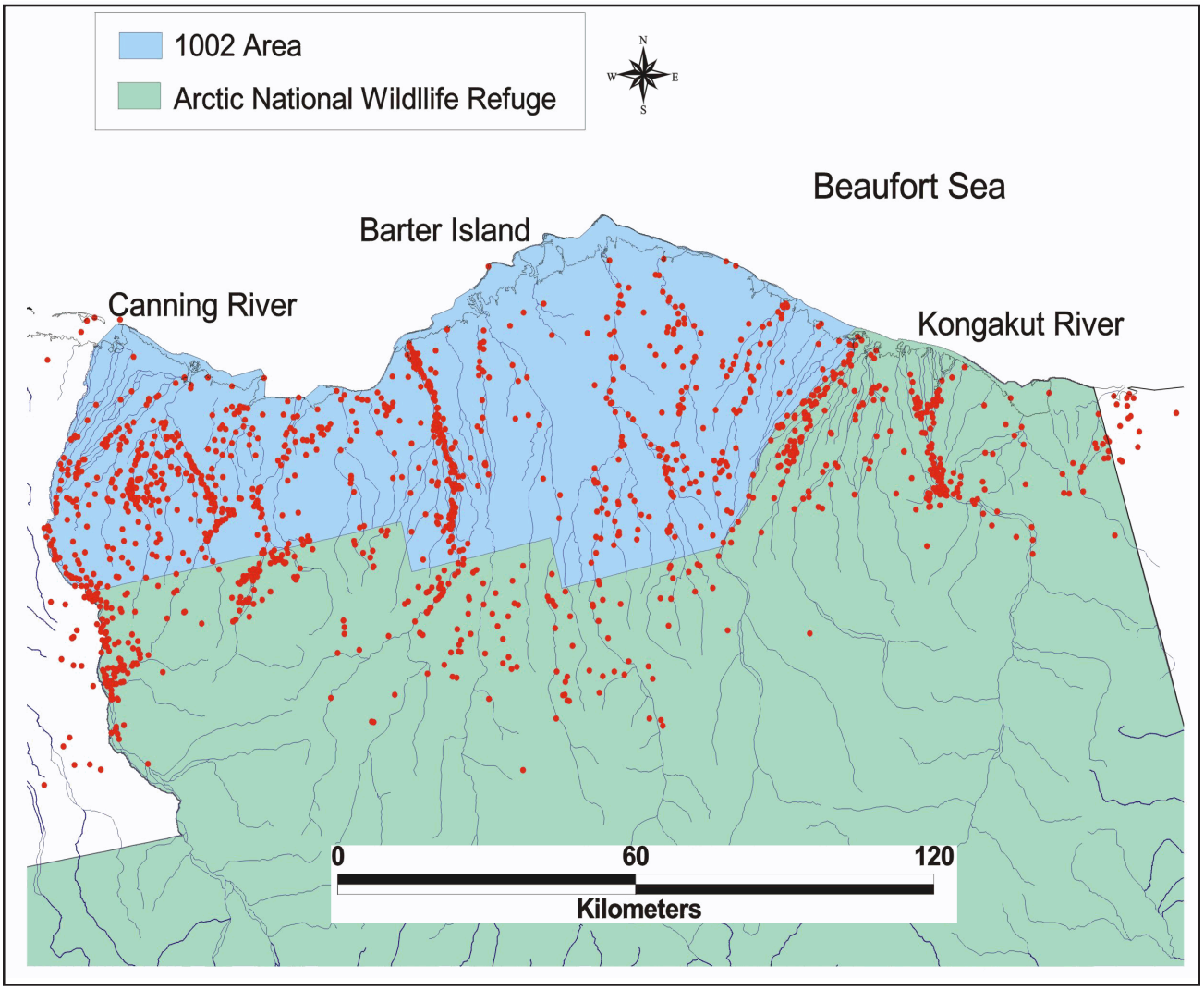

Figure 7.6. Locations of mixed-sex groups of muskoxen seen during winter and summer surveys in the Arctic National Wildlife Refuge, Alaska, USA, 1982-1999.

availability of forage and the energy budgets of muskoxen.

In winter, snow limits forage availability and habitat selection (Jingfors 1980). In late winter, muskoxen selected feeding sites with soft shallow snow (Biddlecomb 1992, Wilson 1992). These sites were frequently narrow windblown bluffs adjacent to rivers where snow accumulation was low (Nellemann and Reynolds 1997). By mid- to late winter, riparian willows and wet-sedge communities may be unavailable to muskoxen as snow depths increase (Wilson 1992, Evans et al. 1989).

Winter forage of muskoxen is of low quality (Staaland and Olesen 1992). Graminoids were a dominant component of the late winter diet of muskoxen in northeastern Alaska (O'Brien 1988, Biddlecomb 1992, Wilson 1992). Muskoxen, however, can digest low quality graminoids efficiently and may have a fasting metabolic rate lower than other ruminants (Adamczewski et al. 1994, Lawler 2001). In winter, muskoxen conserve energy by reducing movements and activity, decreasing the size of use areas, and concentrating in a few habitats where forage is not covered with deep snow.

Unlike caribou that calve in early June when nutritious vegetation is emerging, most muskoxen give birth several weeks before high quality green forage is available. In Alaska, Dall's sheep (*Ovis dalli*) (Rachlow and Bowyer 1994) and moose (*Alces alces*) (Bowyer et al. 1998) have similar calving strategies to muskoxen. To reproduce successfully, female muskoxen must be in good body condition at calving time to fuel the high cost of lactation. Their energy-conserving strategy of restricting movements and activity and selecting habitats with low snowcover allows female muskoxen to maintain body condition throughout the winter and spring (Thing et al. 1987).

Most muskoxen in the Arctic Refuge give birth in April and May and lactate under conditions of poor quality forage and harsh weather. Their increased use of foothill terrain and upland shrub during the calving season reflected shifts into areas where snowcover was shallow or blown free and their energetic costs of foraging were lower. Muskoxen with young calves also may avoid flooded riparian areas during calving and post-calving periods. Movement rates of muskoxen carrying satellite collars reached a yearly low in April at the onset of the calving season.

During the snow-free summer when food quality and quantity are high, muskoxen increase their movement and activity, occupy larger areas, and use diverse habitats as they forage on a variety of high-quality vegetation (Robus 1981, O'Brien 1988). They track the changing plant phenology in local areas to obtain high quality forage and rapidly regain body weight lost during winter, pregnancy, and early lactation. Muskoxen that fail to regain body weight are less likely to breed or successfully reproduce (White et al. 1997) and are less likely to survive a severe winter.

In our study we found that movement rates and activity increased in June as plants began to leaf out and were highest in July as live plant biomass peaked (Chapin 1983). Movement rates and activity of muskoxen carrying satellite-collars began to decline in August as plant senescence and rut occurred (Reynolds 1998*b*).

Seasonal strategies that emphasize energy intake in summer and energy conservation in winter, combined with physical adaptations for cold weather and the ability to process low quality forage, permit muskoxen to survive year-round in locations seasonally avoided by most other animals. Muskoxen are present during all seasons in the potential oil exploration and development area of the Arctic Refuge.

This study did not quantify the effects of petroleum development on muskoxen. But human activities that increase energetic costs to muskoxen in winter or decrease foraging opportunities in summer have the greatest probability to affect the muskox population. Riparian habitats frequently used by muskoxen are also likely to be used as sites for gravel and water extraction and winter road construction if exploration and development of petroleum resources occur on the coastal plain of the Arctic Refuge.

Exploratory and construction activities in northern Alaska often take place in winter. Muskoxen are particularly vulnerable to disturbance in winter because of limited habitat, the length of the arctic winter, and their need to conserve energy throughout the winter including the calving season. The average size of muskox groups is larger in winter than in mid-summer (Reynolds 1993). Large groups of animals often are more easily disturbed than small groups because large groups contain more individuals responsive to perturbations.

Effects of human activities on muskoxen are likely related to the scale of the activity and the availability of alternate habitats that can be used if animals are displaced. Muskoxen that expanded westward from the Arctic Refuge use the wide Sagavanirktok River valley in summer despite the presence of the Dalton Highway and the trans-Alaska oil pipeline. Habitats available to muskoxen in the Arctic Refuge, however, are geographically constricted: The coastal plain is narrower because the mountains of the Brooks Range are closer to the Beaufort Sea (Fig. 1.1).

If undisturbed, muskoxen generally stay in relatively small areas throughout the winter. Avoidance by industry of these areas used by muskoxen could reduce the probability of disturbance and displacement of muskoxen. Minimizing human activities in areas occupied by muskoxen from mid-winter through the calving season could reduce the likelihood of disturbance during the

period when energy conservation is critical to survival. Locating permanent facilities away from river corridors, flood plains, and adjacent uplands could also help to reduce potential effects of industrial development on muskoxen.

Winter Habitat Use by Muskoxen: Spatial Scales of Resource Selection

During the snow season, which lasts up to 9 months in the Arctic Refuge, muskoxen remain in small areas, restricted by the availability of forage and by strategies needed to conserve energy (Reynolds 1998*b*). Human disturbance or destruction of their habitat could displace muskoxen from these limited wintering areas.

To determine what kinds of sites are used by muskoxen in late-winter and why these sites are selected, we set the following research objectives: 1) determine selection of vegetation types based on use and availability, and 2) compare snow depth and hardness, vegetation biomass, and environmental variables at feeding and non-feeding sites. Our study sites were located in the eastern half of the Arctic Refuge coastal plain and 1002 Area, between the Jago River and the Kongakut River.

Fieldwork was conducted in March, April, and July 1989-1990 at 44 late-winter foraging sites used by muskoxen. These sites included *feeding zones* (with feeding microsites or craters), *non-used adjacent zones* (contiguous to the feeding zone), and *non-used nonadjacent zones* (100 m beyond the adjacent zone). At each foraging site, a randomly-oriented transect was laid across the site, passing through the center of the feeding zone and defining unused zones.

Foraging sites were located from observations and tracks of muskox groups in March and April. Fecal pellets were collected for diet selection analysis. Winter foraging sites were relocated the following July when vegetation and environmental characteristics along transects were measured (Wilson 1992). Snow conditions, environmental characteristics, forage cover, and non-vegetated cover were included in an analysis of variables related to habitat selection.

In late winter, muskoxen fed most commonly in moist sedge tundra (37%) and tussock sedge tundra (37%) and used these types in proportion to availability. Dryas terrace (9%), riparian grass forb gravel bars (7%), wet sedge (5%), partially vegetated tundra (2%), and shrub tundra (2%) were selected less frequently than their availability. Muskoxen were not observed feeding in riparian shrub, Dryas ridge, barren ground, or water (Wilson 1992).

Total vegetation cover was greater in feeding zones than in unused adjacent and non-adjacent zones. Cover of evergreen shrubs, sedges, and dead vegetation was greater in feeding zones. Non-vegetative cover was greater in adjacent and nonadjacent zones (Wilson 1992).

Diet selection based on fecal analysis of winter pellets (corrected for digestibility) indicated a high use of sedges (39.1%) and mosses (24.6%) (Wilson 1992). Sedges and grasses were *selected* (use > availability); and horsetails, lichens, willows, and other shrubs were *avoided* (use < availability). Although selection for grasses was high, grasses did not make up a large proportion of the diet or the available habitat.

Analysis of rumen samples indicated that sedges (31%), grasses (19%), mosses (15%), and forbs (13%) comprised most of the diet. The proportion of willows was 8% in rumen samples. In other studies, riparian willows were used by muskoxen in late winter (O'Brien 1998, Robus 1991). During our study, however, snow limited the use of most riparian shrub communities. Willows were browsed in areas where they protruded through the snow (Wilson 1992).

Snow depth was shallower and softer in feeding zones than in nonadjacent zones, and shallower in feeding zones than in adjacent zones (Fig. 7.7). Snow depth and

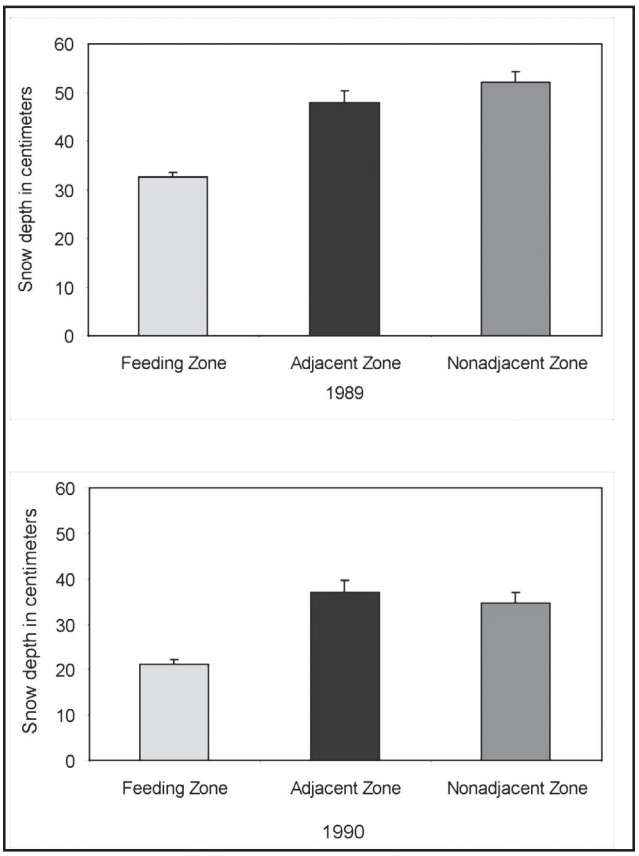

Figure 7.7. Snow depth (cm) in muskox *feeding zones* (areas containing feeding sites), *adjacent zones* (unused areas adjacent to and surrounding feeding zones) and *nonadjacent zones* (unused areas 100 meters beyond adjacent zones) in late winter 1989 (n = 20) and 1990 (n = 24) on the coastal plain of the Arctic National Wildlife Refuge, Alaska, USA. (*from* Wilson 1992)

hardness were less in microsites than in unused portions of feeding sites. Snow depth was the single variable most influential in discriminating between used and non-used areas. Muskoxen also appeared to avoid walking through areas of soft deep snow. Most feeding zones were near some type of topographic relief that had been subjected to wind scarring. Snow depth was shallower in feeding zones of tussock sedge tundra and moist sedge tundra, suggesting that within vegetation types, muskoxen chose feeding zones based on snow depth alone. No differences were detected between feeding zones and adjacent and nonadjacent zones in wetness, slope, micro-relief, or aspect (Wilson 1992).

Snow depth in feeding zones was deeper in 1989 than in 1990 (34.5 cm versus 23.0 cm, respectively), and total vegetation cover was greater in 1990 than in 1989 (Wilson 1992). In 1990, forb cover was greater in feeding zones compared with a greater cover of sedges and non-vegetative material in 1989 feeding zones. Muskoxen did not select for areas of high total vegetative cover in 1989, indicating that detection of vegetation characteristics may require shallow snow cover. In 1989, mean crater depths (29.7 cm) and mean feeding zone depths (34.5 cm) approached or exceeded the maximum snow depths in feeding areas (>30 cm) observed in other muskox studies (Rapota 1984, Smith 1984).

Partially vegetated tundra and Dryas terraces had the shallowest snow; the deepest snow occurred in shrub tundra and moist sedge tundra. Gravel bars with riparian forbs and grass had the greatest total cover of vegetation; moist sedge tundra had the least. Muskoxen selected feeding zones with shallower snow and greater vegetation cover compared with what was available (Wilson 1992).

Winter habitat for muskoxen is limited in quantity because animals must select foraging areas with shallow soft snow and a high cover of vegetation. Areas with little vegetation or deep hard-packed snow were not used. In this study, feeding zones were primarily along narrow bands of windblown vegetated bluffs adjacent to creeks, rivers, and the coastline, reflecting the importance of terrain features to habitat selection (Nellemann and Reynolds 1997).

Snow depth was one of the most important variables distinguishing used and unused area in this study of muskox habitat (Wilson 1992). Snow depth influences the availability of forage and can limit accessibility to some forage types (Evans et al. 1989). Snow depth affects energy budgets. Digging through snow to find forage is energetically costly for ungulates (Fancy 1986). The time lost while digging craters also reduces the daily rate of forage intake (Fleischman 1988).

In high snow years, when some habitats are not available and muskoxen spend more energy moving and foraging, muskoxen may be energetically constrained, resulting in lower survival and less successful reproduction. As winter progresses and snow accumulates, or if deep snow falls early in the winter, muskoxen may be forced to select foraging areas with deep snow or low plant biomass.

If muskoxen are limited in their accumulation of body reserves during summer, effects of a severe winter or overuse of winter range will have greater impacts on reproductive success and survival. If, in addition, animals are disturbed by human activities and cannot optimally use available habitats, the effects of a severe winter likely will be magnified.

Activities associated with the extraction of petroleum resources on the coastal plain of the Arctic Refuge have the potential to displace muskoxen into areas of deeper snow where forage availability is low and energetic costs to procure food are high. Displacement from, or permanent loss of, limited winter habitat could affect reproductive success and survival of muskoxen on the coastal plain of the Arctic Refuge.

To minimize potential effects of petroleum exploration and development on muskoxen in the Arctic Refuge, areas occupied by muskoxen in winter should be avoided; and areas of potential winter habitat should not be selected as sites for permanent facilities.

Summary

Muskoxen are year-round residents of the 1002 Area on the coastal plain of Arctic National Wildlife Refuge. Numbers of muskoxen in the Refuge have declined over time with <300 currently living on the coastal plain including <250 in the 1002 Area. Calf production has also declined over time.

Severe winters (deep snow and prolong snow seasons) and increasing rates of predation are important factors in the dynamics of this population. Muskoxen have expanded their range east and west of the Arctic Refuge coastal plain and emigration has contributed to declining numbers.

Most calves are born in April and May, several weeks before green forage is available. To survive the long months of winter and to maintain body reserves needed for successful reproduction, muskoxen conserve energy in winter by reducing activity and movements. In winter, muskoxen feed on dried sedges and other low quality forage in areas of low snow. Windblown ridges adjacent to rivers are frequently used in winter. During the short weeks of summer, when green forage is available, muskoxen increase their movements and activity and feed on a variety of high quality forage to regain body weight before the next winter. River corridors and nearby uplands are often used by muskoxen in summer.

Muskoxen in the Arctic Refuge are vulnerable to disturbance from activities associated with petroleum exploration and extraction because of their year-round

residency, their small population numbers and their need to conserve energy for the 9 months of winter if they are to successfully reproduce.

Disturbances that displace muskoxen from preferred winter habitats into areas of deeper snow or that increase their activity and movements could significantly increase their energetic costs in winter. Female muskoxen that are required to expend greater energy to survive the winter will have fewer reserves for pregnancy and lactation and may not reproduce successfully. Muskoxen frequently use habitats along or adjacent to rivers. These locations may be sites for gravel and water extraction and winter road construction if petroleum development is permitted in the Arctic Refuge.

Avoidance by industry of areas used by muskoxen and the location of permanent facilities away from river corridors, flood plains, and adjacent uplands could reduce the probability of disturbance and displacement of muskoxen. Status and distribution of muskoxen in and near the 1002 Area should be monitored to document future trends.

References

Adamczewski, J. Z., W. M. Kerr, E. F. Lammerding, and P. F. Flood. 1994. Digestion of low protein grass hay by muskoxen and cattle. Journal of Wildlife Management 58:679-685.

Biddlecomb, M. E. 1992. Comparative patterns of winter habitat use by muskoxen and caribou in northern Alaska. Thesis, University of Alaska, Fairbanks, Alaska, USA.

Bowyer, R. T., V. Van Ballenberghe, and J. G. Kie. 1998. Timing and synchrony of parturition in Alaskan moose: long-term versus proximal effects of climate. Journal of Mammalogy 79:1332-1344.

Chapin, F. S. 1983. Direct and indirect effects of temperature on arctic plants. Polar Biology 2:47-52.

Clarkson, P. L., and I. S. Liepins. 1993. Grizzly bear, *Ursus arctos*, predation on muskox, *Ovibos moschatus*, calves near the Horton River, Northwest Territories. Canadian Field-Naturalist 107:100-102.

Evans, B. M., D. A. Walker, C. S. Benson, E. A. Nordstrand, and G. W. Petersen. 1989. Spatial interrelationships between terrain, snow distribution and vegetation patterns at an arctic foothills site in Alaska. Holarctic Ecology 12: 270-278.

Fancy, S. G. 1986. Daily energy budgets of caribou: a simulation approach. Dissertation, University of Alaska, Fairbanks, Alaska, USA.

Fleischman, S. J. 1988. A model of the energy required by caribou to dig a feeding crater. Page 186 *in*. R. D. Cameron, and J. L Davis, editors. Proceedings of the Third North American Caribou Workshop. Alaska Department of Fish and Game Wildlife Technical Bulletin 8.

Gunn, A., C. Shank, and B. McLean. 1991. The history, status and management of muskoxen on Banks Island. Arctic 44:188-195.

Jingfors, K. T. 1980. Habitat relationships and activity patterns of a reintroduced muskox population. Thesis, University of Alaska, Fairbanks, Alaska, USA.

_____, and D. R. Klein. 1982. Productivity in recently established muskox populations in Alaska. Journal of Wildlife Management 46:1092-1096.

Jorgenson, J. C., P. E. Joria, T. R. McCabe, B. R. Reitz, M. K. Raynolds, M. Emers, M. A. Wilms. 1994. Users guide for the land-cover map of the coastal plain of the Arctic National Wildlife Refuge. U.S. Fish and Wildlife Service, Fairbanks, Alaska, USA.

Kie, J. G., J. A. Balwin, and C. J. Evans. 1996. CALHOME: a program for estimating animal home ranges. Wildlife Society Bulletin 24:342-344.

Klein, D. R. 1988. The establishment of muskox populations by translocation. Pages 298-317 *in* L. Nielsen and R. D. Brown, editors. Translocation of wild animals. Wisconsin Humane Society, Inc., Milwaukee, Wisconsin, USA.

_____. 1992. Comparative ecological and behavioral adaptations of *Ovibos moschatus* and *Rangifer tarandus*. Rangifer 12(2):47-55.

Lawler, J. P. 2001. Heat increment and methane production by muskoxen fed browse. Dissertation, University of Alaska, Fairbanks, Alaska, USA.

Nellemann, C., and P. E. Reynolds. 1997. Predicting late winter distribution of muskoxen using an index of terrain ruggedness. Arctic and Alpine Research 29:334-338.

O'Brien, C. H. 1988. Characterization of muskox habitat in northeastern Alaska. Thesis, University of Alaska, Fairbanks, Alaska, USA.

Olesen, C. R. 1993. Rapid population increase in an introduced muskox population, West Greenland. Rangifer 13(1):27-31.

Rachlow, J. L., and R. T. Bowyer. 1994. Variability in maternal behavior of Dall's sheep: environmental tracking or adaptive strategy? Journal of Mammalogy 75:328-337.

Rapota, V. V. 1984. Feeding ecology of the Taimyr muskoxen. Pages 75-80 *in* D. R. Klein, R. G. White, and S. Keller, editors. Proceedings of the First International Muskox Symposium. Biological Papers, University of Alaska Special Report 4.

Reynolds, P. E. 1989. An experimental satellite collar for muskoxen. Canadian Journal of Zoology 67:122-1124.

_____. 1993. The dynamics of muskox social groups in northeastern Alaska. Rangifer 13:83-89.

_____. 1998*a*. Dynamics and range expansion of a reestablished muskox population. Journal of Wildlife Management 62:734-744.

_____. 1998*b*. Seasonal distribution, activity and habitat use of muskoxen in northeastern Alaska. Chapter 2 *in* Ecology of a reestablished population of muskoxen in northeastern Alaska. Dissertation, University of Alaska, Fairbanks, Alaska, USA.

_____. 1999. Factors associated with stabilization of muskox numbers in northeastern Alaska. Paper presented at the Tenth Arctic Ungulate Conference, 9-12 August 1999, Tromso, Norway. Submitted to Rangifer (in final revision).

_____. 2001. Reproductive patterns of female muskoxen in northeastern Alaska. Alces 37(2):1-8.

_____, and H. V. Reynolds. 1999. Body weight and reproductive status of female muskoxen in northeastern Alaska. Paper presented at the Tenth Arctic Ungulate Conference, 9-12 August 1999, Tromso, Norway. Submitted to Rangifer (in final revision).

_____, _____, and R. Shideler. 2002. Predation and multiple kills of muskoxen by grizzly bears. Ursus 13:in press.

Robus, M. A. 1981. Muskox habitat and use patterns in northeastern Alaska. Thesis, University of Alaska, Fairbanks, Alaska, USA.

Smith, T. E. 1984. Population status and management of muskoxen on Nunivak Island, Alaska. Pages 52-56 *in* D. R. Klein, R. G. White, and S. Keller, editors. Proceedings of the First International Muskox Symposium. Biological Papers, University of Alaska Special Report 4.

Spencer, D. L., and C. J. Lensink. 1970. The muskox of Nunivak Island. Journal of Wildlife Management 34:1-15.

Staaland, H., and C. R. Olesen. 1992. Muskox and caribou adaptation to grazing on the Angujaartorfiup Nunaa range in West Greenland. Rangifer 12:105-115.

Thing, H., D. R. Klein, K. Jingfors, and S. Holt. 1987. Ecology of muskoxen in Jameson Land, northeast Greenland. Holarctic Ecology 10:95-103.

White, R. O., D. F. Holleman, and B. Tiplady. 1989. Seasonal body weight, body condition, and lactational trends in muskoxen. Canadian Journal of Zoology 67:1125-1133.

_____, J. E. Rowell, and W. E. Hauer. 1997. The role of nutrition, body condition and lactation on calving success in muskoxen. Journal of Zoology London 243:13-20.

Wilson, K. J. 1992. Spatial scales of muskox resource selection in late winter. Thesis, University of Alaska, Fairbanks, Alaska, USA.