Report to Parks Canada

Summary of a Recent Study of Microsatellite Variation In the Muskox *Ovibos moschatus* and Notes on Importance of Bathurst Island to Peary Caribou *Rangifer tarandus pearyi* and Muskox Persistence In the High Arctic

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Peter J. van Coeverden de Groot, Ph.D

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Introduction

The lands withdrawn for the Tuktusiuqvialik National Park on northern Bathurst Island were selected from a larger study area because they were the best choice based on a number of different themes in Parks Canada Region 38 (see below). A major consideration of the "wildlife theme" has been the importance of this area to Peary caribou *Rangifer tarandus pearyi* in this region (Miller 1990, 1995, 1998). To underscore the importance of this area to the other arctic ungulate found in this region, this report evaluates the conservation of Bathurst Island muskoxen *Ovibos moschatus* in the context of the overall genetic diversity of other arctic-island, Greenland, and mainland muskoxen. Also, using new techniques incorporating genetic data from geo-referenced individual muskoxen the scale of dispersal was estimated for muskoxen in this region. These estimates provide an additional criterion to evaluate the current Tuktusiuqvialik National Park. Armed with new muskox genetic data and recent census data (Miller 1998), and recent genetic (K. Zittlau, per. comm., 2001) and census (Miller 1990, 1995, 1998) data from Peary caribou, Tuktusiuqvialik National Park can be evaluated from the perspective of the preservation of genetic biodiversity and the preservation of dispersal opportunities for both taxa.

This report consists of five parts moving from a general summary of my recent Ph.D thesis on microsatellite variation in the muskoxen (section 1.0), through a more detailed discussion of the conservation implications of my genetic findings (section 2.0), followed by an integration of recent genetic and census data for muskoxen and Peary caribou supporting the importance of the Bathurst Island complex to the persistence of both species in the High Arctic (section 3.0). Then (section 4.0), I argue that average dispersal opportunities for both species are unlikely to be preserved within the limits of the current lands withdrawn for Tuktusiuqvialik National Park. I submit that within the study area the inclusion of any additional landmass would be of value to muskoxen, however in the case of Peary caribou the inclusion of specific areas to the west and northwest of Bathurst Island – particularly the Governor General Group of islands – will enhance the longevity of this species. Lastly (section 5.0), I conclude with the combined implications of my thesis, recent genetic work on the Peary caribou and census data for both species regarding the importance of Tuktusiuqvialik National Park and the addition of more areas to its proposed boundaries to the longevity of both taxa.

1.0 Ph.D Research Objectives and Summary of Results

Initially my objectives were to 1) characterize molecular genetic variation across the range of endemic muskoxen, 2) use those data to investigate the role ice-bound Arctic Ocean water bodies play in influencing genetic exchange among muskoxen and 3) integrate those data into a genetic evaluation of current conservation and management plans for those muskoxen.

As a result of previously reported low genetic variability in muskoxen (Engel et al. 1996, Groves 1997, Holm et al. 1999), I examined variation in microsatellite DNA in this species. Microsatellites are repeating sequences of DNA of between 2-4 base pairs, which are interspersed throughout the genome and have high rates of mutation (Weber and Wong 1993, Tautz and Schlotterer 1994). Microsatellites take the form of for example *CACACACA… CA* represented as $(CA)_n$, where n = the number of repeating units. A unique microsatellite repeat array in the genome is called a *locus* (plural *loci*) and for my study the measure of interest is the variation in repeating unit length n within and among muskoxen across different *loci*.

For my study I made 17 muskox specific microsatellite loci and included them in an initial survey of microsatellite variability in 30 loci (17 loci from muskoxen and 13 from other ungulate taxa) across 18 samples from throughout their range. It was apparent from this effort that microsatellite variation in muskoxen was lower than the average reported for these types of DNA's in other ungulates. After the completion of this study, I choose 14 of the most variable of the 30 loci and used them to examine variation in 169 muskoxen from 11 different populations sampled from much of the Canadian Arctic and North and East Greenland (see Figure 1).

1.1 *Microsatellite variation throughout the range of endemic muskoxen.*

The major findings of the survey of 169 muskoxen across 14 loci were as follows: 1) the low genetic variation in muskoxen is unequally distributed with muskoxen on the Arctic Islands being much less variable than mainland conspecifics (see Table 1) and, 2) Mainland (ML) muskoxen constitute the sister group of two muskox lineages found on the Arctic Islands – the northern arctic-island (NAI) lineage and the southern arctic-island (SAI) lineage (see Figure 1).

Two likely mechanisms may explain the low and unequal distribution of genetic variability in muskoxen. In one explanation, refugial isolation of some muskoxen on

Banks Island while others were isolated below the large Laurentide Ice Sheet during the Last Glacial Maximum of the Wisconsin resulted in both the low genetic diversity and the current muskox genealogical structure. The second explanation attributes the lack of variability in muskoxen – particularly arctic-island muskoxen to repeated population crashes in their recent past. Muskox numbers are known to decline to precipitously low numbers during times of particularly harsh weather (Miller et al. 1977a, Gunn et al. 1991). During those times, small muskox populations were thought to be isolated in a handful of polar refuges (see Figure 2; Thomas et al. 1981). I was not able to distinguish the relative roles that these two mechanisms played in structuring muskox microsatellite polymorphism.

1.2 *Varied role of arctic waterways*

In the third part of my study, I used regression analyses of *inter-individual* shared allele distance (D_{SA}) and geographic distance to investigate the role of the contiguous frozen water bodies of the Arctic Ocean in muskox genetic exchange. D_{SA} between individuals is computed as the proportion of similar repeat sized units shared (for example CA_{18}) across all microsatellite loci compared in the two individuals. I found that inter-island dispersal of muskoxen was either lesser or greater among different sea ice crossings relative to muskoxen on contiguous land. Multiple regression analysis suggests mathematically that the ice-bound waters of the Arctic Ocean generally expedite or at least do not hinder muskox dispersal in the more northern NAI muskoxen. At the same time, 'Generalized Mantel Analysis' indicated that inter-island movement of SAI muskoxen was in some cases retarded and in others expedited in comparison to movement on contiguous land mass in the range of this taxon. Although I could not measure them, the above results likely reflect the different ice conditions or width of individual ice-bound water bodies. A noticeable finding was the failure to detect any movement of muskoxen between the mainland and the adjacent Arctic Islands of Banks and Victoria.

1.3 *Genetic evaluation of the conservation and management of endemic muskoxen*

The last part of my study involved an evaluation of current conservation initiatives against a backdrop of three criteria informed by microsatellite polymorphism in muskoxen. Criteria 1 – Conservation of the genealogical structure in Canadian muskoxen. With the six extant or proposed conservation areas throughout the range of endemic muskoxen members of all three of the muskox lineages - ML, NAI and SAI - are conserved. Criteria 2 – Conservation of the most genetically diverse population in each of the three muskox lineages. While the most genetically diverse populations of ML muskoxen receive protection in the Thelon Game Sanctuary, the conservation of the most diverse arctic-island muskox population - Bathurst Island which is part of the SAI lineage – remains uncertain. The most diverse NAI population, animals from Devon Island and Grise Fiord, southern Ellesmere Island, receive no protection. Criteria 3 - Conservation of areas large enough to conserve the process of natural dispersal. Here I used the '*area of positive autocorrelation*' from the autocorrelation of interindividual genetic distance D_{SA} on geographic distance to estimate the scale of dispersal indirectly for animals within each of the three lineages (Table 2). The large Thelon Game Sanctuary on mainland Canada encompasses sufficient area (38 400 km^2) to provide natural dispersal opportunities for ML muskoxen where the scale of dispersal estimated from autocorrelation analyses was 38 025 km^2. Similarly, the large National Park of North and East Greenland (200 000 km^2 of ice-free area in a 972 000 km^2 park) provides sufficient dispersal opportunities for NAI muskoxen where the scale of dispersal was estimated at 193 600 km^2. The significant finding of this study was that the proposed Tuktusiuqvialik National Park on Bathurst Island (8442 km^2) is significantly smaller than the area of positive autocorrelation for SAI muskoxen of 102 400 km^2 (see Table 1 for summary). Natural dispersal opportunities for SAI muskoxen would apparently be compromised, if muskoxen had to remain within the current boundaries of the land withdrawn for Tuktusiuqvialik National Park.

2.0 Implications of This Study for the Design and Management of Protected Areas Including National Parks

2.1 *Summary of selection criteria for Tuktusiuqvialik National Park on Bathurst Island.*

Northern Bathurst Island was selected for National Parks status as it is an area with the greatest "theme representation" in region 38 – an area that includes most of the western Queen Elizabeth Islands which are the Queen Elizabeth Islands west of Axel Heiberg, Devon and Ellesmere islands and north of the Parry channel (Parks-Canada 1997). The natural themes considered in this choice include a combination of geology, landforms, vegetation, wildlife and hydrology (D. Harvey, pers. comm., 2001). As an additional reason for its selection, Northern Bathurst Island shows very little impact of human activities with the possible exception of global warming (D. Harvey, pers. comm., 2001). Currently the majority of Bathurst Island north of Polar Bear Pass National Wildlife Area is to form part of the Tuktusiuqvialik National Park with a small coastal portion of Bathurst Island excluded as it is privately owned by Inuit (see Figure 3). The current perimeter of the park is guided by the desire to reflect ecological boundaries - the northern boundary is the shoreline - and to encompass as large an area as possible (D. Harvey, pers. comm., 2001).

2.2. Preservation of biodiversity, evolutionary potential and genetic exchange - important components of a successful design and management strategy.

The results of my study have particular relevance to the *wildlife* theme used as a criterion for park selection. Within this theme are grouped considerations including biodiversity, rarity (of the fauna and flora) and population abundance of particular organism - all of which are important in the selection of areas for reserves (Prendergast et al. 1999). Whereas rarity and population abundance for a target organism can be estimated through traditional ecological methods, the genetic techniques that I used can provide answers to the following questions.

1) Where should reserves be placed that conserve the largest amount of extant muskox genetic diversity?
2) How big should those reserves be if we are to conserve processes responsible for maintaining that biodiversity.

The preservation of extant biodiversity and dispersal are relevant goals for conservation and management of arctic taxa.

With a relatively low (versus more southerly habitats) number of species inhabiting large areas, biodiversity within and among arctic fauna and flora should be quantified not only below the species level at the subspecific level – but at the level of distinct geographic populations (ecotypes). The genetic techniques used in my study describe variation in muskoxen that is not obvious from morphological data. Whereas two incipient subspecies of muskoxen have been recognised - the white-faced *Ovibos moschatus wardi* and the barren-ground *Ovibos moschatus moschatus* (summarized in Tener 1965, Rowell 1990) - my data show three different lineages of muskoxen: the ML, SAI and NAI muskoxen. A system of reserves that includes members of each of these lineages is a first step toward preserving the biodiversity within this species. My study of muskoxen complements an increasing number of intraspecific diversity studies of arctic taxa (Holder et al. 1999, Paetkau et al. 1999, Zittlau et al. 1999, Ehrich et al. 2000). Once data sets are completed across the Arctic, an evaluation of the preservation of biodiversity within arctic flora and fauna at intra-specific levels can be completed.

In addition to the identification of three lineages of muskoxen providing a guide to the general areas of muskox habitat to be conserved, my techniques provide further guidance to site selection within these large areas (see Figure 1). Not all of the individuals in these three widespread lineages can be preserved. Therefore, from a conservation genetic perspective, the preservation of the more genetically diverse populations within each of these three lineages is a good starting point. The more diverse populations are thought to have the greatest evolutionary potential. Hence, they should adapt more readily and to a greater degree to changing environments, which is of increasing concern given the anticipated climate change in the Arctic (Maxwell 1997).

For each lineage I identified the populations with the greatest measure of genetic variability. Of particular importance, the most diverse population of arctic-island muskoxen are found on Bathurst Island.

Critical to the successful management and conservation of any *in situ* population of organisms is an estimate of *natural* genetic exchange within the focal population and among that population and other conspecifics outside that population. Incorporation of these parameters into management means the persistence of the focal population (e.g., population in a national park) is better ensured through maintenance of its genetic evolutionary potential. However, estimating accurate genetic exchange within and among continually distributed taxa with large ranges like muskoxen is both logistically expensive and analytically complex.

In the first instance, the remote distribution of muskoxen makes the sampling of all the potential donor and recipient muskox populations very difficult. Even if adequate samples could be obtained, common analytical methods are not immediately applicable to the natural distribution of muskoxen (Paetkau et al. 1995; Waser and Strobeck 1998). With my limited sample coverage (see Figure 1 & Table 2) any conclusions about genetic exchange using these methods will provide an incomplete (and probably incorrect) picture of muskox genetic exchange. Finally, even under ideal conditions of full sample coverage, the above techniques do not suggest the optimum size of a protected area.

Recasting genetic exchange in terms of dispersal has two benefits. On the one hand, the analytical framework is more tractable allowing the study of limited samples. As a result, one does not have to comprehensively sample potential donor or recipient populations before an accurate estimate of genetic exchange into and out of your target population can be made. Instead an '*area of positive autocorrelation*' for each group of animals (muskox lineage in this case) is calculated. This estimate is closely correlated with dispersal (Epperson 1995). The second attraction of this approach is that the estimate of the scale of dispersal provides a biologically justifiable size requirement for the protected area. By conserving the process of dispersal for the study taxon (muskoxen) a significant diversity generating and maintaining process for muskoxen is preserved. As mentioned above other methods do not provide this information. This type of genetic analysis has yet to be completed for any other arctic taxa.

3.0 Bathurst Island - A Special and Unique Place for Arctic Ungulates

In combination with the Polar Bear Pass National Wildlife Area, the proposed Tuktusiuqvialik National Park is of great importance for both muskoxen and Peary caribou in Parks Canada Natural Region 38. This conclusion is based on data obtained since the 1950s, suggesting that within the western Queen Elizabeth Islands, Bathurst Island together with Melville and Prince Patrick islands may have held persistent populations of muskoxen and Peary caribou since the withdrawal of the ice sheets that covered the region some 8000 years ago. The first line of evidence in support of this conclusion is census data. Those data show that although subject to sporadic fluctuations in population sizes over time, muskox and Peary caribou populations within the Bathurst Island complex and the Melville-Prince Patrick islands complex return to high mean densities during environmentally favourable intervening periods. This is especially true relative to muskoxen and Peary caribou mean densities on other western Queen Elizabeth

Islands and likely throughout the entire Queen Elizabeth Islands. The persistence of these populations become even more impressive when examined against a backdrop of nearly 5 decades of data indicating highly variable muskox and caribou numbers throughout the region (e.g., Tener 1963, Miller et al. 1977a, Miller 1990, 1995, 1998, Gunn and Dragon 2001). Populations of both species occasionally suffer drastic to cataclysmic annual die-offs throughout the western Queen Elizabeth Islands. During climatically favorable times it is known that both species increase in numbers in these two island complexes. It is probable that individuals from these expanding populations supplement adjacent remnant populations or even repopulate extirpated areas. Whereas these census data speak to very recent dynamics of those species on western Queen Elizabeth Islands, the second line of evidence supporting the significance of Bathurst Island to the persistence of both species in Region 38 over the last 8000 years is genetic data.

In general muskoxen prefer the relatively large and productive wet meadows of Polar Bear Pass and similar range within some of the broad valleys on the southeastern and southwestern coastal sections of Bathurst Island for most of the year (F. L. Miller, pers. comm., 2001). However, ranges on northern Bathurst Island provide important food sources for muskoxen when, for a short period in late spring (June), wet meadows can be saturated with standing water. During those times muskoxen will move temporarily to higher and drier sites. A number of those relief sites are on the northwestern and northeastern sides of Bathurst Island. Most muskoxen return to the more favourable muskox sites once the meadows are drier. It is important to note that some muskoxen apparently remain year-round on small patches of suitable habitat scattered about on relatively small, low-lying areas of northern Bathurst Island (F. L. Miller, pers. comm., 2001).

Census data support muskoxen prospering during favorable weather years and apparently still persisting during the most extreme weather years in what could be termed “refugia” on Bathurst Island as well as on Melville Island (e.g., Thomas et al. 1981). Within the western Queen Elizabeth Islands only the Bathurst Island complex and the Melville-Prince Patrick islands complex are known to sustain relatively large numbers of muskoxen and or Peary caribou. Although mean densities of animals on Melville, Prince Patrick and Bathurst islands can be similar during favorable environmental conditions, relative losses during prolonged unfavourable weather may differ among populations of the same species and across both species on those islands. A fuller evaluation of the relative long-term importance of these two island complexes to muskoxen and Peary caribou is not possible with existing census data, as such data have only been sporadically collected since the 1950s.

The importance of Bathurst Island for the long-term persistence of arctic-island muskoxen is, however, demonstrated by the distribution of genetic polymorphism in this species. If muskoxen, in general, are now in an expansion phase and are found over most of their possible range, those populations that are localised in the areas to which muskoxen repeatedly contract during hard times will have the highest genetic diversity. The muskox microsatellite data support a Bathurst Island "refuge". Of all arctic-island muskoxen surveyed, including animals from Greenland, southern Ellesmere (Grise Fiord), northern Ellesmere (which includes 4 samples from Axel Heiberg), Victoria and Banks islands, Bathurst Island muskoxen are the most diverse of a genetically depauperate arctic-island muskox lineage (see Figure 1 for sample locations). One way this can come about is if Bathurst Island is a place where muskoxen have persisted since the withdrawal of the Laurentide Ice Sheet some 8000 years ago.

Some of the same arguments can be made for the conservation of Peary caribou in the proposed Tuktusiuqvialik National Park. Northeastern Bathurst Island consistently has the highest number of caribou within the Bathurst Island complex – even when numbers are low (Miller 1998). The northern portions of Bathurst Island exhibit more relief and tend to be more rugged than the high central plateau and many coastal areas of southern Bathurst Island where snow characteristics in general and the later persistence of snow cover in springtime is less favourable. Orientation of major drainages on northern Bathurst Island and greater expression of microhabitats favour earlier loss of snow cover from both wind action and sublimation than potential foraging areas on southern Bathurst Island. These conditions lead collectively to more favourable areas for Peary caribou on northern Bathurst Island compared to southern Bathurst Island and other nearby Arctic Islands.

The largest populations of Peary caribou are found in the Bathurst Island complex and Melville-Prince Patrick islands complex. Recent (1997) estimates of Peary caribou are of ~1100 animals localized across these two areas, after 3 consecutive years (1994-97) of annual winter and spring die-offs of both species (Miller 1998, Gunn and Dragon 2001). The above estimate is an all-time known low for Peary caribou on the western Queen Elizabeth Islands. Although it is possible that another 1100 Peary caribou could be found collectively on the more easterly islands of Ellef Ringnes, Amund Ringnes, Axel Heiberg, Devon and Ellesmere – such numbers have never been documented there.

This estimate of the possible number of caribou on eastern Queen Elizabeth Islands is based solely on those easterly islands constituting 75% of the collective landmass of the Queen Elizabeth Islands, as no surveys of that region have suggested more than several hundred caribou there.

Genetic data also support the long-term importance of Bathurst Island for Peary caribou. Although recent microsatellite data indicate Peary caribou from Melville and Bathurst islands are genetically significantly different from each other, there is relatively little difference between the levels of genetic variability of the Melville-Prince Patrick Islands population and the Bathurst Island population (K. Zittlau, pers. comm., 2001). Following from arguments similar to those presented for muskoxen, these data indicate that both of these areas are equally important refuges for this species during prolonged periods of excessively severe weather.

In terms of Peary caribou there are two recent findings that suggest the preservation of caribou on northern Bathurst Island may be the best conservation choice in Natural Region 38 and across all of Queen Elizabeth Islands. First, recent microsatellite evidence suggest that Peary caribou from the Melville-Prince Patrick islands complex and the Bathurst Island complex are genetically significantly different from the Banks and Victoria arctic-island caribou populations (K. Zittlau, pers. comm., 2001). From the perspective of preservation of biodiversity, all efforts must be expended to conserve the unique caribou gene pool localized in the Bathurst Island complex. Secondly, recent telemetry data indicates some Peary caribou spend all year on northern Bathurst Island (Miller and Barry, submitted). The needs of these animals are completely contained within northern Bathurst Island. In contrast, 19th century accounts indicated that Peary caribou vacated eastern Melville Island in early winter and did not return until the following late spring (summarized in Miller et al. 1977a). More recent information from surveys and dye-marking studies documented caribou migrate from Melville Island to winter ranges on Prince Patrick Island and Eglinton Island, and then return in spring to Melville Island (Miller et al. 1977a, 1977b, Miller 1990). Although preservation of Peary caribou within the Melville-Prince Patrick islands complex would involve setting aside large portions of both of those islands, the needs of many of the Peary caribou within the Bathurst Island complex would be satisfied, at the very least, in a national park comprising northern Bathurst Island alone.

4.0 Meeting the Dispersal Needs for Peary Caribou and Muskoxen and the Inclusion of Additional Areas into Tuktusiuqvialik National Park

An estimate of the scale of dispersal can inform the selection of area for a National Park. Defined as the movements from location of birth to location of leaving offspring estimates of dispersal are critical to distribution and maintenance of genetic diversity. By conserving these opportunities, the target population is given an enhanced chance of survival. Whereas unique dispersal events are difficult to measure without accurate parentage assignments, the techniques use in my study aim to provide the scale of *average* dispersal. Other genetic methods that detect movements among sampled populations provide estimates of contemporary movement as opposed to *average* recurring dispersal (Paetkau et al. 1995, Waser and Strobeck 1998). Finally, while genetic data can inform the scale of dispersal, ecological data can inform specific choices for areas that are most important to recurring dispersal for muskoxen and caribou. This is particularly relevant in the application of muskoxen and Peary caribou dispersal estimates to the island landscape of the western Queen Elizabeth Islands.

Although my data indicate that muskox dispersal is likely to operate at a scale that is much larger than the current area of the proposed Tuktusiuqvialik National Park, no other areas or islands other than the larger meadows of southern Bathurst Island – are obvious candidates for inclusion in an enlarged park, based on census data. For example, survey data suggest islands to the west of Bathurst Island within the Governor General Group (Alexander, Marc, Massey, Vanier and Cameron islands) and to the north in the Berkeley Group (Helena, Sherard, Osborn and Hosken islands) may be home to only small numbers of muskoxen. Their numbers usually range from none to < 10 and rarely reach 15-30 on a single island at a given time (e.g., Tener 1963, Miller et al. 1977a, Miller 1995, 1998, Gunn and Dragon 2001). Similarly muskox numbers to the east on Cornwallis Island and little Cornwallis Island are not known to exceed several dozen animals and usually markedly less (e.g., Tener 1963, Miller et al. 1977a, Miller 1995, 1998).

In the context of providing opportunities for dispersal for Peary caribou the adjacent islands, especially those to the west in the Governor General Group and to the north in the Berkeley Group (and possibly further north, Lougheed Island in the Findlay Group) are likely to play a critical role. Although the scale of dispersal has not been investigated using my methods for Peary caribou, it is not unreasonable to assume that the likely resultant estimate will exceed the limits of the proposed national park. In contrast to muskoxen, survey data and other aerial search activities suggest that Peary caribou make more use of islands in the Governor General Group to the west and the Berkeley Group to the north of Bathurst Island (e.g., Tener 1963, Miller et al. 1977a, Miller 1995, 1998). For example, recent telemetry studies reported Peary caribou making year-round use of Vanier, Cameron, Alexander, Massey and Marc, with calving taking place on Massey and Alexander islands (Miller, in press). Some Peary caribou also use some or all of those islands plus Bathurst Island (Miller 1998; Miller and Barry, submitted; F. L. Miller, unpubl. data, 1993-97). Furthermore, there is telemetry evidence for a female caribou moving out of the Bathurst Island complex during a period of extreme environmental stress onto Lougheed Island then, within a few days to Borden Island and dying shortly after arriving there (Miller 1998). These data lead to an anticipation of a scale of dispersal for Peary caribou that exceeds the limits of the proposed park. Considering the equivalence of adjacent areas in terms of muskoxen, at the very least, the adjacent islands to the west and north currently included in the national park "study area" should be included in Tuktusiuqvialik National Park when possible.

5.0 Conclusions

There are five immediate implications of the genetic findings reported above coupled with previously reported census data for muskoxen and Peary caribou for the proposed Tuktusiuqvialik National Park.

1) Tuktusiuqvialik National Park will contain one of the two most variable of all arctic-island and Greenland muskoxen (Melville Island muskoxen remain to be sampled). As a result the evolutionary potential of arctic-island muskoxen is best preserved by the protection the animals on Bathurst Island.

2) Tuktusiuqvialik National Park will contain genetically unique Peary caribou. As one of the two major extant populations of these animals – the other one is found on Melville and Prince Patrick islands – the preservation of this gene pool is critical to the persistence of this distinct form of *Rangifer* in the face of a changing arctic climate.

3) Genetic data indicate the current area withdrawn for the proposed Tuktusiuqvialik National Park is smaller than the scale of average dispersal for muskoxen.

4) Genetic evidence for the scale of dispersal of Bathurst Island Peary caribou are not available but census data suggest the current dimensions of Tuktusiuqvialik National Park would limit average dispersal opportunities for Bathurst Island Peary caribou in terms of potential or required areas.

5) When genetic and ecological data for both species are combined the choice of an enlarged Tuktusiuqvialik National Park which includes the additional Governor General Islands is preferred. Whereas genetic data may inform the scale of dispersal, the choice of alternate areas for inclusion in an expanded Tuktusiuqvialik National Park is necessarily informed by ecological data. In the case of muskoxen ecological data is equivocal with respect to adjacent islands. In the case of Peary caribou the choice of Governor General Islands is clear.

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Table 1.

Variability at 14 microsatellite loci in 169 muskoxen from 11 sample locations across their range. Locations are arranged by lineages and approximately from north to south, with abbreviations used in figures in brackets. Four summary statistics of microsatellite variability are reported: 1) the unbiased estimate of expected heterozygosity ± standard error (SE) (Nei and Roychoudhury 1974), 2) the number of alleles per sample location (alleles are the different repeat numbers of the repeating array found in a sample, for example CA_8 CA_{10} and CA_{12}), 3) the number of polymorphic loci per location vary among locations and 4) the probability of any muskoxen from a given location being identical - Probability of Identity (P_{ID}) - to another from the same area using their 14 microsatellite locus genotypes. The P_{ID} formula used is given in (Paetkau et al. 1998). Data from the sample of bones from the Thelon Game Sanctuary are not shown here as only 4 of the 14 loci in the original study were reliable for this tissue type.

Location		Lineage	Latitude (N°)	Sample size	Heterozygosity SE	Number of Alleles	Polymorphic Loci	Probability of Identity (PID)
Northern Ellesmere	(NE)	NAI	81.5	9	0.261(0.078	29	10	7.84E-05
Grise Fiord	(GF)	NAI	77.1	15	0.274(0.006	30	9	9.20E-05
Greenland	(GD)	NAI	74.5	9	0.169(0.077	23	6	3.94E-03
Bathurst Island	(BI)	SAI	76.0	16	0.308(0.060	33	10	2.78E-05
Sachs Harbour	(SH)	SAI	72.0	19	0.198(0.040	23	8	2.92E-03
Kidjuut Lake	(KL)	SAI	71.7	21	0.189(0.044	25	8	2.80E-03
Wellington Bay	(WB)	SAI	69.2	20	0.242(0.056	27	9	7.00E-04
Kugluktuk	(KU)	ML	68.0	17	0.446(0.046	42	13	2.50E-07
Gjoa Haven	(GH)	ML	67.5	10	0.456(0.052	39	14	2.00E-07
Baker Lake	(BL)	ML	65.5	23	0.512(0.018	50	14	2.50E-08
Lutsel Ke	(LK)	ML	63.0	10	0.478(0.005	46	14	2.50E-08

Table 2.

Evaluation of the current conservation of endemic muskoxen with respect to major subdivisions and estimated areas of positive autocorrelation in three different lineages, mainland (ML), southern arctic-island (SAI) and northern arctic-island (NAI). In all calculations except the Highest Allelic Richness values of ML muskoxen, 14 loci were used. For this calculation 4 loci were used. Those samples with the highest allelic richness in each study were identified in this study using CONTRIB (Petit 1999). The Scale of dispersal refers to the area of positive autocorrelation we identified in this study using spatial autocorrelation of inter-individual genetic distances and geographic distances. For these analyses we used GENAIEX (Peakall and Smouse 1998).

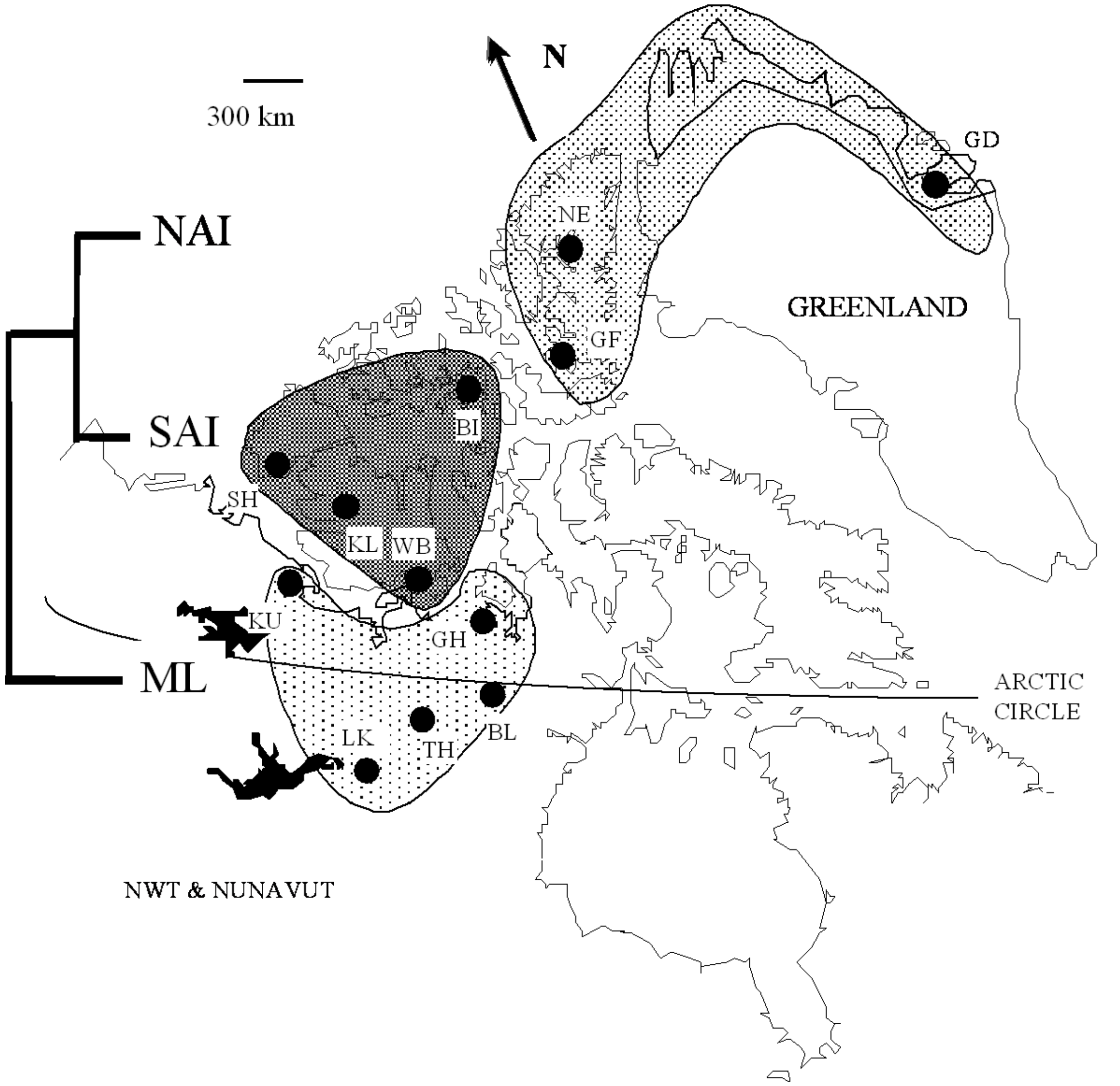
Lineage	Highest Allelic Richness	Protected Areas	Size of protected areas(km^2)	Scale of dispersal (km^2)
ML	Thelon G.S.[a]	Thelon G. S.	38 400	38 025
		Tuktut Nogait N.P.	16 974	38 025
NAI	Grise Fiord (GF) [b]	N. P. of North and East Greenland	200 000[c]	193 600
		Quittinirpaaq N.P.	37 775	193 600
SAI	Bathurst Island (BI)-Tuktusiuqvialik N.P.	Aulavik N.P	12 000	102 400
		Tuktusiuqvialik N.P.[d]	8442	102 400

[a] = Based on 4 variable loci. The next highest regions are KU and BL. KU sampling is very close to the Tuktut Nogait N.P. [b] = The most diverse sampling are in this lineage (GF) is not protected. [c] = The actual park size is 972 000 km^2 but only 200 000 km^2 is ice-free. [d] = This park is proposed.

Figure 1. Evolutionary relationships in extant muskoxen based on 14 microsatellites. NAI refers to the northern arctic-island muskoxen found on Axel Heiberg, Ellesmere, Devon and smaller nearby islands and Greenland. SAI refers to the southern arctic-island muskoxen found on Bathurst Island and the more southerly Arctic Islands. ML refers to the more variable muskoxen on the mainland of northern Canada. Also shown are centers of sampling efforts including the center of a sample of bones collected from Thelon Game Sanctuary (TH) (see Table 1 for other abbreviations).

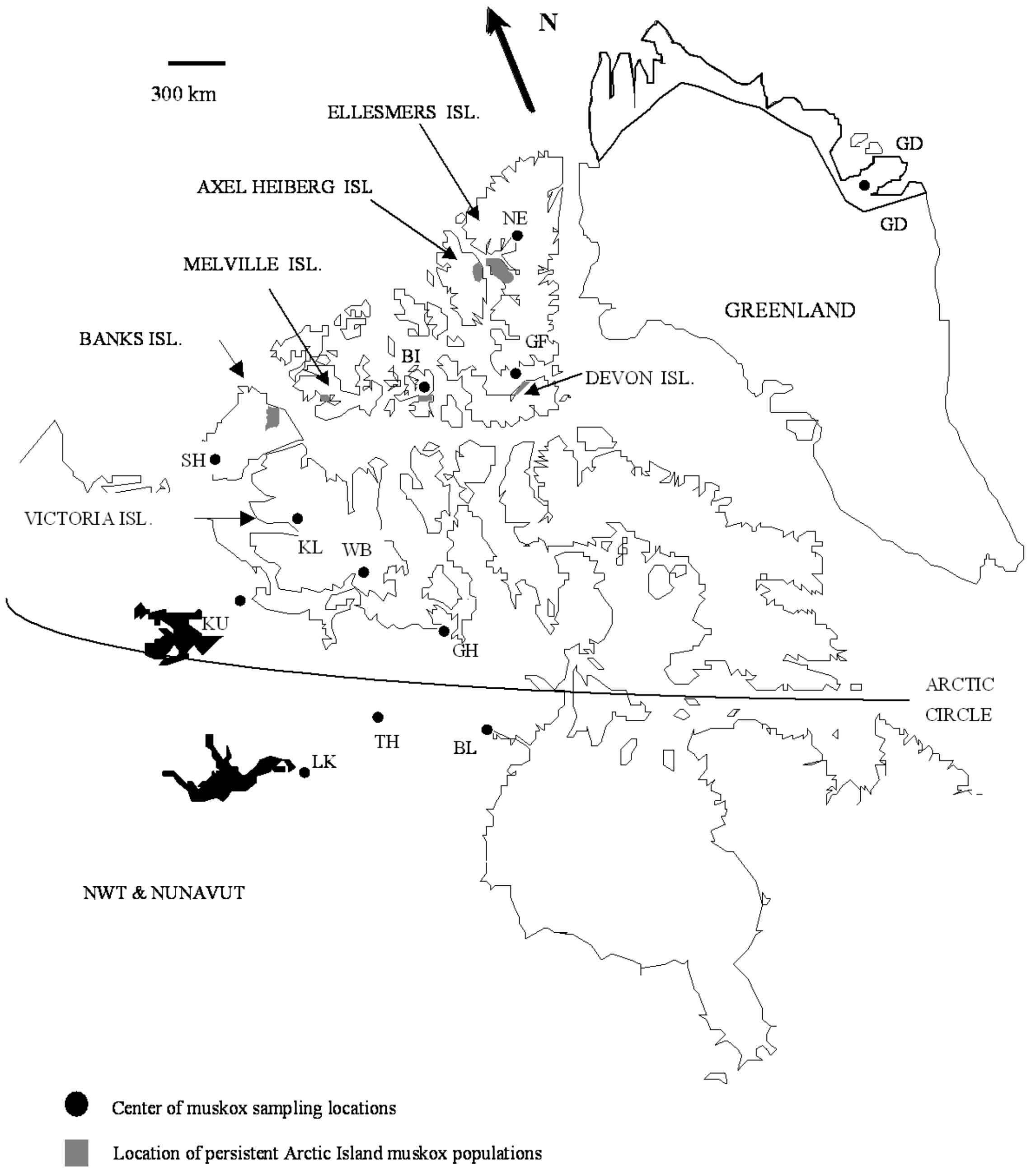
Figure 2. The map shows sample locations and areas considered to be critical refugia during extreme weather conditions in the Arctic Islands: Bailey Point (Melville Island), Fosheim Peninsula (Ellesmere Island), Mokka Fiord (Axel Heiberg Island), Polar Bear Pass (Bathurst Island), Thomsen River Valley (Banks Island) and Truelove Lowlands (Devon Island) (Thomas et al. 1981).

Figure 3. Portion of Bathurst Island complex currently withdrawn for the Tuktusiuqvialik National Park on northern Bathurst Island. The entire study area is not shown. Map courtesy of New Parks North (http://www.newparksnorth.org/images/bathurst_e.gif).



300 km
N
NAI
SAI
ML
GREENLAND
GD
NE
GF
BI
SH
KL
WB
KU
GH
BL
TH
LK
ARCTIC
CIRCLE
NWT & NUNAVUT

Figure 1



N
300 km
ELLESMERS ISL.
AXEL HEIBERG ISL
MELVILLE ISL.
BANKS ISL.
VICTORIA ISL.
DEVON ISL.
GREENLAND
GD
GD
NE
GF
BI
SH
KL
WB
KU
GH
TH
BL
LK
ARCTIC
CIRCLE
NWT & NUNAVUT
Center of muskox sampling locations
Location of persistent Arctic Island muskox populations

Figure 2

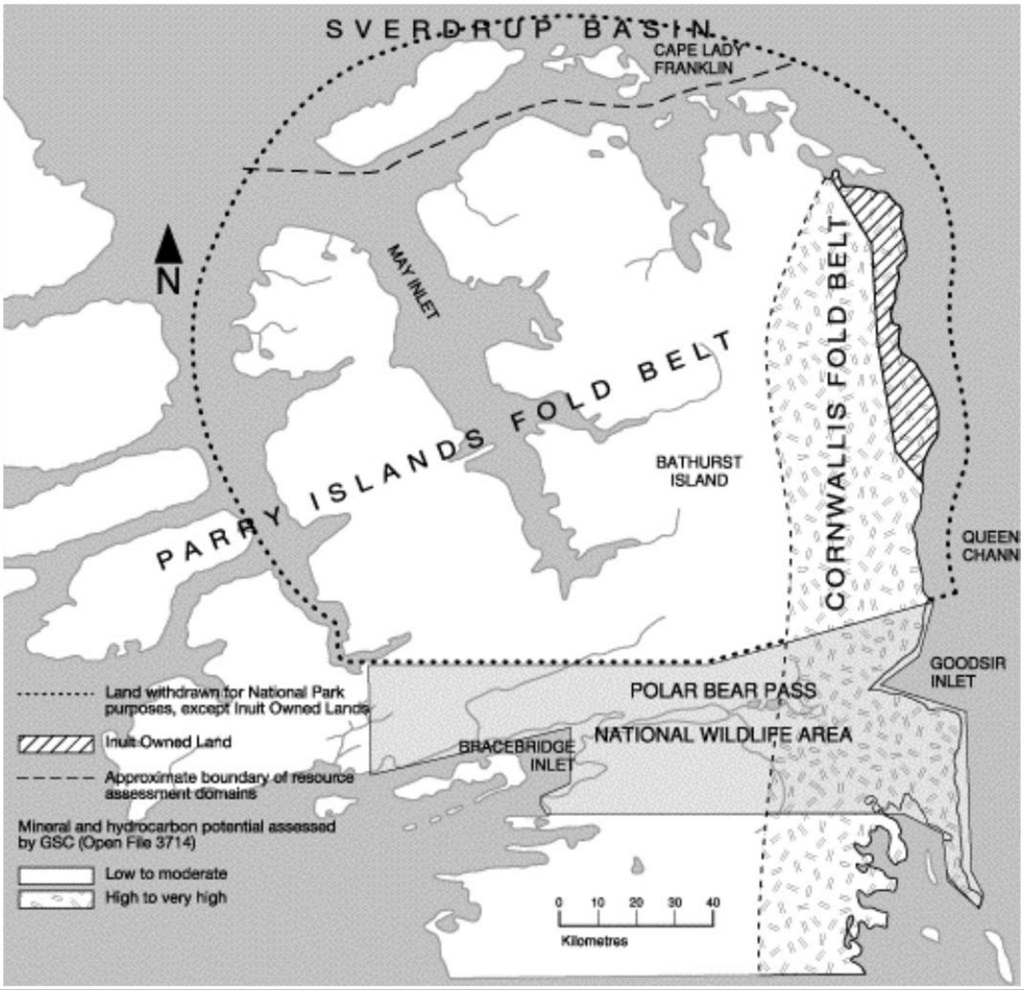

SVERDRUP BASIN
CAPE LADY FRANKLIN
N
MAY INLET
PARRY ISLANDS FOLD BELT
BATHURST ISLAND
CORNWALLIS FOLD BELT
QUEEN CHANN
GOODSIR INLET
POLAR BEAR PASS
NATIONAL WILDLIFE AREA
BRACEBRIDGE INLET
Land withdrawn for National Park purposes, except Inuit Owned Lands
Inuit Owned Land
Approximate boundary of resource assessment domains
Mineral and hydrocarbon potential assessed by GSC (Open File 3714)
Low to moderate
High to very high
0 10 20 30 40
Kilometres

Figure 3