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Aerial surveys for muskoxen in the Sahtú Settlement Area, March 2020 and 2021

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ABSTRACT

Muskox are an important and traditional dietary resource in many Arctic communities, while also having economic, sociocultural and environmental importance. Though some muskox populations in North America are known to be decreasing, other populations such as the muskox in the Sahtú and North Slave region are suspected to be growing in numbers and distribution. Here we evaluate the population size; distribution and calf production of muskoxen in the Sahtú as well as examine the population level habitat selection of an Arctic herbivore above and below tree line. In the study area, we estimate a population of 5,793 individuals in the study area (95% CI 3,385-9,912, CV=0.279) with an estimated 5.6% calf percentage. Overall, we found the current population of muskoxen in the Sahtú to be abundant and stable; however, low calf recruitment may indicate a lack of resilience to additional stressors. We highlight the importance of continued and enhanced monitoring of factors affecting muskox populations in the Sahtu at both the individual and population level.

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INTRODUCTION

Muskox (*Ovibos moschatus*) are the largest terrestrial herbivores in the Arctic (Hansen et al. 2018), with two commonly recognized subspecies, *O.m. wardi* and *O.m. moschatu.* Referred to as "white-faced" and "barren-ground" respectively (Peter and Groot 2001), recent studies have identified genetic differences between the two (Cuyler et al. 2020). Muskox are an important and traditional dietary resource in many Arctic communities, while also having economic, sociocultural and environmental importance (Tomaselli et al. 2018*a*).

Originating from Eurasia, muskox arrived in North America in the early Pleistocene and by the late Pleistocene, they were distributed across the Holarctic (Prewer et al. 2020). They are one of the only species to survive the Pleistocene epoch (Barr 1991, Campos et al. 2010), though, over the last 30,000 years, their range, abundance and genetic diversity have decreased drastically (Hansen et al. 2018). From the Last Glacial Maximum to the mid-Holocene, this species underwent multiple population bottlenecks which led to a decline in their genetic diversity (Prewer et al. 2020).

In the 19th and 20th century, muskoxen were almost extirpated in northern Canada due to unregulated commercial harvesting. This hunting pressure, which may have been exacerbated by environmental and stochastic factors (Barr 1991), significantly reduced muskox populations and further altered their range and distribution (Spencer 1976, Gunn and Barry 1984), with only two main populations remaining in mainland Canada while the Victoria and Banks Island populations were almost extirpated (Barr 1991, Prewer et al. 2020). Muskox populations decreased so drastically in the second half of the 19th century that in 1917 the Government of Canada implemented a moratorium on muskox harvest.

By the 1960s, after a near 50 year hunting moratorium and several translocation efforts, muskox populations began to recover and recolonized a large portion of their historic range in North America (Barr 1991). Aerial surveys flown north of Great Bear Lake and west of the Coppermine River from the 1950s - 1987 suggest that muskox populations were generally increasing during that time (Tener 1965, Kelsall et al. 1971, Case and Poole 1985, McLean 1992). Within the Sahtú, indications that the population of muskox was healthy and potentially expanding resulted in an initial annual quota for a total of eleven muskoxen beginning in the 1994/1995 hunting year (Veitch 1997).

An assessment of the Sahtú population in 1997 estimated that there were approximately 1460 +/- 920 (95% CI) muskox in the Sahtú region north of Great Bear Lake (Veitch 1997). Due to the limited number of surveys and varying methods used, Veitch (1997) was unable to determine a population trend for muskox. However, the survey indicated that range expansion was ongoing and high-density areas had changed over the previous decade. From this, Veitch (1997) recommended an increased quota of up to 27 animals per year for resident hunters. The quota has increased several times and as of 2021, there were 35 tags in the Sahtú available for the Northwest Territories (NWT) resident hunters and outfitting services.

Veitch (1997) also recommended that the harvest pressure be evenly distributed across the range or the current muskox area (S/MX/01) be divided to ensure even distribution. Currently muskox harvest is not evenly distributed and is typically localized in areas that are most accessible (north shore of Great Bear Lake, Lennie Lake, Turton Ridge, and the area surrounding Norman Wells).

Although the recovery of muskoxen across the NWT is considered a conservation success, some communities, have expressed concerns with regards to muskox populations expanding their range (Carter 2020, Winbourne and Benson 2021). In the Sahtú region specifically, communities are worried that this range expansion south of Great Bear River and west across the Mackenzie River could have negative consequences for caribou, moose, and Dall's sheep populations due to competition between species, and the spread of diseases and parasites. As of 2020, in the Sahtú region, muskoxen are known to be present east of the Mackenzie River and north of the Great Bear River. Although there have been a small number of reports of muskoxen seen west of the Mackenzie and south of the Great Bear River, these are rare and there are no indications that muskox populations have established in those areas.

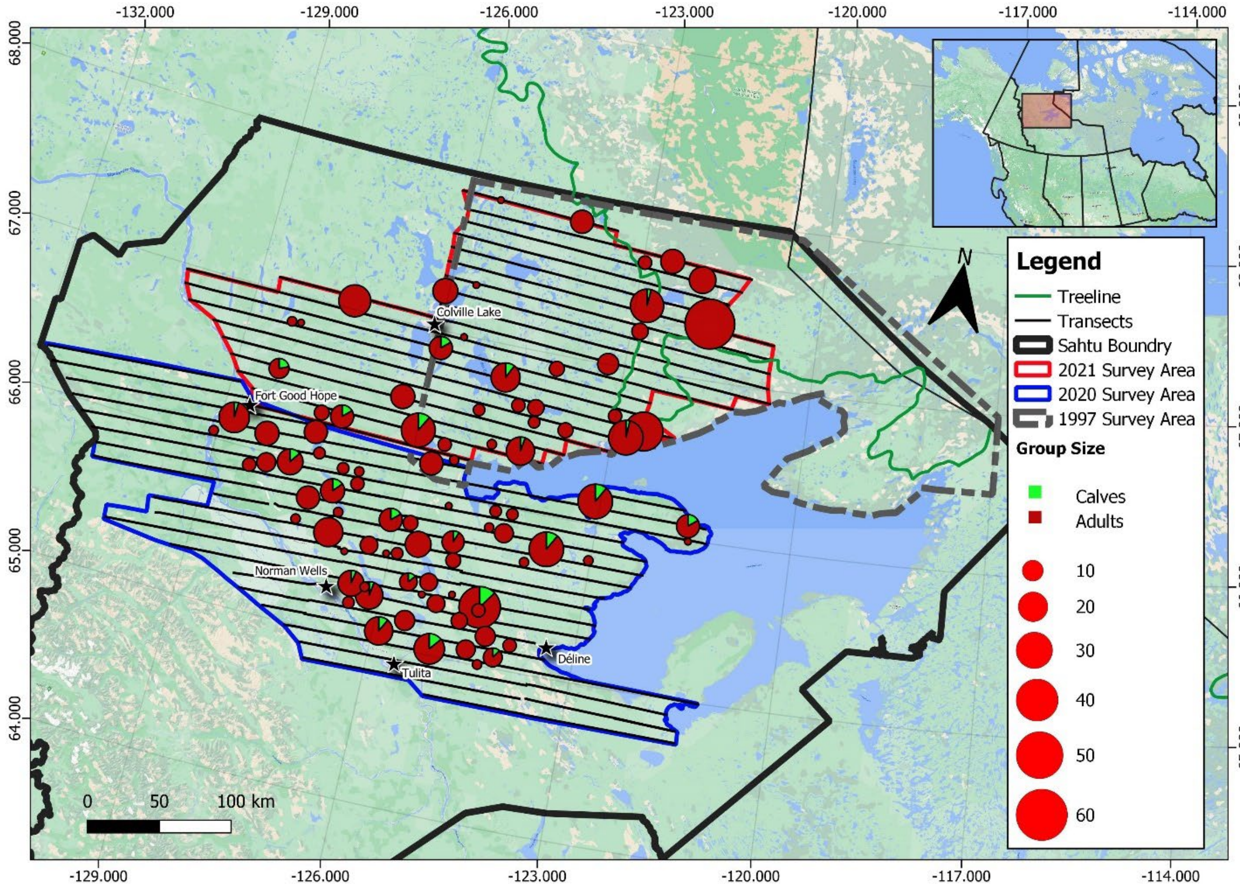

Figure 1. Muskox observations on transect during 2020 and 2021 aerial surveys of the Sahtú Region, where the yellow outline yellow represents the 1997 survey area, the blue represents the 2020 survey area, the red represents the 2021 survey area.

Given limited current information on muskox populations and distribution below treeline, as well as some concerns and interest from communities in the Sahtu, two surveys were conducted in the Sahtú region, in 2020 and 2021, to assess changes since the 1997 survey. This report provides an assessment of the current status of muskoxen in the Sahtú by 1) providing an updated estimate of the population, 2) determining the current distribution and density, 3) assessing calf productivity and 4) examining the population level habitat selection above and below tree line.

METHODS

Study Area

The Sahtú region encompasses 280,238 km^2 of the central NWT surrounding Great Bear Lake (Polfus et al. 2016) and includes the communities of Tulita, Délı̨nę, Norman Wells, Fort Good Hope and Colville Lake. The Sahtú includes areas with rolling hills, plateaus, and mountains, and spans the taiga and barrenlands. Additionally, there are many water bodies present in the Sahtú, including major rivers systems, such as the Anderson, Great Bear and Mackenzie Rivers.

The Sahtú is comprised of four major ecozones: Southern Arctic, Taiga Plains, Taiga Shield and Taiga Cordillera (Polfus et al. 2016). The entire study area is classified as being in the Taiga Plains Ecozone of NWT (Ecosystem Classification Group 2009). The 2020 survey area was located mainly in the Taiga Plains Low Subarctic Ecoregion, with patches of Taiga Plains High Subarctic Ecoregion. In contrast, the 2021 survey area to the north occurred mostly in the High Subarctic Ecoregion, with only a small portion being in the Low Subarctic Ecoregion in the area surrounding Fort Good Hope.

Both the High and Low Subarctic Ecoregions are characterized by having short, cool summers and very cold winters, with an average annual precipitation of 230-350 mm, mainly occurring in late summer/early fall. The High Subarctic Ecoregion is known for having widespread and continuous permafrost, resulting in very open, stunted forests of black and white spruce with a lichen understory. Widespread permafrost is also common in the Low Subarctic Ecoregion , though the forest cover is rather an open canopy of white and black spruce, with lichen and low shrub understory and patches of trembling aspen and paper birch deciduous trees (Ecosystem Classification Group 2009).

Field Methods

A 10% survey (10 km spacing between transect lines) was flown in a small single engine fixed-wing plane (Cessna 206 and Helio Courier), at a ground speed of approximately 90-110 knots on transect and an altitude of approximately 300-600 ft. Altitude was adjusted within these boundaries depending on habitat, weather and terrain to maintain visibility. GPS tracking was used for accurate documentation of flight paths and to measure distances of groups from the flight path. The survey team consisted of a pilot, a navigator in the co-pilot chair, and two observers in the back. When only one observer was available, they were situated behind the pilot on the left side of the aircraft. Both surveys occurred in March to allow for increased visibility of animals below treeline. This also coincided with increased daylight hours for surveying while limiting disturbance to muskox during the calving season which occurs in April/May (Jenkins et al. 2011)

All members of the team would call wildlife observations over the radio throughout the survey. All wildlife observations were recorded along with time of observation, species, number of animals and the observer who spotted the animal. For muskox observations, a GPS point was recorded at the initial sighting location on the line, and another was recorded over the animals to obtain exact locations. High resolution photos of each group were taken whenever possible to determine group size and to assess calf percentage. High altitude photos were taken to capture the entire herd, obtain accurate counts of groups and additional low-level photos were taken for to classify calves. On occasion, additional groups were detected while transiting to obtain overhead waypoints. These observations were denoted as a secondary detection to the primary observation. All other wildlife seen in addition to muskox observations were recorded with GPS points of the initial observation site on the flight line and approximate distance from the survey line (Table 2). Any wildlife observed on ferry to and from daily survey areas and between transect lines were recorded but noted as "off-transect" and not included in the final analysis.

Table 1. Observations of all wildlife seen during the 2020 and 2021 aerial surveys of the Sahtú Region. On-transect observations are observations seen from the transect line (primary) or while obtaining overhead waypoints (secondary). Off-transect observations are ones seen during ferries between daily survey areas and transect lines.

Species	On-transect Individuals (Groups)			Off-transect Individuals (Groups)		
	2020	2021	Total	2020	2021	Total
Muskox	439 (55)	393 (33)	832 (88)	34 (2)	15 (2)	49 (4)
Caribou	69 (9)	4354 (61)	4423 (70)	0	191 (9)	191 (9)
Moose	88 (53)	121 (92)	209 (145)	8 (4)	36 (23)	44 (27)
Wolves	23 (4)	4 (3)	27 (7)	0	3(1)	3(1)
Fox	0	1 (1)	1 (1)	0	1(1)	1(1)

Distance Sampling and Density Surface Modeling

Estimates of the muskox population were calculated using a distance sampling approach in which animal density and/or abundance is estimated by sampling the perpendicular distances from the transect to detected individuals (Buckland et al. 2015). The distances at which animals are detected from the line are used to estimate the detection function f(x), which is defined as the probability of detecting an animal at distance (x) from the line. Consequently, the proportion of animals detected within a given strip can be estimated by calculating the area under the curve f(x) (Buckland et al. 2004). Exact distances of the animals from the survey lines were measured in Google Earth using the overhead GPS points for muskox observations.

The data were analyzed using a two stage spatially explicit distance sampling method known as density surface modeling (DSM; Buckland et al. 2004, Miller et al. 2013). In the first stage, we fitted competing detection functions to model the detectability of muskox using two distributions (half-normal and hazard rate) and number of observers was used as a covariate at the observation level for a total of four competing models. Primary and secondary observations were included in the analysis to maintain adequate sample size (Buckland et al. 2015) but observations on ferries (off-transect) were excluded. The most parsimonious model was identified from other candidate models using the lowest ΔAICc, with models ΔAICc <2 being considered as statistically indistinguishable (Burnham and Anderson 2002). In the second stage, transects were divided into 5 km segments and generalized additive models (GAMs) were used to fit per-segment abundance spatially across the study area. We fit three models using a quasi-Poisson, tweedie, and negative binomial distribution and the model with the highest deviance explained was selected (Roberts et al. 2016). The top model was predicted across the study area using an array of 5 km by 5 km grid cells. All analyses were performed using the DSM and distance packages in R . Estimates of the mean ($\widehat{\mathrm{D}}$) were reported with 95% log-normal confidence intervals (95% CI) and coefficient of variation (CV) given by the following equations (Buckland et al. 2015):

$$(\text{Lower confidence limit}, \text{Upper confidence limit}) = (\widehat{\mathrm{D}}/\mathrm{C}\,, \widehat{\mathrm{D}} \cdot \mathrm{C}) \qquad (1)$$

where:

$$\mathrm{C} = \exp\left[1.96 \cdot \sqrt{\log_e[1 + \mathrm{CV}^2]}\right] \qquad (2)$$

1997 Survey Re-analysis

Veitch (1997) used a strip transect survey with a 1 km strip, classifying animals as either on-transect (<500 m from plane) or off-transect (>500 m from plane) and estimating the population size using Jolly's method 2 for transects of unequal length (Krebs 1989). Because this method did not collect distance information other than on- and off-transect, on-transect observations from the 1997 10% coverage survey were provided distances randomly sampling from a distribution of distances from observations in the 2020 and 2021 survey that were >500 m. These observations were fitted with the same methodology described above excluding covariate models using the Distance and DSM packages in R (D.L Miller et al. 2019a, D.L. Miller et al. 2019b, R Development Core Team 2020). The estimates for the 1997 and current survey were calculated in the overlapping areas for comparison.

Habitat Selection

We examined the Type 1 winter habitat selection of muskoxen representing a population-level response to land cover variables by pooling use locations across muskoxen groups and evaluated available locations with pooled random locations (Johnson 1980). We used the 2015 Landcover of Canada (Latifovic 2019) classification raster with a 30 m resolution. The 12 available landcover classes were aggregated by pooling classes occurring at low frequencies (mean available ≤1.5%) with like classifications (Appendix: Table A1) resulting in the following classifications: Taiga, Mixed Forest, Conifer, Shrubland, Grassland, Barrenland, Wetland, and Water.

Use sites were defined using a 500 m buffer around each muskox observation in the study area and proportions of land cover classes were calculated within each buffer. Availability was defined as all survey areas north of the Great Bear River and east of the Mackenzie Rivers and grid cells in the DSM analysis were used to define the perimeter. Random locations were generated at a ratio of 2:1 within the selected area to ensure adequate sampling of background habitat variation (Fedy et al. 2014, Carter 2020). We extracted the proportions of land cover classes for random sites using the same methodology for use sites.

We performed a chi squared goodness of fit test to see whether the proportion of used habitat was significantly different from available. Post-hoc tests with a Bonferroni correction were performed on each landcover class compared the proportion of all other landcover classes combined to identify significant differences in landcover selection.

RESULTS

Field Results Summary

The 2020 aerial survey covered the area south of Fort Good Hope and was conducted from March 16-31, 2020, flying a total of 21 lines at 10 km spacing over 60 hours. The survey covered an area north-south spanning 15 km north of Fort Good Hope to 20 km south of Tulita, and east-west from Saoyú-?ehdacho on Great Bear Lake to the foothills of the Mackenzie Mountains (Figure 1). On transect the survey covered 5,732 km covering 55,228 km^2 in approximately 40 hours over the course of ten days. There was no right rear observer for most days with the exception of March 17, 18 and 29, 2020 due to restrictions from the COVID-19 pandemic.

The 2021 survey occurred from March 3-19, 2021, and covered the area north of Fort Good Hope to the Inuvialuit Settlement Region, with the Mackenzie River acting as the western border and the Dease Arm of Great Bear Lake as the eastern border (Figure 1). This survey was conducted using a fixed-wing, single engine Cessna 206 on wheel-skis. A total of 19 lines at 10 km spacing were flown over 65.9 hours. On transect the survey covered 4,760 km covering 43,397 km^2 in approximately 35 hours over the course of 11 days. On March 13, 15, 17 and 18, 2021 no right rear observer was present.

Observations and Population Characteristics

A total of 832 muskoxen, in 88 groups were seen on transect during the two surveys (Figure 1). In 2020, a total of 439 muskoxen in 55 groups were seen on transect in groups that ranged from 1-39. An additional 34 muskoxen in two groups were seen during ferries and off transect during the 2020 survey. In 2021, a total of 393 muskoxen in 33 groups were seen on transect with group sizes ranging from 1-56 animals. An additional 15 muskox in two groups were seen off transect in 2021. No muskoxen were observed south of the Great Bear River or west of the Mackenzie River.

The average group size in the study area was 9.6 individuals, with the average being 8.0 in the 2020 survey and 11.9 in the 2021 survey. Most muskoxen seen on this survey were found below treeline with only 85 muskoxen in three groups being found above treeline. The average group size above treeline was 28.3 muskoxen, while group size below treeline was 8.9.

Within the study area we estimate a calf percentage of 5.6% (47/832 muskoxen). This varied between the 2020 and the 2021 survey area, which had calf percentages of 6.8% and 4.3 % respectively. On transect, the 2020 survey had 14 groups with calves out of 55 groups seen, while the 2021 survey had ten groups with calves out of 33 groups seen. All wildlife observations for the 2020 and 2021 surveys are summarized in Table 1.

Population and Density Estimation

Model section results for the detection function and GAM are summarized in Table 2. The top model was a hazard rate detection function using the number of observers as a covariate and had a GAM with a negative binomial distribution. The DSM from the combined 2020 and 2021 surveys estimated a total population of 5,793 individuals in the study area, with a 95% log-normal confidence interval (95%CI) ranging from 3,385-9,912 muskoxen (CV=0.279). The average density in the study area is approximately 54.0 muskoxen/1,000 km^2. Given that the muskox range in the study area is, to our best knowledge, bounded by the Great Bear and Mackenzie Rivers, the population estimate adjusted for this restricted area is approximately 5,593 (95%CI = 3,269-9,570) with an adjusted density estimate of 66.9 muskoxen/1,000 km^2.

Table 2. Model selection results for the detection function and the density surface models.

	Model	2020/2021			1997		
		ΔAICc	Rank	Weight	ΔAICc	Rank	Weight
Detection Function	*Uniform*	5.43	3	0.05	0.00	1	0.44
	Half-normal	6.17	4	0.02	2.58	3	0.12
	Half-normal + no. observers	7.00	5	0.04	-	-	-
	Hazard rate	2.53	2	0.19	**0.00**	**1**	**0.44***
	Hazard rate + no. observers	**0.00**	**1**	**0.70**	-	-	-
	Model	**Deviance explained**					
DSM	Quasi-Poisson	15.3%			55.2%		
	Tweedie	16.5%			**27.8%****		
	Negative binomial	**19.6%**			2.36%		

* model selected due to lower total coefficient of variation. Hazard rate model and uniform models are indistinguishable in the model selection.
** model with lower deviance explained selected due to over dispersion in the quasi-Poisson model.

Muskox distribution was not even across the study area, with the highest density of muskox found north-east of Norman Wells and north of Tulita, in the areas surrounding Kelly, Mahoney, and Willow Lake (Figure 2). The DSM from the 2020 survey estimates a population of 3,800 muskoxen (95%CI=2,205-6,547), and a density estimate of 62.7 muskoxen/1,000 km^2. The DSM from the 2021 survey estimates a population of 2,046 individuals (95%CI=1,188-3,526), and a density estimate of 43.1 muskoxen/1,000 km^2. Given the overlap in the 2020 and 2021 study areas, the population estimates of each area individually do not add up to the total population estimate.

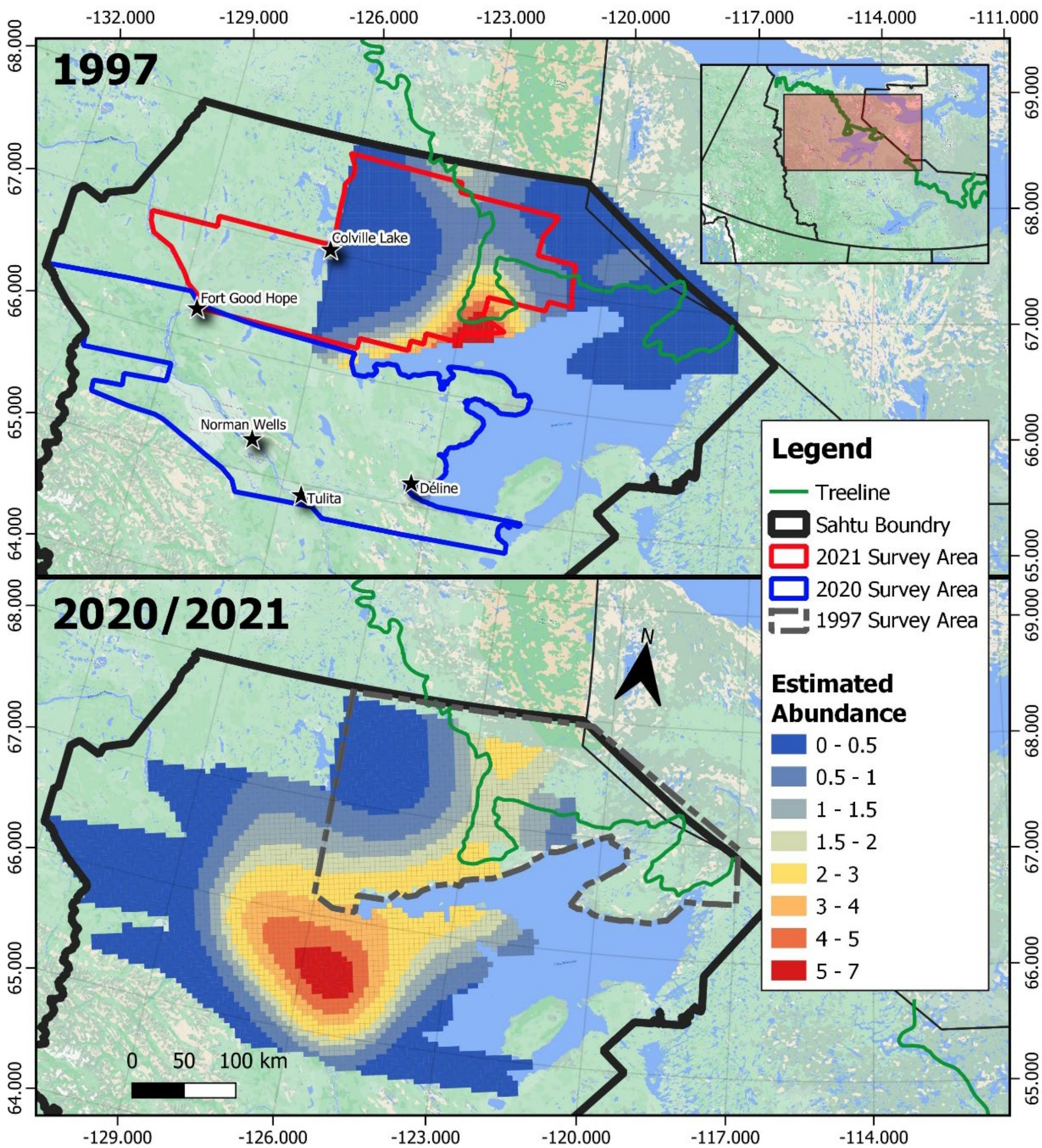

Figure 2. Density surface models comparing muskox distributions from the 1997 Veitch survey with the 2020/2021 surveys of the Sahtú region. Densities are calculated on 5 km x 5 km (25 km^2) grid cells with dark blue indicating the lowest densities of muskox (0-0.5) and red indicating the highest densities of muskox (five to seven).

1997 Survey Re-analysis

Of the three competing models, we found that the top models were the uniform and hazard-rate (Table 2). Mean estimates from both models were identical, but we report the results of the hazard-rate model due to the CV being lower (hazard rate = 0.388, uniform = 0.514). Although the GAM using a quasi-Poisson distribution had the highest deviance explained (55.2%), the diagnostic plots indicated issues with over dispersion, and the model had unrealistic predictions of over 90 individuals in some cells (>360/100 km^2). Therefore, we excluded the quasi-Poisson distribution in favour of the tweedie distribution (deviance explained = 27.8%). The model estimated a total population of 1,858 individuals ranging from 892-3,823 individuals (CV=0.388).

In the overlapping regions on the north shore of Great Bear Lake, we estimated that in the 1997 survey there were 1,278 individuals (95% CI=621–2,630 individuals) compared to 1,654 individuals (95% CI=967–2,830 individuals) in the 2020/2021 survey area. The distributions between the 1997 and 2021 survey appear to be consistent with the areas of highest concentration located in the same location on the north shore of Great Bear Lake. Although the estimated populations in this overlapping area are nearly identical, the distribution in the 2021 survey appears more diffuse compared to 1997. These surveys differ in that the 1997 survey predicts a more concentrated abundance along the treeline, whereas the 2021 survey shows this concentration extending eastward towards the barrenlands. The distributions for both surveys are shown in Figure 2.

Habitat Use and Selection

We found a significant difference in the proportions of habitats used by muskox compared to the available habitat in the study area ($X^2_{(7,N=16)}$= 21.7, p-value = 0.003). Examining the selection ratio (proportion used/ proportion available) we find values >1 for barren-ground, temperate and subpolar conifer, and wetland (Figure 3). The lowest selection values were found in the water (0.45) and grassland (0.55) classes. Landcover classes were assessed individually using eight chi-squared tests with a Bonferroni adjusted alpha level of 0.00625 per test (0.05/8). Results suggest that only selection of conifer was significantly different ($X^2_{(1,N=4)}$=13.7, p-value = 0.0002).

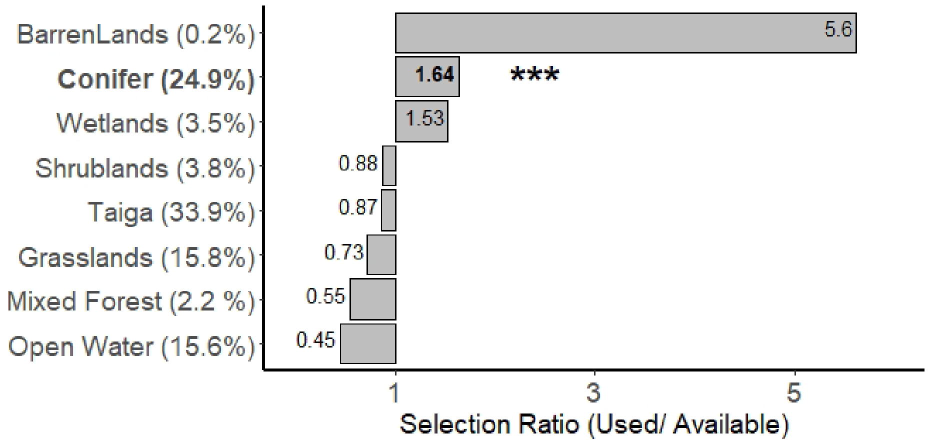

Figure 3. Selection ratios of muskox comparing proportions of land cover classes found at observed muskox locations (used) and proportions at random locations within the study area north of the Great Bear River and east of the Mackenzie (available). Ratios with values above 1 indicate that classes are selected for and below 1 are likely avoided. * indicates $p < 0.1$, ** indicates $p<0.05$ and *** indicates $p<0.01$ with using post-hoc chi-squared tests with Bonferroni correction. Landscape covariate percentages indicate the proportion of the study area covered by each land cover class.

DISCUSSION

Overall, the current population of muskoxen in the combined Sahtú study area was estimated to be 5,793 animals (95% CI 3,385-9,912, CV=0.279) and has potentially increased when compared to the 1997 study area. However, we highlight that there is a marked decline in the proportion of calves between the 1997 and current survey. Timing of the surveys in March was based on recommendations by Veitch (1997), due to the increase in daylight hours, and higher visibility of the dark animals on a white background. Although tracks were not followed, they were indicators of when animals were likely nearby. This has a potential to skew the detectability of muskox, though methods were consistent for both 2020 and 2021 surveys and the effects are likely minimal. Previous muskox surveys north of Great Bear Lake (Case and Poole 1985, McLean 1992) have occurred in March and August and researchers have recommended conducting surveys in July as muskox distribution is more predictable and animals are less grouped, reducing issues with variance estimation. However, there is limited information comparing the distribution and group sizes of muskox in summer and winter and less below treeline. Above treeline, timing of the surveys is likely more flexible as the detection function is not likely to be as affected by environmental conditions. However, below treeline, detectability is greatly improved by snow cover.

It should be noted that the current survey used muskox groups as a unit of measurement rather than individuals as was commonly used in previous surveys. Many animal species occur in groups, violating the assumption that individuals are distributed independently of transect lines and causing over dispersion in the estimate. The general practice with such grouping behaviours is to assume that groups are independently distributed and multiply estimates of group density by the mean group size to obtain an estimate of individual density (Buckland et al. 2010, 2015). However, simulations have shown that even when the assumption of independence is violated (i.e., using individuals rather than groups), estimation of densities can be good despite issues with over fitting (Buckland et al. 2010). Given the robustness of distance sampling and strip transect estimation to over fitting and dispersion, in addition to multiple methods to allow for reliability in a variety of conditions, it is likely more beneficial to prioritize sightability and increasing the number of muskox detections when determining the timing of surveys.

The distributions in our model projections were largely consistent with our observations; however, the model did predict muskoxen in areas south of the Great Bear River and west of the Mackenzie River. While negligible (~200 individuals), this is likely a result of several factors. First, the model estimates densities based on probability of detection and while the estimates are low, they are not zero. It is possible that we may have missed some detections, and there have been rare previous reports of muskox crossing these rivers, though not establishing on the opposite shores. Second, the grid cells used are 5 km x 5 km and predictions in these cells could be along the shoreline but span the river resulting in predictions in areas across the river. Third, no habitat covariates were used in our DSM and our model does not account for selection or avoidance of habitat by muskox. Areas with a high proportion of open water were clearly avoided in our habitat selection analysis and incorporating this into our model would likely reduce the numbers of individuals predicted in areas where they have not been detected.

Based on our observations, muskoxen in the Sahtú appear to select temperate and subpolar conifer. This differs from Carter (2020) who reported an avoidance of woodland in relation to a reference (shrub tundra) in the summer and fall. Veitch (1997) reported finding nine groups in forest as opposed to seven groups in tundra though this study did not classify what was available. A photo survey of the population on the east arm of Great Slave Lake in 2018 (Adamczewski et al. In Prep) also reported that most muskox groups were in areas with either relatively open forests or openings due to rugged terrain (ridges or small hills). Ridges, small hills, and the edges of lakes tended to be wind-swept with shallow snow cover and likely offered good feeding conditions. While our results vary from that of other reported results, it is important to note that there is currently no published research available on what muskox eat below treeline (Jorgensen 2021).

Comparing our survey with the estimates of the 1997 survey, we found that the population is likely stable though has likely dispersed from isolated concentrations such as the north shore of Great Bear Lake. Our estimates (1858, 95% CI=892-3,823) were higher than the previously reported 1460 (95% CI=538-2,376) in Veitch (1997). Distance sampling typically will have higher estimates than strip transect methods as it estimates the proportion of animals detected rather than assuming complete detection. This combined with the inclusion calves in our estimate resulted in the larger estimate. Removal of calves from our methods resulted in an estimate of 1,537 individuals (95% CI=747-3,162 individuals, CV=0.380). Unfortunately, the prior study did not cover areas overlapping the 2020 survey area. It has been documented through local observation and reporting that the muskox population in the 2020 survey area has been expanding and increasing since the late 1980s (R. Popko. Pers. Comms, GNWT unpublished data) and is likely more dynamic than the area where the 1997 survey overlapped.

The most notable difference is the proportion of calves in the study area (5.6%, 47/832 muskoxen) was substantially lower in 2021 compared to the 1997 calf percentage of 14.3% (45/314 muskoxen; Veitch 1997). There was also a small difference between the southern survey area (6.8%, 30/439 muskoxen) and in the northern survey area (4.3%, 17/393 muskoxen). Because muskox calve in April-May, these estimates are more reflective of a maximum recruitment rate (i.e. nearly one year old) than productivity. As the population estimate from 1997-2021 for the overlapping northern survey area has remained largely unchanged, lower calf percentages may be indicative of a density dependent response associated with stabilization and a population at carrying capacity.

Larter and Nagy (2001) reported calf survival and recruitment were higher on Banks Island during periods of population increase and showed pronounced decline as population peaked. Similarly, populations undergoing growth and expansion in Quebec (Le Henaff and Crete 1989), Greenland (Olesen 1993), and southern NWT (Adamczewski et al. In Prep) have reported high calf proportions (>20%) associated with population growth at near maximum rates. Since the current population appears to be abundant, these low calf percentages likely correspond to density dependent factors such as competition, predation, and disease which can result in low pregnancy rates and/or calf survival.

Inter-and intraspecific competition in muskoxen is not well studied though some individuals and communities suggested that muskox and caribou compete for similar resources (Larter et al. 2002, Carter 2020, Winbourne and Benson 2021). In regions where there is continuous Traditional Knowledge available with regards to muskox populations (i.e., populations were not extirpated), there have been indications of periodic shifts or pronounced cycles in muskox abundance and distribution (Winbourne and Benson 2021). Both Indigenous and scientific knowledge have reported an abundance of muskox on Banks Island when caribou decline and vice versa (Davison et al. 2017, Winbourne and Benson 2021). Whether these shifts in abundance are a result of competition remains unresolved. Given the drastic declines in caribou populations, it is unlikely that low recruitment is the result of interspecific competition with caribou. With regards to intraspecific competition, little is known about the requirements and carrying capacity of muskox below treeline.

Calves are generally the most vulnerable demographic for predation and wolves and grizzly bears have been shown to be effective predators of muskoxen (Reynolds et al. 2002). In Alaska (Reynolds et al. 2002), it has been observed that there is a lag between the first occurrences of muskoxen in a region and incidents of known kills suggesting that densities need to reach a certain threshold to facilitate predator prey interactions. Adamczewski et al (In Prep) have suggested that in the east arm of Great Slave Lake, that the high calf proportions may be due to low predator densities, or naive predators unable to effectively kill muskox. Since muskoxen have more recently expanded into the 2020 survey area, it is plausible that predators in this area are less experienced compared to those north of Great Bear Lake and may explain the differences we see between calf proportions in the 2020 and 2021 survey areas. Two incidents of muskox predation by wolves were found prior to the survey within 5 km of each other on the Franklin range. One was an adult male (>4 years old) and the other was an unknown age-class. Due to the proximity of these events, it is possible that it may be the same pack involved in both cases. However, information on predator densities, diet, and predation rates in the Sahtú are deficient.

Diseases and parasites are an important factor affecting muskox health and can influence populations via lethal (i.e., mortality events) or sub-lethal (i.e., reduced fitness) effects (Afema et al. 2017*a*, Di Francesco et al. 2017). A number of pathogens have been confirmed in muskox populations, and some hunters have suggested that muskoxen tend to have more internal parasites compared to other species hunted in the area (Winbourne and Benson 2021). *Erysipelothrix rhusiopathiae* has been identified as a pathogen with strong association with recent mortality events documented on Banks and Victoria Islands (Kutz et al. 2015) and increased seroprevalence has occurred simultaneously with population declines (Mavrot et al. 2020). *Yersinia pseudotuberculosis* has also resulted in muskox mortality on Banks Island (Blake et al. 1991, Afema et al. 2017*b*). Of additional concern are the potential for range expansions (Kutz et al. 2013) and a host switching (Kafle et al. 2020) of parasites attributed to climate change and host expansion respectively (Hoberg et al. 2002). Several parasites, such as *Umingmakstrongylus pallikuukensis,* do not appear to be lethal in muskoxen but are suspected to have sub-lethal effects on survival, fecundity, and recruitment (Kutz et al. 2004, Tomaselli et al. 2016). When coupled with other stressors such as increased predation and low genetic diversity (Prewer et al. 2020), diseases and parasites may negatively impact the resiliency of muskox populations (Di Francesco et al. 2017).

Although northward expansion of several parasites associated with muskox have been documented (Kafle et al. 2020), southward expansion of muskox populations and overlap with other wildlife species may impact the spread and transmission of existing and new diseases and parasites, and alter pathogen distribution, prevalence and intensity. Local outfitters have not formally reported observations of any signs of sickness or disease in the muskox populations surrounding Great Bear Lake (Winbourne and Benson 2021), but in 2020/2021, Three separate disease related mortalities were reported between the communities of Tulita and Fort Good Hope. In Nunavut, aerial surveys and passive surveillance have been demonstrated to be inadequate for effectively detecting significant mortality events of muskoxen and systematic community involvement in population health monitoring (such as documenting low recruitment, poor body condition, increased morbidity, and mortality events) has been beneficial detecting changes in wildlife populations (Tomaselli et al. 2018*b*). Ongoing scientific and community-based monitoring of wildlife health will be important to document the presence and potential impacts of diseases and parasites.

In addition to community-based monitoring, active or targeted approaches to muskox health surveillance by ENR and research and monitoring partners should be explored to supplement an effective and coordinated effort towards better understanding the health status and trends of muskox populations.

CONCLUSIONS

Our recent survey of muskox in the Sahtú study area resulted in a population estimate of 5,793 animals, and suggests the population is likely stable though it is important to note the low recruitment in this population. Low calf percentages do not necessarily indicate that the population may decline, but it is potentially indicative of a population's resilience against stressors. The muskox quota in the Sahtú has been raised several times in recent years without assessment of population or demographic information and the current quota stands at 35 animals. Currently muskox harvest is not evenly distributed and is typically localized in areas that are most accessible (north shore of Great Bear Lake, Lennie Lake, Turton Ridge, and the area surrounding Norman Wells). The 1997 quota was determined based on a proportion of the population estimate. Current harvest levels are unlikely to impact the overall muskox population in the Sahtú but could affect muskox numbers in local areas with high harvest pressure. Populations of social ungulates in the Arctic can be impacted by predation (Reynolds et al. 2002), disease interactions (Afema et al. 2017*a*), and stochastic events (Berger et al. 2018) and have the ability to change quickly and drastically. Given the impacts of climate change on polar and subpolar ecosystems, management actions for muskox in the Sahtu including determination of sustainable harvest levels should continue to incorporate results of the best available scientific, local, and traditional knowledge on muskox abundance, distribution and health.

Recommendations summary

1. Reconnaissance surveys for Bluenose-West caribou occur every three years and this survey was used as an opportunity to incorporate a design to estimate muskox populations. The population distribution appears consistent across years and can likely be stratified in future surveys. Stratification can help improve confidence intervals, reduce flight lines and reduce cost. The southern area around Norman Wells, Tulita, and Délı̨nę is likely to be an important and dynamic environment and should be surveyed more frequently to assess the trend, recruitment, and distribution. Survey planning should seek to incorporate a multi-species design to optimize monitoring efforts.
2. Surveys should prioritize increasing the number of observations over obtaining a good (dispersed) distribution of muskoxen on the landscape. Estimation methods have been shown to be robust when applied to grouped animals and below treeline and winter surveys greatly improve the ability of observers to locate wildlife. Stratification of future surveys may help narrow confidence intervals and reduce survey costs. Habitat selection and population distribution across seasons is a question that should be addressed especially due to the muskox population rapidly expanding below treeline.

3. Although the study area population is likely stable, low calf recruitment and localized harvest should be considered when assigning quotas. Although harvest at current levels is unlikely to affect the overall population by itself, low recruitment may indicate a lack of resilience to increased pressures on mortality. Quota changes should occur gradually, be consistently monitored, and consider multiple metrics of population health as arctic ungulate populations can change quickly and drastically.
4. Identification and enhanced understanding of various determinants of muskox health, their complex interactions, and the ultimate impacts on muskox population dynamics is needed. Continued and enhanced monitoring of factors affecting muskox populations in the Sahtu should continue, including potential impacts of harvest, predation, disease/parasites, stress, nutrition, behaviour, and demographics at both the individual and population level. Efforts should incorporate a multi-disciplinary approach incorporating local and Traditional knowledge, community- or harvest-based sampling, and targeted surveillance efforts to inform management actions.

   As we continue to see declines in caribou populations and increasing demand for securing availability and safety of country foods, it is essential that we prioritize determining the health status of alternative harvest species such as muskox.

5. Local communities expressed both interest and concern increasing number of muskoxen within the treeline. It is uncertain how the increasing muskox range and distribution will affect the ecological community as a whole and there is a need to consider organisms in a multispecies and ecosystem context. It follows that management decisions will benefit from a greater understanding of multispecies interactions.

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LITERATURE CITED

Adamczewski, J., K. Olesen, D. Olesen, J. Williams, and J. Boulanger. In Prep. Late winter 2018 muskox photo composition survey, east arm of Great Slave Lake. Yellowknife, NWT.

Afema, J. A., K. B. Beckmen, S. M. Arthur, K. B. Huntington, and J. A. K. Mazet. 2017*a*. Disease complexity in a declining alaskan muskox (Ovibos moschatus) population. Journal of Wildlife Diseases 53:311–329.

Afema, J. A., K. B. Beckmen, S. M. Arthur, K. B. Huntington, and J. A. K. Mazet. 2017*b*. Disease complexity in a declining alaskan muskox (*Ovibos moschatus*) population. Journal of Wildlife Diseases 53:311–329.

Barr, W. 1991. Back From the Brink. Arctic Institute of North America.

Berger, J., C. Hartway, A. Gruzdev, and M. Johnson. 2018. Climate Degradation and Extreme Icing Events Constrain Life in Cold-Adapted Mammals. Scientific Reports 8:1–9. Springer US.

Blake, J. E., B. D. Mclean, and A. Gunn. 1991. Yersiniosis in Free-Ranging Muskoxen on Banks Island, Northwest Territories, Canada. Journal of Wildlife Diseases 27:527–533.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2004. Advanced Distance Sampling. Oxford University Press, Oxford, UK.

Buckland, S. T., A. J. Plumptre, L. Thomas, and E. A. Rexstad. 2010. Design and Analysis of Line Transect Surveys for Primates. International Journal of Primatology 31:833–847.

Buckland, S. T., E. A. Rexstad, T. A. Marques, and C. S. Oedekoven. 2015. Distance sampling: Methods and applications. S. T. Buckland, E. A. Rexstad, T. A. Marques, and C. S. Oedekoven, editors. Springer, Cham, Switzerland.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York, NY, USA.

Campos, P. F., E. Willerslev, A. Sher, L. Orlando, E. Axelsson, A. Tikhonov, K. Aaris-Sørensen, A. D. Greenwood, R. D. Kahlke, P. Kosintsev, T. Krakhmalnaya, T. Kuznetsova, P. Lemey, R. MacPhee, C. A. Norris, K. Shepherd, M. A. Suchard, G. D. Zazula, B. Shapiro, and M. T. P. Gilbert. 2010. Ancient DNA analyses exclude humans as the driving force behind late Pleistocene musk ox (Ovibos moschatus) population dynamics. Proceedings of the National Academy of Sciences of the United States of America 107:5675–5680.

Carter, L. 2020. Muskox (Ovibos moschatus) Habitat Associations and Interactions with Caribou (Rangifer tarandus). McGill University.

Case, R. L., and K. G. Poole. 1985. Distribution, abundance and composition of muskoxen north of Great Bear Lake, March 1983. Yellowknife, NWT.

Cuyler, C., J. Rowell, J. Adamczewski, M. Anderson, J. Blake, T. Bretten, V. Brodeur, M. Campbell, S. L. Checkley, H. D. Cluff, S. D. Côté, T. Davison, M. Dumond, B. Ford, A. Gruzdev, A. Gunn, P. Jones, S. Kutz, L. M. Leclerc, C. Mallory, F. Mavrot, J. B. Mosbacher, I. M. Okhlopkov, P. Reynolds, N. M. Schmidt, T. Sipko, M. Suitor, M. Tomaselli, and B. Ytrehus. 2020. Muskox status, recent variation, and uncertain future. Ambio 49:805–819.

Davison, T., J. Williams, and J. Adamczewski. 2017. Aerial Survey of Peary Caribou (Rangifer tarandus pearyi) and Muskoxen (Ovibos moschatus) on Banks Island, July 2014. Manuscript Report No. 270. Yellowknife, NWT.

Ecosystem Classification Group. 2009. Ecological Regions of the Northwest Territories – Taiga Plains. Department of Environment and Natural Resources, , Government of the Northwest Territories. Yellowknife, NWT.

Fedy, B. C., K. E. Doherty, C. L. Aldridge, M. O'Donnell, J. L. Beck, B. Bedrosian, D. Gummer, M. J. Holloran, G. D. Johnson, N. W. Kaczor, C. P. Kirol, C. A. Mandich, D. Marshall, G. McKee, C. Olson, A. C. Pratt, C. C. Swanson, and B. L. Walker. 2014. Habitat prioritization across large landscapes, multiple seasons, and novel areas: An example using greater sage-grouse in Wyoming. Wildlife Monographs 190:1–39.

Di Francesco, J., N. Navarro-Gonzalez, K. Wynne-Edwards, S. Peacock, L.-M. Leclerc, M. Tomaselli, T. Davison, A. Carlsson, and S. Kutz. 2017. Qiviut cortisol in muskoxen as a potential tool for informing conservation strategies. Conservation Physiology 5. Oxford University Press.

Gunn, A., and T. W. Barry. 1984. Possible causes and consequences of an expanding muskox population, Queen Maud Gulf area, Northwest Territories.

Hansen, C. C. R., C. Hvilsom, N. M. Schmidt, P. Aastrup, P. J. Van Coeverden de Groot, H. R. Siegismund, and R. Heller. 2018. The Muskox Lost a Substantial Part of Its Genetic Diversity on Its Long Road to Greenland. Current Biology 28:4022-4028.e5. Elsevier Ltd.

Le Henaff, D., and M. Crete. 1989. Introduction of muskoxen in northern Quebec: the demographic explosion of a colonizing herbivore. Canadian Journal of Zoology 67:1102–1105.

Hoberg, E. P., S. J. Kutz, J. Nagy, E. Jenkins, B. Elkin, M. Branigan, and D. Cooley. 2002. Protostrongylus stilesi (Nematoda: Protostrongylidae): Ecological isolation and putative host-switching between Dall's sheep and muskoxen in a contact zone. Comparative Parasitology 69:1–9.

Jenkins, D. A., M. Campbell, G. Hope, J. Goorts, and P. McLoughlin. 2011. Recent trends in abundance of Peary caribou (Rangifer tarandus pearyi) and muskoxen (Ovibos moschatus) in the Canadian Arctic Archipelago, Nunavut. Wildlife Report 1, Version:184.

Johnson, D. H. 1980. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology 61:65–71.

Jorgensen, A. 2021. Wildlife Forage Recovery Following Boreal Wildfire. Wilfrid Laurier University.

Kafle, P., P. Peller, A. Massolo, E. Hoberg, L. M. Leclerc, M. Tomaselli, and S. Kutz. 2020. Range expansion of muskox lungworms track rapid arctic warming: implications for geographic colonization under climate forcing. Scientific Reports 10:1–14. Nature Publishing Group UK.

Kelsall, J. P., V. D. Hawley, and D. C. Thomas. 1971. Distribution and Abundance of Muskoxen North of Great Bear Lake. Arctic 24.

Krebs, C. J. 1989. Ecological Methodology. Harper & Row, New York, NY.

Kutz, S., T. Bollinger, M. Branigan, S. Checkley, T. Davison, M. Dumond, B. Elkin, T. Forde, W. Hutchins, A. Niptanatiak, and K. Orsel. 2015. Cross-Canada Disease Report: Erysipelothrix rhusiopathiae associated with recent widespread muskox mortalities in the Canadian Arctic. Canadian Veterinary Journal 56:560–563.

Kutz, S., E. Garde, A. Veitch, J. Nagy, F. Ghandl, and L. Polley. 2004. Muskox lungworm (Umingmakstrongylus pallikuukensis) does not establish in experimentally exposed thinhorn sheep (Ovis dalli). Journal of Wildlife Diseases 40:197–204.

Kutz, S. J., S. Checkley, G. G. Verocai, M. Dumond, E. P. Hoberg, R. Peacock, J. P. Wu, K. Orsel, K. Seegers, A. L. Warren, and A. Abrams. 2013. Invasion, establishment, and range expansion of two parasitic nematodes in the canadian arctic. Global Change Biology 19:3254–3262.

Larter, N. C., and J. A. Nagy. 2001. Calf production, calf survival, and recruitment of muskoxen on Banks Island during a period of changing population density from 1986-99. Arctic 54:394–406.

Larter, N. C., J. A. Nagy, and D. S. Hik. 2002. Does seasonal variation in forage quality influence the potential for resource competition between muskoxen and Peary caribou on Banks Island? Rangifer 22:143.

Latifovic, R. 2019. 2015 Landcover of Canada. Government of Canada. <https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6>.

Mavrot, F., K. Orsel, W. Hutchins, L. G. Adams, K. Beckmen, J. E. Blake, S. L. Checkley, T. Davison, J. Di Francesco, B. Elkin, L. M. Leclerc, A. Schneider, M. Tomaselli, and S. J. Kutz. 2020. Novel insights into serodiagnosis and epidemiology of Erysipelothrix rhusiopathiae, a newly recognized pathogen in muskoxen (Ovibos moschatus). PLoS ONE 15:1–14.

McLean, B. 1992. An aerial survey of muskoxen north of great bear lake, August 1987. Inuvik, NWT.

Miller, D. L., M. L. Burt, E. A. Rexstad, and L. Thomas. 2013. Spatial models for distance sampling data: Recent developments and future directions. Methods in Ecology and Evolution 4:1001–1010.

Miller, David L, E. Rexstad, L. Burt, M. V Bravington, and S. Headley. 2019. dsm: Density Surface Modelling of Distance Sampling Data.

Miller, David L., E. Rexstad, L. Thomas, J. L. Laake, and L. Marshall. 2019. Distance sampling in R. Journal of Statistical Software 89:1–28.

Olesen, C. R. 1993. Rapid population increase in an introduced muskox population, West Greenland. Rangifer 13:27.

Peter, J., and C. De Groot. 2001. Conservation Genetic Implications of Microsatellite Variation in the Muskox Ovibos moschatus: the Effect of Refugial Isolation.

Polfus, J. L., M. Manseau, D. Simmons, M. Neyelle, W. Bayha, F. Andrew, L. Andrew, C. F. C. Klütsch, K. Rice, and P. Wilson. 2016. Łeghágots'enetę (learning together): the importance of indigenous perspectives in the identification of biological variation. Ecology and Society 21:18.

Prewer, E., S. Kutz, L. M. Leclerc, and C. J. Kyle. 2020. Already at the bottom? Demographic declines are unlikely further to undermine genetic diversity of a large Arctic ungulate: muskox, Ovibos moschatus (Artiodactyla: Bovidae). Biological Journal of the Linnean Society 129:459–469. Oxford University Press.

R Development Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Reynolds, P. E., H. V Reynolds, and R. T. Shideler. 2002. Predation and multiple kills of muskoxen by gizzly bears. Ursus 13:79–84.

Roberts, J. J., B. D. Best, L. Mannocci, E. Fujioka, P. N. Halpin, D. L. Palka, L. P. Garrison, K. D. Mullin, T. V. N. Cole, C. B. Khan, W. A. McLellan, D. A. Pabst, and G. G. Lockhart. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Scientific Reports 6:1–12. Nature Publishing Group.

Spencer, W. 1976. Muskox (Ovibos mochatus) surveys, central western Arctic.

Tener, J. S. 1965. Muskoxen in Canada. Ser. No. 2. Canadian Wildlife Service Monogr., Ottawa, ON.

Tomaselli, M., C. Dalton, P. J. Duignan, S. Kutz, F. van der Meer, P. Kafle, O. Surujballi, C. Turcotte, and S. Checkley. 2016. Contagious ecthyma, rangiferine brucellosis, and lungworm infection in a muskox (Ovibos moschatus) from the Canadian Arctic, 2014. Journal of Wildlife Diseases 52:719–724.

Tomaselli, M., S. C. Gerlach, S. J. Kutz, S. L. Checkley, S. Arctic, N. March, M. Tomaselli, S. C. Gerlach, S. J. Kutz, and S. L. Checkley. 2018*a*. Local Perspectives about the Importance of Muskoxen , Contemporary and Traditional Use and Practices. Arctic 71:1–14.

Tomaselli, M., S. Kutz, C. Gerlach, and S. Checkley. 2018*b*. Local knowledge to enhance wildlife population health surveillance: Conserving muskoxen and caribou in the Canadian Arctic. Biological Conservation 217:337–348. Elsevier.

Veitch, A. M. 1997. An aerial survey of muskoxen in the northern Sahtu Settlement Area, March 1997. Norman Wells, NWT.

Winbourne, J., and K. Benson. 2021. Species Status Report (Traditional and Community Knowledge Component) for Muskoxen (Ovibos moschatus) in the Northwest Territories. Yellowknife, NWT.

APPENDIX 1

Table A1. Pooled classification of land cover types based on the Landcover of Canada 2015 base layer.

Variable	Landcover of Canada 2015	Description
Conifer	Temporate or Subpolar Needle Leaf	Forests generally taller than 3 m and accounting for more than 20% of total vegetation cover. The tree crown cover consists of at least 75% needle-leaved species.
Taiga	Subpolar Taiga	Forests and woodlands with trees generally taller than 3 m, accounting for more than 5% of total vegetation cover, with shrubs and lichens commonly present in the understory. The tree crown cover consists of at least 75% needle-leaved species. This type occurs across northern Canada and may consist of treed muskeg or wetlands. Forest canopies are variable and often sparse, with generally greater tree cover in the southern parts of the zone than in the north.
Mixed	Temporate or Subpolar Broadleaf Deciduous	Forests generally taller than 3 m and accounting for more than 20% of total vegetation cover. These forests have more than 75% of tree crown cover represented by deciduous species.
	Mixed Forest	Forests generally taller than 3 m and accounting for more than 20% of total vegetation cover. Neither needle leaf nor broadleaf tree species make up more than 75% of total tree cover, but they are co-dominant.
Shrubland	Temperate or Subpolar Shrub Land	Areas dominated by woody perennial plants with persistent woody stems, <3 m tall and typically accounting for more than 20% of total vegetation cover.
	Subpolar or Polar Shrub Land-lichen-moss	Areas dominated by dwarf shrubs with lichen and moss, typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada.
Grassland	Temporate or Subpolar Grassland	Areas dominated by graminoid or herbaceous vegetation, generally accounting for more than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be used for grazing.

Variable	Landcover of Canada 2015	Description
	Subpolar or Polar Grassland-lichen-moss	Areas dominated by grassland with lichen and moss, typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada.
Barrenland	Subpolar or Polar barren-lichen-moss	Areas dominated by a mixture of bare areas with lichen and moss, typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada.
	Barrenland	Areas characterized by bare rock, gravel, sand, silt, clay, or other mineral material, with little or no "green" vegetation present regardless of its inherent ability to support life. Generally, vegetation accounts for <10% of total cover.
Wetland	Wetland	Areas dominated by perennial herbaceous and woody wetland vegetation which is influenced by the water table at or near surface over extensive periods of time. This includes marshes, swamps, bogs, etc., either coastal or inland, where water is present for a substantial period annually.
Urban	Urban	Areas that contain at least 30% urban constructed materials for human activities (cities, towns, transportation, etc.).
Water	Water	Areas of open water, generally with <25% of non-water cover types. This class refers to areas that are consistently covered by water.