LATE WINTER 2018 MUSKOX PHOTO COMPOSITION SURVEY,

EAST ARM OF GREAT SLAVE LAKE

WORKING DRAFT September 12, 2019

For review—contents may change in future drafts

Jan Adamczewski[1]
Kristen Olesen[2]
Dave Olesen[2]
Judy Williams[1]
Dean Cluff[3]
John Boulanger[4]

1 - Wildlife Division, Environment and Natural Resources, Government of Northwest Territories, Box 1320, Yellowknife, NT, Canada X1A 2L9.

2 - Hoarfrost River Huskies Ld., P.O. Box 607, Yellowknife, NT, Canada X1A 2N5.

3 - North Slave Region, Environment and Natural Resources, Government of Northwest Territories, P.O. Box 2668, Yellowknife, NT, Canada X1A 2P9.

4 - Integrated Ecological Research, 924 Innes, Nelson, BC, Canada, V1L 5T2.

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ABSTRACT

A strip-transect fixed-wing survey of muskoxen in the East Arm region of the Northwest Territories in late winter 2018 (Cluff et al. 2019) demonstrated that muskox densities had increased by approximately 6-fold since the last previous muskox survey in this area in 2010. This represented an exceptionally high annual growth rate of about 25%/year over this period. A large portion of the survey area was above tree-line and a substantial proportion was below tree-line, either in transition boreal-tundra zones or well into the boreal forest. To add to our understanding of this expanding population, additional flying was carried out to obtain a demographic profile through a photographic composition survey.

An Aviat Husky, a small fixed-wing aircraft, was used with a crew of D. Olesen (pilot) and K. Olesen (photographer) in late winter 2018 for this composition survey. Muskox groups found during the larger regional muskox survey were photographed, with the emphasis on obtaining frontal views of the muskoxen. The Husky is a small, quiet and slow-flying aircraft, and alarm responses of muskoxen appeared limited. Multiple photos and photo passes were taken to improve the chances of clear images showing the heads of the muskoxen. The photos were later reviewed on a computer and calves (approaching one year of age), 2-year-old females, 2-year-old males, 3-year-old females, 3-year-old males, females 4-years-old or older, and males 4-years-old or older, were identified on the photos. In most cases, one main photo often provided a clear view of most of the muskoxen in the group. Having a sequence of photos made it possible to identify all or nearly all individuals in a group where some individuals were turned away or hidden in the main photo. These were compared to ground-based photos of these classes of muskoxen from an Alaska Fish and Game photo guide to sex and age classes of muskoxen (Alaska Department of Fish and Game 2010).

Overall, classification of muskoxen was possible in 56 of 75 (75%) of the groups photographed. Some muskox groups were in thickly forested areas where most of the animals could not be identified. In some cases it was not possible to record the frontal views needed to classify individual muskoxen. Classification of muskoxen was limited to groups where at least 80% of the animals could be classified.

In total, 56 groups and 891 muskoxen were classified. Totals of each category of muskox classified were: calves 215, 2-year-old females 87, 3-year-old females 68, 4-year-old+ females 148, unknown females 34 (identified as females but the age class based on horns was not quite clear in photos), females total 337, 2-year-old males 88, 3-year-old males 72, 4-year-old+ males 122, total males 282, and unknown 57 (6.4%). These results yielded a male-female ratio of 83.7 bulls:100 cows, a calf-cow ratio of 63.8 calves: 100 cows when all cows were included, and a calf-cow ratio of 86 calves: 100 cows if the 87 2-year-old females were omitted. Females approaching 2 years of age would have had to breed at about 6 months of age to have a calf nearly a year old at the time of the survey, which is unlikely in muskoxen. This demographic profile is consistent with a population growing at a near-maximum rate, and suggests that pregnancy rates were very high along with very high survival rates of calves and adults.

There were 17 bull-only groups, which ranged in size from single bulls (4) to pairs (6), three bulls (4) and single instances of 5, 7, and 8 bulls. There were 39 mixed groups, which were generally larger and ranged in size from 5 to 40, with groups of 10-15 (7), 16-20 (8) and 21-25 (6) occurring most frequently.

Extensive feeding sign and trails in the snow around several groups suggested that muskoxen often remained at the same site for several days or weeks.

Habitats in which muskox groups were found were defined at a broad scale as tundra, transition (tundra-boreal) and forest. Of the 56 groups, 39 (69.6%) were in the boreal forest, 10 (17.9%) were in transition areas, and 7 (12.5%) were on the tundra. The high proportion of groups photographed south of tree-line compared to tundra is largely a reflection of the flying effort, which was primarily in the boreal forest. Habitats south of tree-line were further divided on a finer scale, and the numbers and proportions of groups found in these habitats from most common to least common were: rocky ridge 17 (34.7%), sparse forest 14 (28.6%), lake edge 9 (18.4%), thick forest 8 (16.3%), and old burn 1 (2.0%). These habitat types are not based on any rigorous analysis of vegetation/terrain types, rather they are designations of convenience from the photos.

INTRODUCTION

Free-ranging muskoxen (*Ovibos moschatus*) have shown a highly variable productivity of calves, depending primarily on whether the population was growing, stable or declining. Gray (1987) observed muskoxen on the ground in the Polar Bear Pass region of Bathurst Island between 1968 and 1980 and in the first three years (1968-1970) did not see a single calf and little evidence of rutting behavior. Tener (1965) noted that “The evidence gathered by early travellers in muskox country suggested that cows produced calves in alternate years.” Percentages of calves recorded by observers in the 1950s and early 1960s in Tener (1965) varied “from 0 to as high as 18%”. Introduced populations in Alaska showed very rapid growth in some cases; the calf-cow ratio in the Sadlerochit River muskox herd was 89 calves: 100 cows of reproductive age in 1979 (Jingfors and Klein 1982). A rapidly expanding population in northern Quebec (Le Hénaff and Crête 1989) had similar calf productivity and grew at 25%/year. In an Alaskan introduced population in the Arctic National Wildlife Refuge, some cows (early 1980s) initially produced calves in several successive years, but by 1991-1993 most females successfully reproduced at intervals of 2-3 years (Reynolds 2001). Larter and Nagy (2001) documented substantial variation in calf production and yearling recruitment in Banks Island muskoxen between 1986 and 1999 while this population increased from 1986 to 1994 and then declined to 1999.

Muskoxen can be identified to sex and age class by their growth and horn development. A number of guides to age and sex classification have been published: Henrichsen and Grue (1980) developed one of the first guides in Greenland; Gray (1987) included a guide to muskox classification on Bathurst Island in his book; Olesen and Thing (1989) developed a muskox photo guide in West Greenland; and Alaska Department of Fish and Game (2010) developed a photo guide for Alaskan muskoxen. Comparison of these guides suggests that the rates at which muskoxen reach mature size and horns grow vary, depending on the population phase that the animals are in. The guide in Gray (1987) included males identified as 1, 2, 3, 4, 5 and 6+ years old, Henrichsen and Grue (1980) recognized males 1, 2, 3, 4 and 5+ years old, while the Alaska Department of Fish and Game guide (2010) included 1, 2, 3 and 4+ year old male classes. These differences most likely reflect more rapid growth and better nutrition in expanding populations (e.g. Olesen and Thing 1989, Alaska Fish and Game 2010) than in stable or declining populations (e.g. Gray 1987).

Classification surveys to identify muskox sex and age classes have been primarily conducted on the ground with binoculars and spotting scopes (Jingfors and Klein 1982, Larter and Nagy 1999, 2001), usually with air support on large remote ranges (Larter and Nagy 2001). A photographic approach was used in muskox surveys of the Nelson and Nunivak Islands (e.g. Jones 2015a, b). These were conducted by small, quiet slow-flying aircraft such as Piper PA-18 Supercubs, which tend to disturb the animals relatively little and allow high-resolution photos to be taken of the front ends of the muskoxen. Muskoxen can later be classified to age and sex classes from the photos (see Jones 2015a,b).

A large-scale muskox survey in an area around the East Arm of Great Slave Lake in the Northwest Territories (NWT) by Cluff et al. (2019) in February and March 2018 showed an increase of approximately six-fold in abundance from a previous similar survey in 2010. This translates to an annual growth rate of about 25%, similar to the 25% annual growth rate documented in an expanding colonizing muskox population in northern Quebec (Le Hénaff and Crête 1989).

To more fully understand the demography of this rapidly growing muskox population in the East Arm area, we flew a photographic composition survey in March and early April 2018 with an Aviat Husky, a modern-day Supercub. The purpose was to photograph a sample of the muskox groups found during the survey by Cluff et al. (2019) and identify proportions of muskox sex and age classes. Unlike the muskoxen on Nelson and Nunivak Islands, which are on open tundra, much of the study area around the East Arm of Great Slave Lake is below tree-line in the boreal forest, thus our survey was in part a pilot project to assess whether this photographic method could also be used for muskoxen in forested country.

METHODS

Survey flying

A fixed-wing muskox survey was flown between February 26 and March 2, 2018 in an area around the East Arm of Great Slave Lake in the Northwest Territories (Cluff et al. 2019; Figure 1).

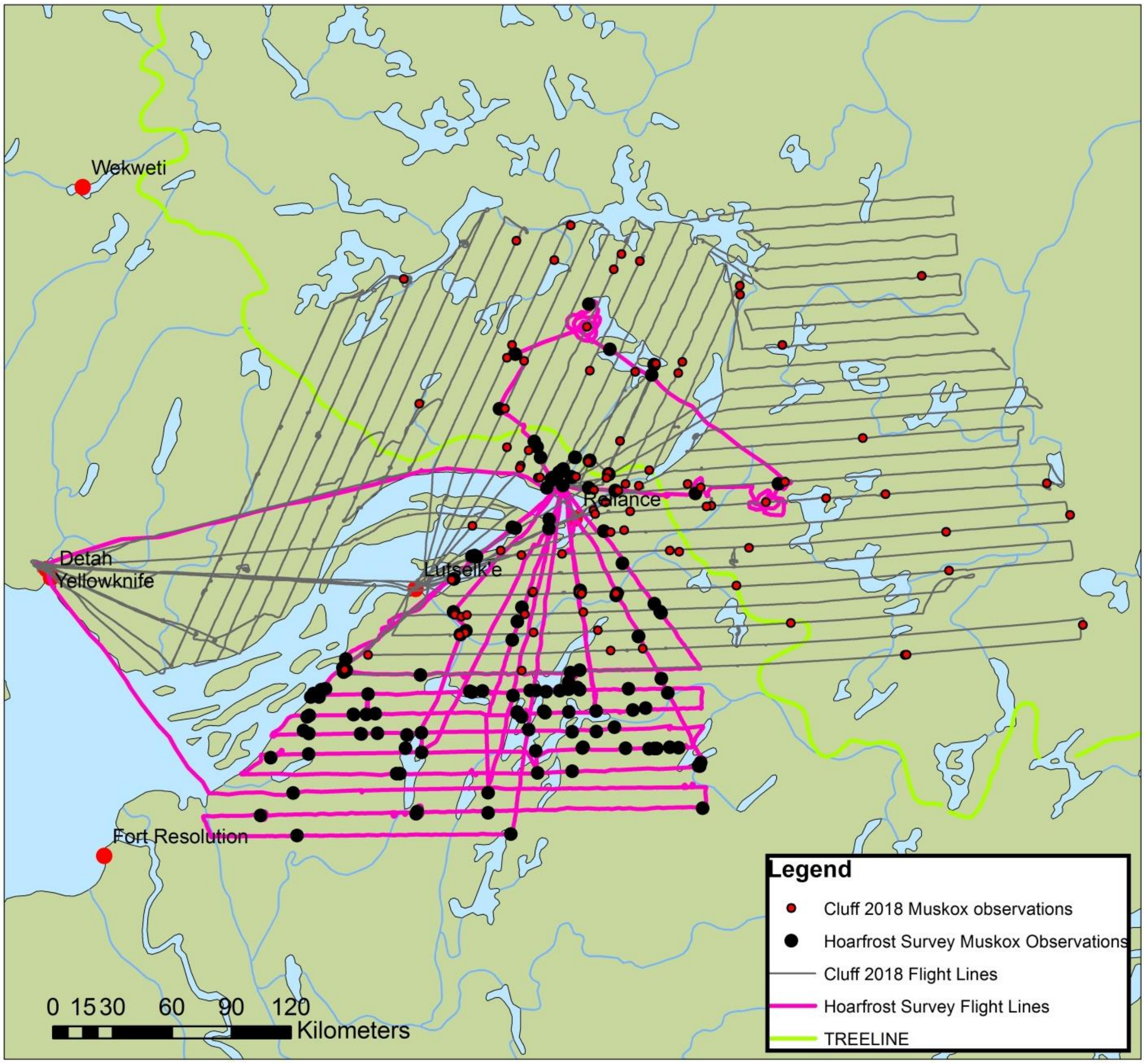


Figure 1. Muskox fixed-wing survey area in late winter 2018 in the East Arm area of Great Slave Lake. Grey lines were part of the large regional survey flown by Cluff et al. (2019). Red dots show locations of muskox groups. Pink lines are the additional lines flown in the southern part of the survey area with the Husky and the additional flying to photograph muskox groups. Black dots show muskox groups seen during the Husky flying.

Yellowknife and Lutsel K'e were the main bases of operation for fixed-wing aircraft, with additional flying based at the Hoarfrost River on the north shore of the East Arm. Two Cessna 185 aircraft were used for most of the flying and an Aviat Husky based at the Hoarfrost River also flew a number of the survey lines. Lines were spaced 10 km apart. This survey followed a similar one in the same area in March 2010 (Cluff et al. 2019; Figure 2).

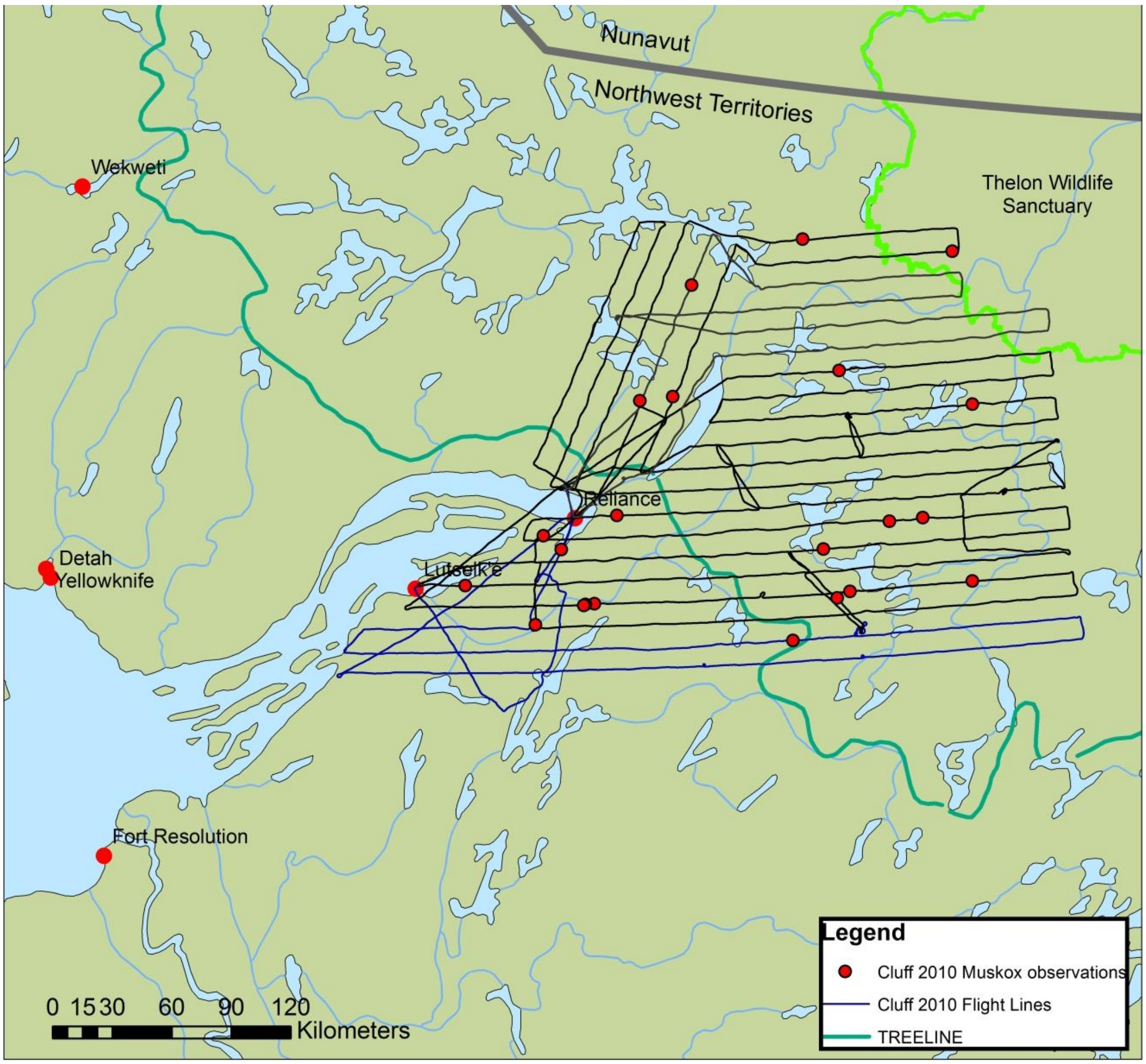


Figure 2. Muskox fixed-wing survey area in March 2010 in the East Arm area of Great Slave Lake (from Cluff et al. 2010). Red dots show locations of muskox groups.

The area surveyed in 2018 was larger and included an area east of the survey area from 2010, to provide information on muskox abundance in an area that had some reported muskox sightings in recent years. Further flight lines were added to the south of the main survey area using the Husky in March and April 2018, to provide further information on muskox abundance in that area. Information from local observers, and particularly D. Olesen who is a pilot based at the Hoarfrost River and has flown this area extensively, indicated that muskoxen were abundant in that area and had increased substantially in recent years. The overall survey area was mostly on the tundra above tree-line, but also included a substantial proportion below tree-line. The highest densities of muskox groups were at the south end of the survey area south of Lutsel K'e, well below tree-line.

Overall, muskox density (number per km^2) in the East Arm area had increased about 6-fold over the period between 2010 and 2018 (Cluff et al. 2019), and the increase in numbers of muskox groups recorded is readily apparent by comparing Figures 1 and 2.

Photography of muskox groups

The additional flying that was used to photograph muskox groups for classification, which this report describes, was carried out by D. and K. Olesen in March and April, 2018 in the Aviat Husky. The aircraft is small and suited to one pilot and one passenger, and no ENR biologists were on board during these flights. K. Olsen is an experienced photographer and we were interested in obtaining clear high-resolution photos from which muskoxen could be classified, thus her skills were an essential part of the field work. Some of the photography was taken while flying the southern-most flight lines in Figure 1, and some was flown opportunistically in following weeks when suitable weather occurred and when the aircraft and pilot were available. Waypoints recorded on GPS units for muskox groups from the fixed-wing survey lines in Figure 1 were also used to fly to, a few days or a few weeks after the fixed-wing survey lines had been completed. Muskoxen in late winter are fairly localized in their movements, thus GPS locations recorded a few days earlier or even a week or two previously almost always meant that the animals would not be far away. Photos were taken on 8 days: March 4, 12, 13, 14, 16, and 19, and April 7 and 19.

Figure 3. A group of muskoxen photographed March 4, 2018 on a small ridge in the boreal forest in the East Arm area of Great Slave Lake. Most are standing facing the aircraft and can readily be identified to age and sex.

A Nikon D3X and a Nikon D800 camera were used for the photography, in combination with a number of zoom lenses, and primarily a Nikkor AF-S 28-300mm lens. For most groups, a number of photo passes (2-3) were made. The emphasis was on photos that showed most of the muskoxen in a group from a frontal view where their horns were clearly visible. In some cases, it appeared that the muskoxen were not much disturbed by the aircraft and they lined up facing the aircraft and the camera (Figure 3).

For all groups photographed, multiple photos were taken in sequence, to increase the chances that most or all of the animals would be positioned so that their front ends could be clearly seen. All photos of muskoxen were stored on an external hard drive, together with information about the group's location and habitat they were found in. All photos were taken by K. Olesen, including all examples in this report.

Classification of muskoxen from photos

All the photos of muskox groups were reviewed on a computer monitor. For most groups, one photo pass generally had the most suitable photos with the animals largely facing the camera. Within that photo pass, it was often possible to select the one best photo where most of the muskoxen were clearly identifiable. A program was used to place a mark digitally on each muskox, which increased by one as each animal was classified, and each animal was then classified using the photo guide from Alaska Department of Fish and Game (2010). We used this guide in preference to the other guides listed earlier, as it appeared that the Alaskan guide was from a muskox population growing rapidly, thus most appropriate for a population in the East Arm area also growing rapidly. Photos in the sequence before and after the main photo were also used as this sometimes meant that muskoxen that were obscured by other animals or behind trees or were turned away from the camera, could in a further photo be seen clearly and classified.

For most groups, it appeared that the muskoxen were not greatly alarmed by the aircraft, which is relatively small and quiet and can fly relatively slowly. On several photos there were bedded muskoxen that did not stand up. In several cases the best photos were taken on the first pass when the animals lined up to face the aircraft and the camera. An example of a small group of muskoxen that included calves and 2 and 3 year old males is shown in Figure 4.

In some groups photographed, most or many of the muskoxen could not be classified, either because they were obscured in thick forest (Figure 5), or photos of the front ends were not feasible, or in a few cases they were tightly bunched so that some individuals were behind others, or they were on the run. We used only classification of groups where we could classify at least 80% of the animals, as we were concerned that in groups where we classified lower percentages of the animals, the counts might be biased towards fairly obvious animals like large bulls or calves. Although the bulk of the muskox groups were photographed south of tree-line, many were in relatively open areas, such as ridges or small hills, lake edges with few trees, or relatively open, sparsely forested areas. For obvious reasons of visibility, muskox groups on the tundra were relatively easy to photograph, and muskox groups in thickly forested locations tended to be more difficult to photograph.

Bootstrap methods (Manly 1977) were used to obtain percentile-based confidence limits on bull-cow and calf-cow ratios. The *boot* package in *R* statistical software (R Development Core Team, 2009) was used for bootstrap estimates. Pie charts maps were generated using the QGIS software package (QGIS Foundation 2015).

Figure 4. Part of a group of muskoxen photographed April 9, 2018 on a small ridge in the boreal forest in the East Arm area of Great Slave Lake. From left to right, the muskoxen are: a calf, a 2-year-old male, a calf, a calf, and a 3-year-old male.

Figure 5. A group of muskoxen photographed March 12, 2018 in the boreal forest in the East Arm area of Great Slave Lake.

RESULTS

Overall classification results

We classified 869 muskoxen in 56 groups and were unable to obtain adequate classification in another 19 groups, hence we classified 75% of the groups photographed (Table 1). The muskox classes we identified based on the Alaskan guide included calves (approaching one year), 2-year-old females, 3-year-old females, females at least 4-years-old, 2-year-old males, 3-year-old males, and males at least 4-years-old. Calves are difficult to identify as males and females as their body size is similar and there are no obvious differences yet in the horns. Of the 869 muskoxen, 57 (6.5%) were classified as unknown. In addition, 34 muskoxen (out of 337 total females, or 10.1% of the females) were identified as females based on thin horn bases, but could not be definitively identified to age class. Numbers of each sex and age class in each group classified are listed in Appendix 1. A selection of photos of muskox groups is provided in Appendix 2 (mixed groups) and Appendix 3 (bull-only groups).

Calves accounted for nearly a quarter (24.7%) of the 891 total muskoxen classified. If all the females are included, then the calf:cow ratio was 63.9 calves:100 cows. However, the survey was carried out in March, when all the muskoxen would have been approaching their birth dates (calving likely occurred in late April and early May). Two-year-old cows would have had to breed at 5 months of age to have a newborn calf in April/May 2017, which is unlikely. If the 87 2-year-old females are excluded, then the calf:cow ratio was 86.0 calves:100 cows.

Table 1. Numbers of muskoxen classified in each category in March-April 2018 in the East Arm area of Great Slave Lake, and resulting bull:cow and calf:cow ratios. Bootstrap-based 95% confidence limits are given for ratios. Bull:cow ratio includes bull-only and mixed groups. Upper confidence limit on calf:cow ratio is truncated at 100 calves:100 cows.

Category	**Number Classified**	**% of Total**	**Notes**
Calves (nearly one year old)	215	24.7	% of 891
Females 2 years old	87	10.0	% of 891
Females 3 years old	68	7.8	% of 891
Females at least 4 years old	148	17.0	% of 891
Unknown Females	34	3.9	% of 891
Total Females	337	*54.4*	*% of Total Males & Total Females (619)*
Males 2 years old	88	10.1	% of 891
Males 3 years old	72	8.3	% of 891
Males at least 4 years old	122	14.0	% of 891
Total Males	282	*45.6*	*% of Total Males & Total Females (619)*
Unknown	57	6.6	% of 891
Total	891	99.9	
Ratios			
Bulls:100 Cows	83.7:100, (SE=9, CI=69-106).		282 Males & 337 Females
Calves:100 Cows	63.8:100 (SE=5, CI=55-74:100)		215 Calves & 337 Females
Calves:100 Cows (excluding Females 2 years old)	86.0:100 (SE=8, CI=71-100:100)		215 Calves & 250 Cows 3 years old or older

The representation of 2 and 3 year old males and females was high in this survey, consistent with the high representation of calves in the population. The total of 2 and 3 year old females was 155, larger than the total of females classified as 4 years old or older (148), and the total of 2 and 3 year old males was 160, substantially more than the total of males classified as 4 years old or older (122).

Close assessment of the males classified as at least 4 years old suggested that many of these males were no more than 4 or 5 years old, as their bosses appeared light-coloured and did not shown the full central development and darker colour often seen in older males (Figure 6).

Figure 6. Two muskox bulls photographed during March-April 2018 in the East Arm area of Great Slave Lake. Both were identified as at least 4 years old when compared to the Alaska Department of Fish and Game (2010) guide, however the one on the left has a very light-coloured boss and lacks the full development of the boss compared to the male on the right. The bull on the left is likely just 4 years old while the one on the right is likely at minimum 5 or 6 years old.

Distribution and composition of muskox groups classified

Muskox groups classified in March and April 2018 were mapped in Figure 7a and 7b. Group size and composition were generally similar throughout the survey area. Bull-only groups tended to be more common at the southern end of the distribution.

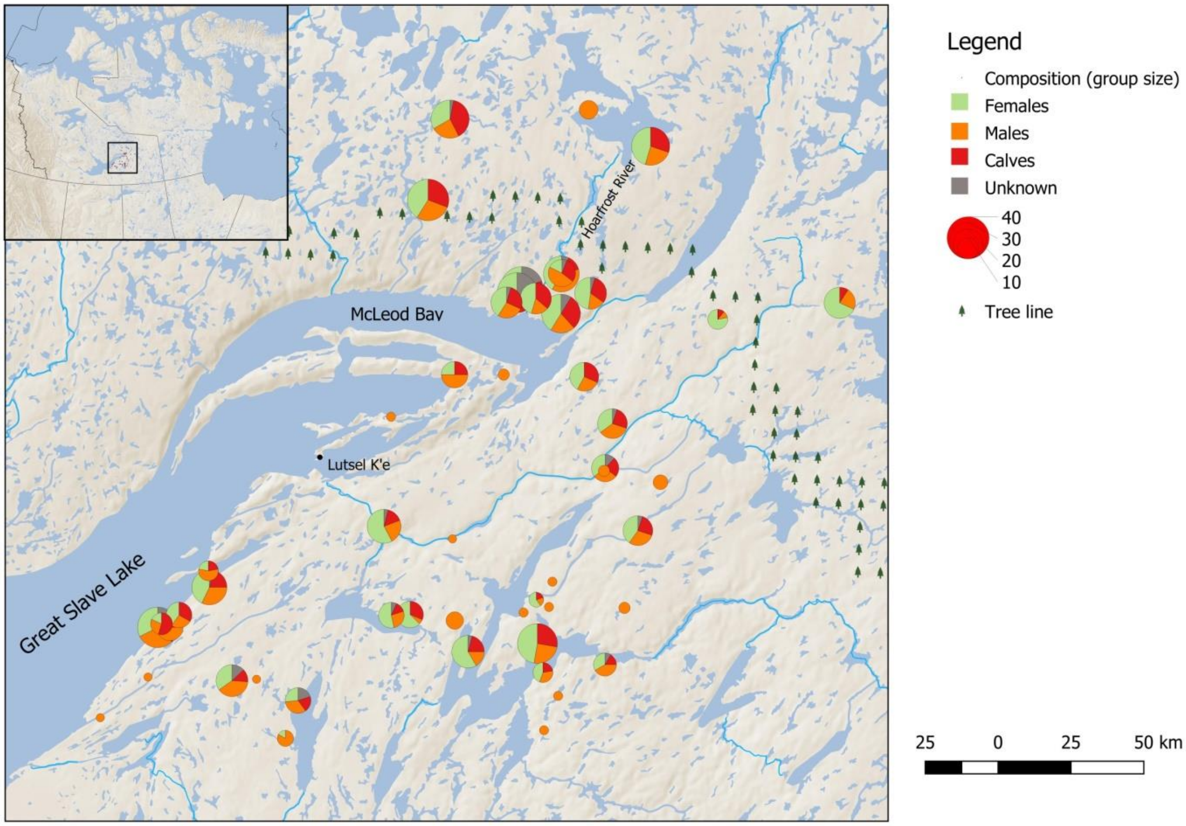


Figure 7a. Locations, group size and composition of muskox groups classified in the East Arm area of Great Slave Lake in March-April 2018. Circles are sized in proportion to group size. Calves, males, females and unknown muskoxen are shown in the pie charts.

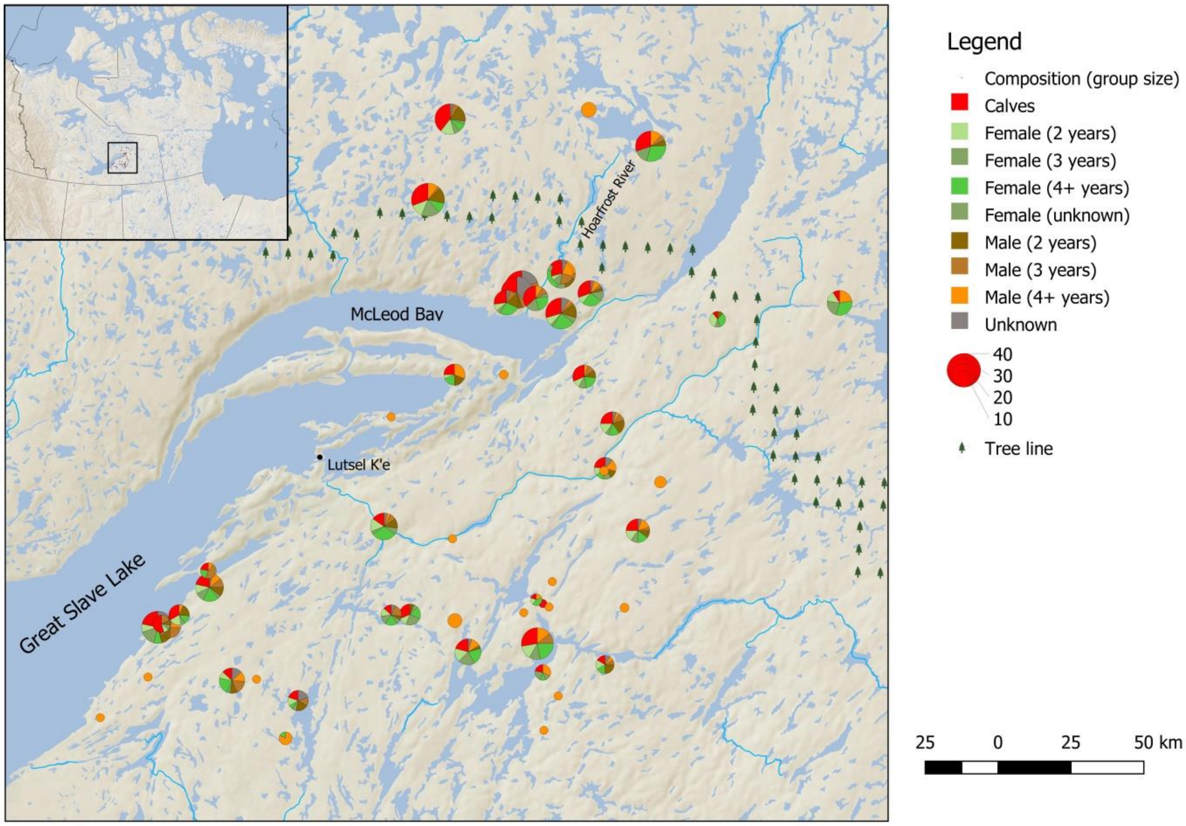
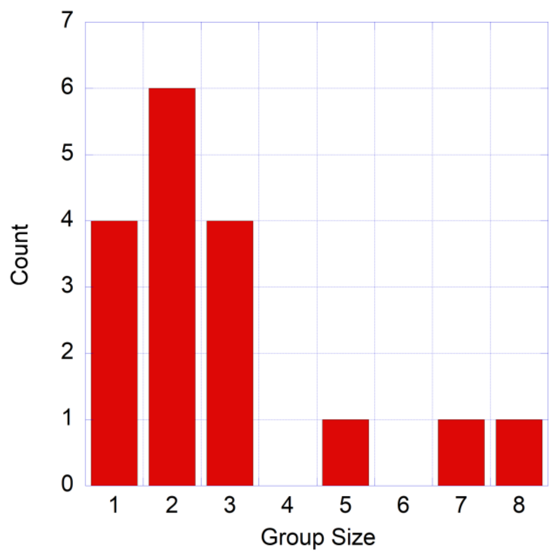


Figure 7b. Locations, group size and composition of muskox groups classified in the East Arm area of Great Slave Lake in March-April 2018. Circles are sized in proportion to group size. Calves, males and females 2, 3, and 4+ plus years old, and unknown muskoxen are shown in the pie charts.

Muskox group sizes

There were 17 bull-only muskox groups among the 56 groups classified. Bull-only groups ranged in size from lone bulls to a group of 8 bulls, with the most common being pairs (Figure 8a). Mixed groups were generally larger and ranged in size from 5 to 40, with groups of 11-15, 16-20 and 21-25 being most frequent (Figure 8b).



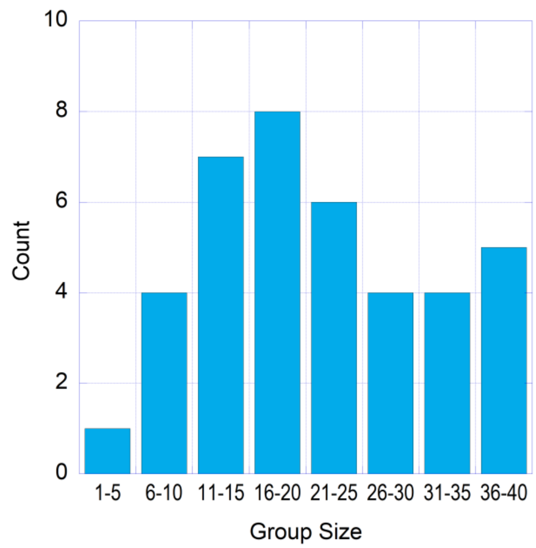


Figure 8. (a) Group size distribution of bull-only (left) and (b) mixed (right) muskox groups classified in the East Arm area of Great Slave Lake in March-April 2018.

Wolves and wolf kills

In the flying carried out by the Aviat Husky, two wolves (one black, one grey) were seen at a kill site location, which appeared to be the remains of a muskox (Figure 9). One additional muskox kill site was found during the flying. As bears would not have been active yet at this time of year, this was likely also a wolf kill.

Figure 9. (a) A black wolf photographed March 16, 2018 in the East Arm area of Great Slave Lake during a muskox survey (left); (b) nearby kill site on the same day (right). A second wolf (grey) was also seen at this site at the same time. The remains appear to be a muskox.

Habitats used by muskoxen

Of the 58 muskox groups photographed and classified, 41 (71.9%) were in the boreal forest, 10 (17.2%) were in transition areas, and 7 (12.1%) were on the tundra. The high proportion of groups photographed south of tree-line compared to tundra is largely a reflection of the flying effort of the Aviat Husky, which was primarily in the boreal forest. Habitats were further divided on a finer scale below tree-line, and the numbers and proportions of groups found in these habitats were as follows: rocky ridge 17 (29.3%), sparse forest 14 (24.1%), thick forest 9 (17.2%), lake edge 9 (15.5%), and old burn 1 (1.7%). Continuous snow cover on the tundra did not allow identification of specific vegetation or habitat types. We acknowledge that these habitat classes do not derive from any formal habitat definition; they were rather units of convenience based on the photos. Some muskox groups were found in relatively thick boreal forest but most were in fairly rugged terrain with at least some openings.

Figure 10a. A group of muskoxen photographed south of tree-line on April 7, 2019 in rugged terrain with multiple ridges and relatively sparse forest cover, in the East Arm area of Great Slave Lake. Extensive sign of feeding, bedding sites and trails in the snow suggested that the muskoxen had been in the area for several days and possibly longer.

Figure 10b. A group of muskoxen photographed on the tundra on April 7, 2018 in the East Arm area of Great Slave Lake. As in Figure 10a, extensive sign of feeding and bedding sites suggested that the muskoxen had been in the area for several days and possibly longer.

A common observation during the survey flying was that muskox groups observed on one day could often be found nearby (from the GPS waypoint) a few days or even a few weeks later. Areas used by muskoxen often showed extensive feeding craters, trails and signs of use consistent with multiple days of use (or longer) in the area (Figures 10a and 10b).

DISCUSSION

Demographic profile of the muskox population in the East Arm area of Great Slave Lake

The results of the composition survey in the East Arm area of Great Slave Lake in March/April 2018 are consistent with the exceptionally rapid growth of this population documented by Cluff et al. (2019) between 2010 and 2018. The annual growth rate of about 25% for this population matches the 25% annual growth rate documented by Le Hénaff and Crête (1989) between 1983 and 1986 in a muskox population that was colonizing new range near Baie D’Ungava in northern Québec. This muskox population originated from a captive herd that was released north of Kuujuaq in an area with no historic or archaeological record of muskox presence. Calves were 26 and 23% of the population in June 1983 and 1986, very similar to the 24.7% we recorded in 2018. The numbers are not quite directly comparable as the Québec surveys were carried out in June when calves would be two months old or less, whereas our survey was in late winter when calves were just under one year of age.

Growth rates of 23 and 24%/year were also recorded in small introduced muskox populations in northeast Alaska and the Seward Peninsula (Jingfors and Klein 1982). A calf:cow ratio of 89 calves:100 cows of reproductive age was observed in one of these Alaskan introduced herds on the Sadlerochit River in 1979, albeit the entire herd in this case was 58 animals. We recorded a very similar calf:cow ratio of 86 calves: 100 cows of reproductive age in March/April 2018, although again the surveys are not directly comparable as the Alaskan surveys were in May and June when new-born calves had been born just a few weeks earlier, whereas our survey was in late winter when calves of the previous year were approaching one year of age.

A further example of a muskox population increasing at near-maximum rates between 1977 and 1990 was described by Olesen (1993) in the Angujaartorfiup Nunaa range in West Greenland. In this population, the average calf percentage was 24.0% and the average annual population increment averaged 30% (Olesen 1993). Representation of sex and age classes in this population followed Olesen (1989) and included the same categories as the Alaska Fish and Game (2010) guide. The high representation of muskoxen that were 1, 2 and 3 years old observed by Olesen (1993) was similar to our results, although ground-based surveys of the West Greenland population varied in seasonal timing through the year.

The Banks Island muskox population increased from an estimated 3,800 in 1972 to 34,225 in 1989 (Gunn et al. 1991) and then further to 64,608 in 1994 (Larter and Nagy 2001). Over the period 1972-1989, the annual rate of increase was 13% (Gunn et al. 1991), a rapid increase although well below the more rapid rates of increase in the Alaskan, West Greenland, and Québec populations cited above and in the East Arm population (Cluff et al. 2019). The highest muskox calf percentages recorded on Banks Island during aerial surveys occurred in June 1971 (25.4%) and 1972 (23.1%) but they were generally lower in the 1980s (Gunn et al. 1991).

Overall, these comparisons suggest that the muskox population in the East Arm area of Great Slave Lake was increasing between 2010 and 2018 at rates similar to the highest population growth rates observed in Alaska (Jingfors and Klein 1982), northern Québec (Le Hénaff and Crête 1989) and West Greenland (Olesen 1993). The authors of these three studies indicated that mortality rates of all sex and age classes appeared to be minimal. The very high calf:cow ratio we documented in late winter (86.0 calves: 100 cows of reproductive age), together with the 25% annual growth rate 2010-2018, could only have happened if the pregnancy rate was very high and the mortality rates of calf, young and mature muskoxen were very low in the East Arm population.

Wolves are present in the East Arm region and two muskox kill sites were recorded in the Husky flying summarized in this report, one of them with two wolves present. Grizzly bears are also present in the region and they can be effective predators of calf and adult muskoxen (Reynolds et al. 2002). We assume that as of 2018, predation rates by wolves and bears in the East Arm muskox population were very low, either due to low numbers of wolves and bears or due to the predators not being used to hunting muskoxen as a “new” potential prey animal.

We suggest regular monitoring of the East Arm muskox population via population surveys augmented by composition surveys like the one we carried out in 2018. The near-maximal rate of increase documented between 2010 and 2018 is unlikely to last more than a few years. Rapid increases of endemic muskox populations have sometimes been followed by large declines: the muskox population on Banks Island increased rapidly in the 1970s and 1980s but then declined, with a very rapid decline between 36,676 muskoxen estimated in 2010 and 13,767 muskoxen estimated in 2014 (Davison et al. 2017). Die-offs attributed at least in part to the bacterial pathogen Erysipelothrix were implicated in the rapid decline of muskoxen on Banks Island (Kutz et al. 2015). Introduced populations in Alaska have sometimes increased rapidly during an initial phase (Jingfors and Klein 1982), but later predation (Reynolds et al. 2002), reduced productivity (Reynolds 2001) and a complex of health issues (Afema et al. 2017) have contributed to decline.

It is possible to use population survey and composition data to model the demography of muskox populations. A study with bison (Boulanger et al. 2015) found that it was possible to obtain survival rate estimates based on composition surveys in the absence of collar data. The demographic approach might allow further inference in trends in overall productivity as well as calf and sub-adult survival. This general approach would be most applicable when there is a time series of population and composition survey available.

Utility of a small fixed-wing photographic survey to classify muskoxen

Muskoxen have been classified to sex and age classes in many locations across their circumpolar range; in most studies ground-based methods have been used for classification. In Canada the Banks Island population has had relatively frequent monitoring of population size as well as composition (Gunn et al. 1991, Larter and Nagy 1999, 2001). Given the large ranges to be covered, aerial support (helicopter) has been used and classification has been mostly carried out from the ground with binoculars and spotting scopes between June and August (Larter and Nagy 1999, 2001). For small populations in Alaska, ground-based observation has been used (e.g. Jingfors and Klein 1982, Reynolds 2001). A colonizing muskox population in northern Quebec was surveyed using a combination of a helicopter to find groups and ground-based methods to count and classify the animals (Le Hénaff and Crête 1989). Photography to count and classify muskoxen from the air using a small, quiet fixed-wing aircraft has been used for several years for the Nelson and Nunivak Island populations in Alaska (e.g. Jones 2015a and b).

The survey described here was in part undertaken to test whether photography from a small fixed-wing aircraft could be used to classify sex and age classes in an increasing muskox population in the East Arm area of Great Slave Lake. Overall, we believe that the photographic method developed in Alaska was successfully adapted to the study area around the East Arm of Great Slave Lake. The area is remote and has no roads, and a substantial part of the muskox population is below tree-line. We were concerned that muskox groups in the forest would be difficult to photograph in such a way as to allow most animals to be classified, with a clear view of their heads and horns. Classification was unsuccessful in about a quarter of the muskox groups photographed, either because of thick cover or because we did not obtain clear photos of the heads of the muskoxen. In a few cases muskoxen were so closely bunched that some animals were obscured, and occasionally the animals were on the run. However, most muskox groups below tree-line were on ridges or small hills, in sparsely forested areas, or on edges of lakes or ponds, thus photos were possible. It appeared that most muskoxen were not overly alarmed by the Husky, which is small and relatively quiet and can fly at relatively low speeds. In many cases groups of muskoxen stood and faced the aircraft, allowing photos that showed their front ends clearly.

A photographic survey with a small fixed-wing aircraft to classify muskoxen has some advantages over methods that rely on a helicopter, as would be necessary otherwise because of the large, remote survey area. Strictly ground-based methods would not have been practical, given the large remote area to cover. The hourly rate of the Husky is about 1/3 to ¼ the hourly rate on a helicopter. The aircraft did not appear to greatly alarm the animals, as evidenced by many photos of muskoxen lined up standing to face the aircraft. In some photos some or most of the animals were bedded. High-resolution photos can be examined carefully and repeatedly on a computer monitor, and classification checked by more than one observer. The results form a long-term record, and can be shown to other observers (see Appendices 2 and 3), where results of visual-only surveys are only visible to the survey crew.

We recognize that not being able to classify all muskox groups from photos is a drawback, however we have no reason to think that the unclassified groups (25% of the groups photographed) were different in composition from the ones classified successfully. Of the 891 muskoxen classified in 56 groups, 57 animals (6.6%) remained unclassified, which introduces a degree of variability to the data. However, it is unlikely that classification of those 57 muskoxen would have substantively changed the results of the survey.

Habitat use by muskoxen in the East Arm area

This survey was not designed to assess habitat selection by muskoxen, and the habitat types we used in Table 1 are units of convenience based on the photos of muskox groups, not rigorously chosen habitat types. However, the photos did provide an indication of the kinds of terrain and vegetation that muskoxen south of tree-line in the East Arm area were using. Habitats in which muskox groups were found were defined at a broad scale as tundra, transition (tundra-boreal) and forest. Of the 56 groups, 39 (69.6%) were in the boreal forest, 10 (17.9%) were in transition areas, and 7 (12.5%) were on the tundra. The high proportion of groups photographed south of tree-line compared to tundra is largely a reflection of the flying effort, which was primarily in the boreal forest.

Habitats south of tree-line were further divided on a finer scale, and the numbers and proportions of groups (49 total) found in these habitats from most common to least common were: rocky ridge 17 (34.7%), sparse forest 14 (28.6%), lake edge 9 (18.4%), thick forest 8 (16.3%), and old burn 1 (2.0%). Overall, 83.7% of the muskox groups were in areas with either relatively open forests or openings due to rugged terrain (ridges or small hills). Ridges or small hills tended to be wind-swept with shallow snow cover, which likely offered good feeding conditions. We assume that muskoxen found near the edges of lakes or ponds used these areas to forage on sedges or grasses. Extensive feeding sign and trails in the snow around several groups suggested that muskoxen often remained at the same site for several days or weeks. A few muskox groups were in relatively thick boreal forest, but the most common type of terrain used by muskoxen was rugged areas – ridges or small hills – that were wind-swept with limited snow cover. It appeared that muskoxen would remain in these areas for several days or weeks.

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REFERENCES

Afema, J. A., K. B. Beckmen, S. M. Arthur, K. B. Huntington, and J. A. K. Mazet. 2017. Disease complexity in a declining Alaskan muskox (*ovibos moschatus*) population. Journal of Wildlife Diseases, 53(2):311-329.

Alaska Department of Fish and Game. 2010. Muskox: a guide to identification, hunting and viewing. Alaska Department of Fish and Game, PO Box 1148, Nome, Alaska.

Boulanger, J., K. G. Poole, and C. DeMars. 2015. Review of bison monitoring program for the Northwest Territories. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report (in prep.)

Cluff, D., and co-authors. 2019. A muskox survey in the East Arm area of Great Slave Lake, Northwest Territories, Canada, in late winter 2018. Department of Environment and Natural Resources, Government of Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report (in prep.).

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. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 270.

Gray, D.R. 1987. The muskoxen of Polar Bear Pass. Markham, Ontario: Fitzhenry and Whiteside.

Gunn, A., C. Shank and B. McLean. 1991. The history, status and management of muskox on Banks Island. Arctic 44(3): 188-195.

Henrichsen, P., and H. Grue. 1980. Age criteria in the muskox (*Ovibos moschatus*) from Greenland. Danish Review of Game Biology 11:3–15.

Jingfors, K.T., and D.R. Klein. 1982. Productivity in recently established muskox populations in Alaska. Journal of Wildlife Management 46:1092–1096.

Jones, P. 2015a. 2015 Nelson Island Muskox Survey Results. Alaska Department of Fish and Game, Division of Wildlife Conservation Northwest, Bethel, Alaska, Unpublished report, 7 pp.

Jones, P. 2015b. 2015 Nunivakand Island Muskox Survey Results. Alaska Department of Fish and Game, Division of Wildlife Conservation Northwest, Bethel, Alaska, Unpublished report, 4 pp.

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

Larter, N.C., and J.A. Nagy. 1999. Sex and age classification surveys of muskoxen on Banks Island, 1985–1998: A review. Department of Resources, Wildlife and Economic Development, Government of Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report No.113.

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.

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

Manly, B. F. J. 1997. Randomization and Monte Carlo Methods in Biology. 2nd edition. Chapman and Hall, New York.

Olesen, C.R., and H. Thing, H. 1989. Guide to field classification by sex and age of the muskox. Canadian Journal of Zoology 67:1116–1119.

Olesen, C. R. 1993. Rapid population increase in an introduced muskox population, West Greenland. Rangifer 13:27-32.

QGIS Foundation. 2015. QGIS: A free and open geographic information system (www.qgis.org).

R Development Core Team. 2009. R Foundation for Statistical Computing, Vienna, Austria.

Reynolds, P.E. 2001. Reproductive patterns of female muskoxen in northeastern Alaska. Alces 37(2):403-410.

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

Tener, J.S. 1965. Muskoxen in Canada: a biological and taxonomic review. Canadian Wildlife Service Monograph Series 2. Queen’s Printer, Ottawa, Ontario, Canada.

Appendix 1. Composition, habitat types, and locations of muskox groups classified in East Arm area of Great Slave Lake, NWT, March-April 2018

C=Calf (born previous year), F2=Female 2 years old, F3=Female 3 years old, F4=Female at least 4 years old; UF= Female Unknown Age, F All=All Females, M2=Male 2 years old, M3=Male 3 years old, M4=Male at least 4 years old, M All=All Males, U=Unknown.

Date	Group #	C	F2	F3	F4	UF	F All	M2	M3	M4	M All	U	Total	Habitat	Fine Habitat	Latitude	Longitude
March 4 2018	1	8	0	4	5	1	10	0	2	2	4	0	22	transition	Sparse forest	62.899722	-109.18333
March 4 2018	2	5	1	2	0	0	3	0	4	4	8	1	17	forest	Sparse forest	62.973333	-108.99778
March 4 2018	3	4	0	2	7	3	12	4	2	5	11	2	29	tundra	Tundra	62.971111	-109.00278
March 4 2018	4	7	2	0	6	3	11	1	1	2	4	1	23	transition	Sparse forest	62.9075	-108.81167
March 4 2018	5	12	1	0	5	7	13	5	2	0	7	8	40	transition	Sparse forest	62.935	-109.27389
March 4 2018	6	9	0	0	5	4	9	2	2	0	4	14	36	transition	Sparse forest	62.92	-109.30722
March 4 2018	7	6	2	1	6	0	9	4	2	0	6	1	22	transition	Sparse forest	62.890833	-109.38194
March 12 2018	8	6	2	2	4	0	8	2	2	1	5	0	19	forest	Lake edge	62.65148	-108.88193
March 12 2018	9	5	3	1	3	0	7	4	2	1	7	1	20	forest	Lake edge	62.502838	-108.71008
March 12 2018	10	0	0	0	0	0	0	0	0	5	5	0	5	forest	Lake edge	62.314269	-108.41204
March 12 2018	11	0	0	0	0	0	0	0	0	2	2	0	2	forest	Sparse forest	62.025556	-109.15778
March 12 2018	12	0	0	0	0	0	0	0	0	2	2	0	2	forest	Sparse forest	61.947906	-109.18696
March 12 2018	13	0	0	0	0	0	0	0	0	3	3	0	3	forest	Lake edge	61.934167	-108.69389
March 12 2018	14	2	1	0	3	0	4	3	1	2	6	1	13	forest	Rocky ridge	No wpt; near group 13	
March 12 2018	15	0	0	0	0	0	0	0	0	3	3	0	3	forest	Rocky ridge	No wpt; near group 13	
March 13 2018	16	4	1	0	3	0	4	3	0	5	8	0	16	forest	Rocky ridge	62.675245	-109.75054
March 13 2018	17	0	0	0	0	0	0	0	0	2	2	0	2	forest	Rocky ridge	62.551328	-110.18407
March 13 2018	18	2	0	0	2	0	2	0	4	1	5	0	9	forest	Thick forest	62.087986	-111.41419
March 13 2018	19	6	3	3	5	1	12	3	3	3	9	1	28	forest	Rocky ridge	62.036803	-111.40877
March 13 2018	20	1	1	0	2	0	3	0	0	1	1	0	5	forest	Thick forest	61.97215	-109.26825
March 13 2018	21	0	0	0	0	0	0	0	0	2	2	0	2	forest	Thick forest	61.934436	-109.35495
March 13 2018	22	5	2	4	3	1	10	1	0	0	1	0	16	forest	Old burn	61.94115	-110.09775
March 13 2018	23	2	2	2	3	1	8	1	3	0	4	1	15	forest	Thick forest	61.94069	-110.22019
March 13 2018	24	0	0	0	0	0	0	0	0	1	1	0	1	forest	Thick forest	62.16946	-109.80263
March 13 2018	25	0	0	0	0	0	0	0	0	3	3	0	3	forest	Lake edge	62.66915	-109.42112

Date	Group #	C	F2	F3	F4	UF	F All	M2	M3	M4	M All	U	Total	Habitat	Fine Habitat	Latitude	Longitude
March 14 2018	26	0	0	0	0	0	0	0	0	3	3	0	3	forest	Rocky ridge	62.35855	-108.78146
March 14 2018	27	4	2	0	2	2	6	2	0	3	5	2	17	forest	Sparse forest	62.36656	-108.77311
March 14 2018	28	5	3	2	3	0	8	2	1	3	6	1	20	transition	Rocky ridge	62.16912	-108.57919
March 14 2018	29	0	0	0	0	0	0	0	0	2	2	0	2	forest	Thick forest	61.56935	-109.25533
March 14 2018	30	0	0	0	0	0	0	0	0	2	2	0	2	forest	Thick forest	61.67321	-109.15426
March 14 2018	31	2	2	0	2	0	4	3	1	1	5	1	12	transition	Sparse forest	61.76283	-108.83995
March 14 2018	32	2	0	2	1	1	4	0	0	3	3	0	9	transition	Sparse forest	61.74727	-109.24565
March 14 2018	33	4	4	1	8	2	15	3	2	1	6	1	26	forest	Thick forest	62.21467	-110.25206
March 16 2018	34	5	3	1	2	0	6	3	0	1	4	0	15	forest	Rocky ridge	61.95261	-111.60884
March 16 2018	35	3	1	1	2	1	5	2	2	0	4	0	12	forest	Rocky ridge	No wpt; near group 36	
March 16 2018	36	8	3	6	3	0	12	4	5	2	11	6	37	forest	Rocky ridge	61.91464	-111.7488
March 16 2018	37	6	1	1	0	0	2	1	2	0	3	0	11	forest	Rocky ridge	61.92572	-111.72383
March 16 2018	38	3	2	0	0	1	3	2	4	3	9	1	16	forest	Rocky ridge	61.91447	-111.66896
March 16 2018	39	0	0	0	0	0	0	0	0	1	1	0	1	forest	Rocky ridge	61.76171	-111.81396
March 16 2018	40	3	2	0	5	1	8	2	4	3	9	3	23	forest	Lake edge	61.74919	-111.268
March 16 2018	41	0	0	0	0	0	0	0	0	1	1	0	1	forest	Sparse forest	61.75221	-111.10798
March 16 2018	42	0	0	0	1	0	1	0	0	5	5	0	6	forest	Lake edge	61.56901	-110.9265
March 16 2018	43	0	0	0	0	0	0	0	0	1	1	0	1	forest	Rocky ridge	61.63697	-112.1234
March 16 2018	44	3	2	0	1	1	4	3	2	0	5	3	15	forest	Lake edge	61.68465	-110.84001
March 16 2018	45	8	6	1	4	0	11	2	6	0	8	3	30	forest	Rocky ridge	No wpt; near group 38	
March 19 2018	46	10	5	4	8	0	17	0	4	5	9	0	36	forest	Lake edge	61.83735	-109.27361
March 19 2018	47	5	4	5	5	0	14	1	0	3	4	1	24	forest	Rocky ridge	61.82033	-109.72696
April 7 2018	48	12	5	7	4	0	16	6	1	4	11	0	39	tundra	Tundra	63.21617	-109.88883
April 7 2018	49	13	5	2	3	1	11	6	2	0	8	1	33	tundra	Tundra	63.46267	-109.71757
April 7 2018	50	12	7	2	4	1	14	5	3	0	8	0	34	tundra	Tundra	No wpt; near group 49	
April 7 2018	51	0	0	0	0	0	0	0	0	8	8	0	8	tundra	Tundra	63.47253	-108.76001
April 7 2018	52	10	0	5	10	0	15	2	2	4	8	0	33	tundra	Tundra	63.34973	-108.34719
April 7 2018	53	2	3	5	7	0	15	0	0	5	5	0	22	tundra	Tundra	62.8285	-107.13645
April 7 2018	54	1	3	1	3	0	7	1	0	0	1	0	9	transition	Sparse forest	62.80488	-107.96432

Date	Group #	C	F2	F3	F4	UF	F All	M2	M3	M4	M All	U	Total	Habitat	Fine Habitat	Latitude	Longitude
April 7 2018	55	10	3	1	8	2	14	5	1	1	7	3	34	transition	Rocky ridge	62.84955	-109.01676
April 19 2018	56	0	0	0	0	0	0	0	0	7	7	0	7	forest	Sparse forest	61.91782	-109.80638
Totals		215	87	68	148	34	337	88	72	122	282	57	869				