



LATE WINTER 2024 AERIAL MUSKOX ABUNDANCE SURVEY, EAST ARM OF GREAT SLAVE LAKE

JAMES HODSON, STEFAN GOODMAN

ENVIRONMENT AND CLIMATE CHANGE, GOVERNMENT OF THE
NORTHWEST TERRITORIES

2026

MANUSCRIPT NUMBER 342

The content(s) of this paper are the sole responsibility of the author(s).

Government of
Northwest Territories

ABSTRACT

From March 2-27, 2024, a fixed-wing aerial muskox abundance survey was undertaken around the East Arm of Great Slave Lake using a distance-based sampling design with survey lines spaced 10 km apart. A total of 9,348 km was flown on 54 transects within a 98,665 km² area. During the survey, including observations made on and off transect, 2,387 muskoxen were recorded in 136 groups, with group sizes ranging from one to 76 individuals, and a mean group size of 17.6 muskoxen. When considering only those groups observed while flying on transect, a total of 2,073 muskoxen were counted in 120 groups. The study area and transect lines were split into two strata, Taiga and Tundra, using the treeline, and distance sampling models were then used to estimate the density and abundance of muskox in each stratum as well as a pooled (total) estimate for the entire survey area. Several candidate models were considered that included variables potentially affecting detection such as aircraft type, percent tree cover, and muskox group size. Model-averaged estimates for the 2024 muskox survey predicted a total of 9,542 muskoxen (95% CI: 6,334-12,751; CV: 17.2%) in the study area, and a density of 9.67 muskoxen/100 km² (95% CI: 6.42-12.92; CV: 16.5%). To evaluate whether muskox abundance and density had changed significantly since the last survey completed in 2018, we fit detection models and compared estimates for a reduced 2024 study area that more closely matched the 2018 survey area. Model-averaged predictions for the reduced 2024 study area (82,348 km²) were 9,168 muskoxen (95% CI: 6,212-12,125; CV: 16.5%). and a density of 11.13 muskoxen/100 km² (95% CI: 7.54-14.72; CV: 16.5%). Model-averaged predictions for the 2018 muskox survey (79,758 km² area) were 8,029 muskoxen (95% CI: 4,630-11,430; CV: 21.6%) and a density of 10.07 muskoxen/100 km² (95% CI: 5.80-14.33; CV: 21.6%). Using bootstrapping, differences in density estimates between the reduced 2024 study area and the 2018 study area from a detection model that included a stratum-year (Taiga and Tundra) covariate indicated that in both survey years muskox density was significantly higher in the Taiga stratum than the Tundra stratum (two-tailed *p*-value = 0.04), but, between years (2024 vs. 2018), differences in muskox density within the same stratum were not significant (Taiga: two-tailed *p*-value = 0.54; Tundra: two-tailed *p*-value = 0.42). Although we observed muskox in areas further west than previously recorded, when considering similar survey extents, the muskox population around the East Arm of Great Slave Lake does not appear to have significantly increased since 2018.

TABLE OF CONTENTS

Abstract.....	iii
List of Figures	v
List of Tables	vii
List of Photos	ix
Introduction	1
Methods	3
Survey Design and Area	3
Survey Timing and Conditions	4
Survey Methods	5
Data Analysis.....	5
Results	9
2018 Muskox Observations.....	9
2024 Muskox Observations.....	9
Other Wildlife Species Incidentally Observed in 2024.....	10
Summary of Data Used in Distance Analyses	11
Left and Right Truncation of the Detection Data	12
Assessment of Different Key Functions and Adjustment Terms	13
Covariates Influencing Muskox Detection	16
Influence of Detection Covariates – 2018 Muskox Survey	17
Influence of Detection Covariates – 2024 Muskox Survey	17
Muskox Abundance and Density Estimates – 2018 vs. 2024	18
Muskox Abundance and Density Estimates – 2018 vs. Reduced 2024 Study Area	23
Discussion	30
Acknowledgements	34
Literature Cited.....	35
Appendix A: Sample Photos from the 2024 Muskox Aerial Survey – East Arm of Great Slave Lake	37
Appendix B: Supplementary Figures	42

LIST OF FIGURES

Figure 1. Study area and transects flown during the 2018 muskox aerial survey around the East Arm of Great Slave Lake.....	3
Figure 2. Study area and transects flown during the 2024 muskox survey area around the East Arm of Great Slave Lake.....	4
Figure 3. All muskox groups recorded (on-transect and incidental) during the 2018 aerial muskox survey - East Arm, Great Slave Lake.....	9
Figure 4. All muskox groups recorded (on-transect and incidental) during the 2024 aerial muskox survey - East Arm, Great Slave Lake.....	10
Figure 5. Other wildlife species incidentally observed during the 2024 aerial muskox survey - East Arm, Great Slave Lake.....	11
Figure 6. Frequency of perpendicular detection distances (km) of muskox groups from flight lines during 2018 and 2024 aerial surveys.....	12
Figure 7. Plots of fitted detection functions and a histogram of observed detection distances using the full (on-transect) 2018 and 2024 muskox observation datasets.....	13
Figure 8. Comparison of detection functions with a hazard-rate key and uniform key with cosine adjustment fitted to the 2024 right-truncated muskox (mx) survey data.....	15
Figure 9. Quantile-quantile (Q-Q) plots comparing the fitted cumulative distribution function (cdf; y-axis) of the detection function to the distribution of the observed data (empirical cumulative distribution function [cdf]; x-axis).....	16
Figure 10. Muskoxen density estimates (muskoxen/100 km ²) (points) and 95% CIs for Taiga and Tundra survey strata, and ‘Total’ survey areas, from top detection models for the 2018 and full 2024 survey areas.	19
Figure 11. Muskox abundance estimates and 95% CIs from top detection models for Taiga and Tundra survey strata, and ‘Total’ survey areas, for the 2018 and full 2024 survey areas.	20
Figure 12. Reduced 2024 muskox survey area boundaries and transects used to make more direct comparison of density and abundance estimates to the 2018 muskox survey.	23
Figure 13. Comparison of 2018 and reduced 2024 muskox survey area extents and survey strata polygons.	24
Figure 14. Muskoxen density estimates (muskoxen/100 km ²) and 95% CIs for Taiga and Tundra survey strata, and ‘Total’ survey areas, from top detection models for the 2018 and reduced 2024 survey areas.	27

Figure 15. Muskoxen abundance estimates and 95% CIs from top detection models for Taiga and Tundra survey strata, and ‘Total’ survey areas, for the 2018 and reduced 2024 survey areas.	28
Figure 16. Comparison of muskox density estimates (muskoxen/km ²) between strata (Taiga and Tundra) within years and between survey years (2018 vs. 2024) within stratum using a bootstrapping procedure.	29
Figure 17. Extent of the 2024 muskox survey area relative to the U/MX/01 wildlife management zone which is open to Resident and outfitter muskox harvest in the southeast NWT.....	32

LIST OF TABLES

Table 1. Other wildlife species incidentally observed during the 2024 aerial muskox survey - East Arm, Great Slave Lake.....	11
Table 2. Summary of survey effort (total km's flown on transect), survey area size, number of muskox groups recorded (n), total number of muskoxen observed, and perpendicular detection distances (km) of muskox groups from flight lines during aerial surveys around the East Arm of Great Slave Lake in 2018 and 2024.....	12
Table 3. Model comparison based on AIC of different combinations of detection function key and adjustment series using right-truncated 2018 and 2024 muskox survey data.	14
Table 4. Candidate detection function models tested on the 2018 and 2024 muskox survey datasets to evaluate the influence of factors influencing detection probability.....	16
Table 5. Comparison of support for candidate detection models with different detection covariates based on AICc using 2018 muskox survey data.	17
Table 6. Comparison of support for candidate detection models with different detection covariates based on AICc using 2024 muskox survey data.	18
Table 7. Predicted muskox density (muskoxen/ km ²) in 2018 from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates.....	21
Table 8. Predicted muskox abundance in 2018 from top-performing detection models, including standard error (SE), coefficient of variation ('cv') and lower and upper 95% CIs (LCL and UCL) around the estimates.	21
Table 9. Predicted muskox density (muskoxen/100 km ²) in 2024 from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates.....	22
Table 10. Predicted muskox abundance in 2024 from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates.	22
Table 11. Comparison of support for candidate detection models with different detection covariates based on AICc using the reduced 2024 muskox survey dataset.....	24
Table 12. Predicted muskox density (muskoxen/100 km ²) for the reduced 2024 survey area from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates.....	26

Table 13. Predicted muskox abundance in the reduced 2024 survey area from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates..... 26

LIST OF PHOTOS

Photo 1: Survey aircraft (Cessna 180 and Cessna 185) refuelling at a fuel cache on Whitefish Lake.....	34
Photo 2. Aerial photo of muskoxen in sparsely treed habitat in the Taiga stratum.....	37
Photo 3. Aerial photo of muskoxen in the Tundra stratum.....	38
Photo 4. Aerial photo of muskoxen in the Tundra stratum.....	38
Photo 5. Aerial photo of muskoxen in the Tundra stratum.....	39
Photo 6. Aerial photo of muskoxen in moderately treed habitat in the Taiga stratum.....	39
Photo 7. Aerial photo of muskoxen in sparsely treed habitat in the Taiga stratum.....	40
Photo 8. Aerial photo of muskoxen in moderately treed habitat in the Taiga stratum.....	40
Photo 9. Aerial photo of muskoxen in the Tundra stratum.....	41
Photo 10. Aerial photo of muskoxen in densely treed habitat in the Taiga stratum.....	41

INTRODUCTION

Muskox (*Ovibos moschatus*) populations in mainland Northwest Territories (NWT) appear to be increasing and re-occupying parts of their historical southern range, in some cases extending further south of the treeline than previously documented in the 1800s (Gunn et al. 2024, Rentmeister 2024). Periodic aerial surveys are undertaken to estimate muskox abundance in the North Slave region of the NWT. In addition to tracking muskox population trends and changes in late-winter distribution, the population estimates from these surveys are used to inform management decisions about the number of tags allocated to Resident and Non-Resident/Non-Resident Alien harvesters within Wildlife Management Zone U/MX/01, which encompasses a large area to the south and east of the northern shore of the East Arm of Great Slave Lake (GNWT 2024). Currently, up to 55 tags are issued to Resident harvesters on a draw system to harvest muskox within this zone each year, with another 30 tags issued to outfitters for guided hunting of Non-Resident and Non-Resident Alien harvesters.

The first systematic survey between the East Arm of Great Slave Lake (GSL) and the Thelon Game Sanctuary was flown in 1989, and repeat surveys covering this general area have been conducted in 1998, 2010, and 2018 (see Figure 25 in Gunn et al. 2024). Results from these surveys suggested that the muskox population increased between 1989 and 1998 and then decreased between 1998 and 2010 (Gunn et al. 2024). The 2018 survey area was expanded westward along the shore of GSL compared to 2010 to capture the westward expansion of the muskox population. Results from the 2018 survey indicated a substantial (~6-fold) increase from the 2010 estimate, equating to a roughly 21% population increase per year (Cluff 2018, Adamczewski et al. 2021, Gunn et al. 2024). An additional, separate, aerial photographic composition survey was completed in 2018 to identify proportions of muskox sex and age classes in this rapidly growing population (Adamczewski et al. 2021). That survey recorded a calf:cow ratio of 86 calves per 100 females aged three years and older, which indicated a population growing at a near-maximum rate and suggested that pregnancy rates and survival rates of adults and calves were very high (Adamczewski et al. 2021).

In March 2024, another aerial muskox abundance survey was conducted using the same methodology and survey transects as those used in 2018. Additional transects were added to the 2018 survey area to capture the full extent of Thaidene Nëné National Park Reserve, Territorial Protected Area and Territorial Wildlife Conservation Area, as well as a new area to the west to capture the proposed Lockhart All-Season Road project. The Lockhart All-Season Road (LASR) Project was being proposed by the Government of the Northwest Territories (GNWT) as a 174 km all-season public highway based on a preliminary alignment running from Highway 4 at Tibbitt Lake to Lockhart Lake.

This report also includes a re-analysis of the 2018 muskox survey data to provide a more direct comparison of results from the 2018 and 2024 surveys to assess the degree of change in muskox density and abundance in the region.

The 2024 aerial survey was conducted under GNWT Wildlife Research Permit WL501252 and Parks Canada Agency Research and Collection Permit TDNNPR-2024-45704.

METHODS

Survey Design and Area

A distance-based sampling design (Buckland et al. 2001) was used to conduct an aerial survey to estimate density and abundance of muskoxen. In this method, the distribution of the number of observations made at different distances to survey transects is used to estimate a detection function to model how the probability of recording observations decreases as a function of distance from the line. The detection function is then used to estimate the density of muskoxen within different strata of the study area while accounting for decreasing likelihood of recording animals that are farther from the transect.

The 2018 East Arm of GSL muskox aerial survey study area and transects were used as the basis for the 2024 survey. A map of the 2018 study area and transects flown is provided in Figure 1. Survey transects were spaced 10 km apart and oriented east to west in the area to the east of Artillery Lake and Łutsel K'e, whereas to the north of Great Slave Lake and west of Artillery Lake, transects were oriented southwest to northeast.

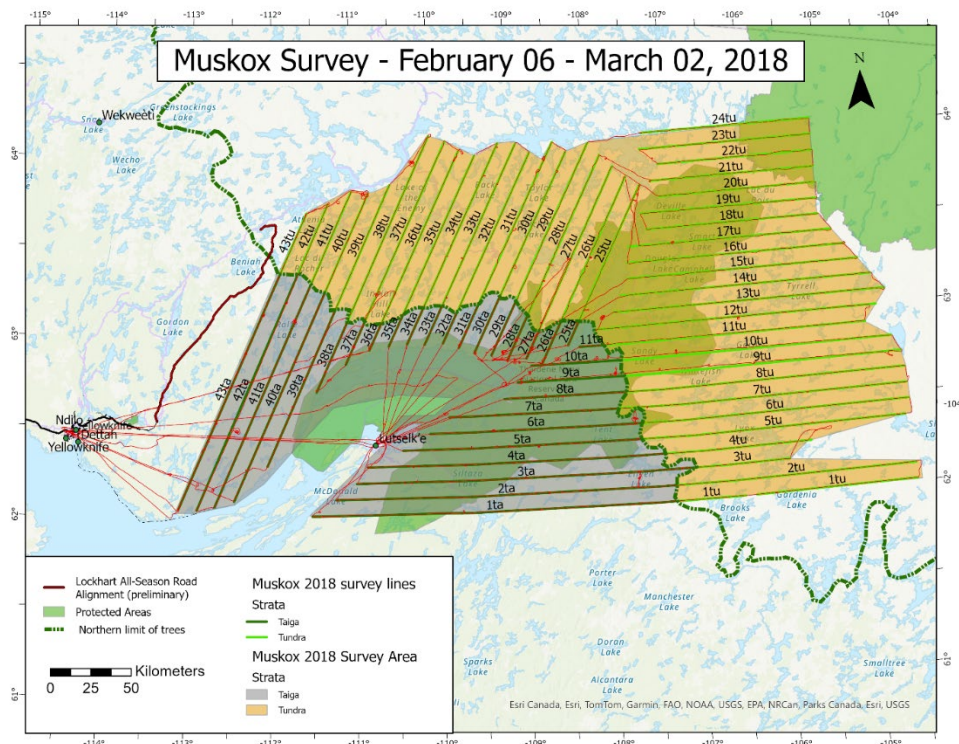


Figure 1. Study area and transects flown during the 2018 muskox aerial survey around the East Arm of Great Slave Lake. The study area and survey lines were further divided into Taiga and Tundra strata using the treeline as the dividing line.

The 2024 survey area was expanded westward with nine new transects added to cover the area surrounding the preliminary alignment of the proposed LASR project, and an additional transect

was added at the southern boundary of the study area to cover the southern extent of the Thaidene Nënë National Park Reserve, Territorial Protected Area and Territorial Wildlife Conservation Area (TDN) (Figure 2).

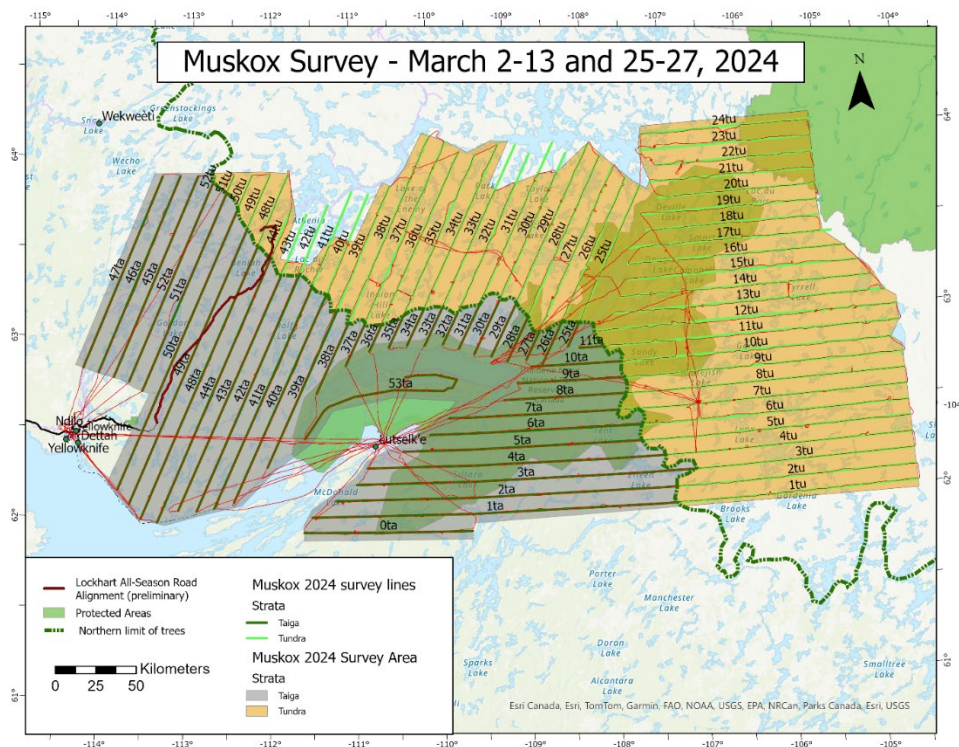


Figure 2. Study area and transects flown during the 2024 muskox survey area around the East Arm of Great Slave Lake. The survey area and transects were further stratified into Taiga and Tundra strata as in 2018.

The 2018 survey covered an area of 79,758 km², with 43 transects flown totaling 7,617 km. The 2024 survey covered an area of 98,665 km², with 54 transects flown totaling 9,348 km.

Survey Timing and Conditions

The aerial survey mainly occurred from March 2-13, 2024, and involved two aircraft (a Cessna 180 from Goose Flying Service piloted by S. Mjateski and a Cessna 185 from Nahoni Air piloted by D. Drinnan). The survey was based out of Łutsel K'e from March 2-9, and the planes then repositioned to Yellowknife to complete the westernmost survey transects on March 11-13. Navigation and data recording were completed by S. Goodman and J. Hodson from GNWT, Department of Environment and Climate Change (ECC). Observers from Łutsel K'e included Charlie Catholique (Łutsel K'e Dene First Nation (LKDFN)), Gabriel Enzoe (LKDFN), Joseph Parsch (LKDFN), and Aileen Drybones (LKDFN; TDN Guardians). For the flights based out of Yellowknife, observers included Janik'ah (Jericho) Camsell (Tłıchų), Orna Phelan (North Slave Metis Alliance (NSMA)), Dylan Coumont (NSMA), Darren Marlow (Yellowknife Dene First Nation (YKDFN)), Jonathan Mackenzie (YKDFN), Arianne Depot-Bernier (ECC) and Bethany Nesbitt (ECC).

We had three weather days (March 6, 10 and 12) where we could not fly transects, and one plane that had mechanical issues and was unavailable between March 4-7. Consequently, a few lines in the northeastern portion of the survey area could not be completed during early March and were later completed between March 25-27 using an Aviat Husky (Hoarfrost River Huskies Ltd.) piloted by D. Olesen (data was also recorded by the pilot).

Temperatures during the survey ranged from -3°C to -30°C. Skies were clear, and visibility was rated as good on most survey days, except three days with cloudy/overcast conditions which resulted in poorer visibility. Additionally, some northern portions of eight planned transects could not be completed due to ice fog conditions in those areas (Figure 2).

Survey Methods

The distance sampling method involves measuring the perpendicular distance of each muskox observation from the survey lines (transects). In both surveys, GPS locations were recorded on the transect when a group of muskoxen was first observed, and the aircraft would then break off the transect to take a GPS location directly overhead of where the group was observed. Large groups of muskoxen were photographed (see [Appendix A](#) for examples of survey photos), and the photographs were later used to verify and correct field counts using the software 'ImageJ' to tag and count each muskox. GPS points were then used to measure the perpendicular distance (in km) between the aircraft's flight line (based on the track log from the GPS) and each muskox group using the GIS software ArcGIS Pro 3.2 (ESRI, Redlands, CA). During the 2024 survey, percent (%) tree cover around each muskox observation was recorded in classes of 0%, 25%, 50%, 75% and 100%. In cases where it was not recorded in the field, tree cover was later determined from the photos of the muskox group (n=11), or if there was no photo, it was estimated from satellite imagery (n=1).

Incidental sightings of other species (e.g. caribou, moose and wolves) were also recorded using GPS, with group sizes counted or estimated where feasible. Groups of muskoxen seen while ferrying to and from bases of operation and fuel caches, or when ferrying between survey transects, were recorded, but the aircraft did not change course to fly over these incidental groups to record a precise location over them.

Data Analysis

Distance sampling methods (Buckland et al. 2001, Thomas et al. 2010) were used to estimate density and abundance of muskoxen. In this method, the distribution of the number of observations made at different distances to survey transects is used to estimate a detection function to model how the probability of recording observations decreases as a function of distance from the line. The detection function is then used to infer how many groups of muskoxen were missed and thereby estimate the density and abundance of muskoxen within different strata of the study area (Miller et al. 2019).

Data analysis was completed using the '*Distance*' package (version 2.0.0; Miller et al. 2019) in version 4.4.2 of program R (R Core Team 2024) to produce density and abundance estimates of muskoxen for each survey year. This requires specification of the area (in km²) of each strata surveyed within the overall survey area, and the length of each line surveyed within each strata as a measure of survey effort. For the analysis, separate 'Region Tables', 'Sample Tables', and 'Observation Tables' were created for each survey year. 'Region Tables' specify the name and size of each strata surveyed. 'Sample Tables' specify the unique Transect IDs and length (km) of each survey transect flown within each strata. 'Observation Tables' contain each muskox group observed, along with the group size. Each observation is tagged by the Transect ID and Strata, and other covariates such as aircraft type and percent forest cover. Additional rows for surveyed transects without muskox observations are included in the 'Observation Tables', but the 'group size' field is left blank.

To help ensure comparability of predicted muskox density and abundance from the 2018 and 2024 surveys, only those muskox observations made "on-transect" were included in the analysis. Incidental observations made while ferrying to and from bases of operation and fuel caches, or when ferrying between survey transects, were not included. Note that this approach differs from Rentmeister (2024), who included muskox observations made when transiting between transects in her analysis of the 2018 muskox survey data.

The 2018 and 2024 survey data were analyzed separately as there was a sufficient number of muskox detections in each survey year to fit detection functions to each year separately.

Data were first screened using histograms of number of muskox groups recorded versus perpendicular detection distance from the aircraft flight line to determine the need for right and left truncation of the distance sampling data. In many cases, animals directly under the plane are invisible to observers, causing a "blind spot" in this area. The blind spot under the plane and the method of recording distances means that observations in the immediate area of the plane are potentially underrepresented in the dataset. Distance methods assume that the probability of detection = 1 on the transect line and therefore inclusion of the full dataset could bias estimates. Lower detection rates very close to the plane could indicate the need for left truncation of those observations.

Data were also screened to determine if right truncation was required. Right truncation eliminates outlier observations that are at much further distances than most observations and therefore may overly influence model fitting. Buckland et al. (2001) suggest setting a right truncation distance that results in having a dataset with <5% of observations with a detection probability of <0.2, and none that have a detection probability <0.1. In Rentmeister's (2024) analysis of the 2018 muskox survey data, a right truncation distance of 1.9 km was identified, based on where detection probability fell between 0.15 or 0.10 or below from a detection model fit to all of the data. To identify and confirm appropriate right truncation distances for the 2018 and 2024 data, distance models without covariates were run using a half-normal key without adjustment terms using all

observations. The predictions from the models were then plotted to assess where detection probabilities fell below 0.10 to inform the right truncation distance.

After determining appropriate left and right truncation distances, a series of candidate detection models were fit to each dataset (2018 and 2024) using different combinations of key functions and adjustment terms to identify the combination that best fit each dataset. Key functions determine the general shape of the detection function. Options for the key function include uniform ('unif'), half-normal ('hn'), and hazard-rate ('hr'). There are three options for adjustment terms which further influence the shape of the detection curve: cosine ('cos'), Hermite polynomial ('herm'), or polynomial ('poly'). Package '*Distance*' will identify the optimal number of adjustment terms to include using Akaike's Information Criterion (AIC) (Burnham and Anderson 2003) if the 'nadj' option is left blank in the model specification (Miller et al. 2019).

In cases where more than one key-function/adjustment term combination provided a similarly good fit to the data (those models that were within two Δ AIC of the top model), model fit was further assessed visually using Q-Q plots and with Cramér-von Mises tests, where a non-significant test (p-value >0.05) indicates failure to reject the null hypothesis that the model fits the data.

Once the appropriate key function and adjustment terms to use for each dataset were determined, the influence of covariates potentially affecting the detection of muskox groups were tested. Detection covariates included muskox group size, survey strata (Taiga and Tundra), aircraft type, and percent tree cover (only measured in 2024). Models including both group size and survey strata, and group size and tree cover were also tested. Survey strata and tree cover were not included as covariates in the same model, as they were likely to be highly correlated, because tree cover was very low to absent within the Tundra strata (see [Appendix B](#), Figure B4). Accounting for group sizes (referred to as 'cluster' size in the model outputs) of muskoxen as a detection covariate is important because the average size of groups recorded during the survey is likely an overestimate of the average size of groups in the population (Centre for Research into Ecological and Environmental Modelling 2024). As small groups are unlikely to be detected at great distances, it can potentially bias the estimate of average group size, which in turn can lead to a positive bias in the number of individuals estimated in the population. Candidate models including detection covariates were compared against a 'naïve' model without covariates using AIC adjusted for small sample sizes (AICc).

Muskox density and abundance predictions from the top-performing models from candidate model sets were used to assess the degree of change in the muskox population from the 2018 to 2024 survey. The '*ggplot2*' package (Wickham 2016) was used to produce plots of predicted muskox density and abundance with associated confidence intervals (CI). Maps of the study area, survey transects, and muskox and other wildlife observations were produced using ArcGIS Pro 3.2 (ESRI, Redlands, CA). In cases where there was more than one plausible model predicting muskox abundance and density (i.e., several models within two Δ AIC of the top model), model-averaged

estimates of abundance and density were generated using the '*AICcmodavg*' package (Mazerole 2023).

RESULTS

2018 Muskox Observations

In total, 1,656 muskoxen were seen in 88 groups that ranged from 1 to 95 muskoxen during the 2018 aerial survey (Figure 3). This includes groups recorded on-transect, as well as those seen while ferrying to and from bases of operation and fuel caches, and between survey transects (Cluff 2018). Average group size was 18.8 muskoxen, while the median group size was 15 (Cluff 2018).

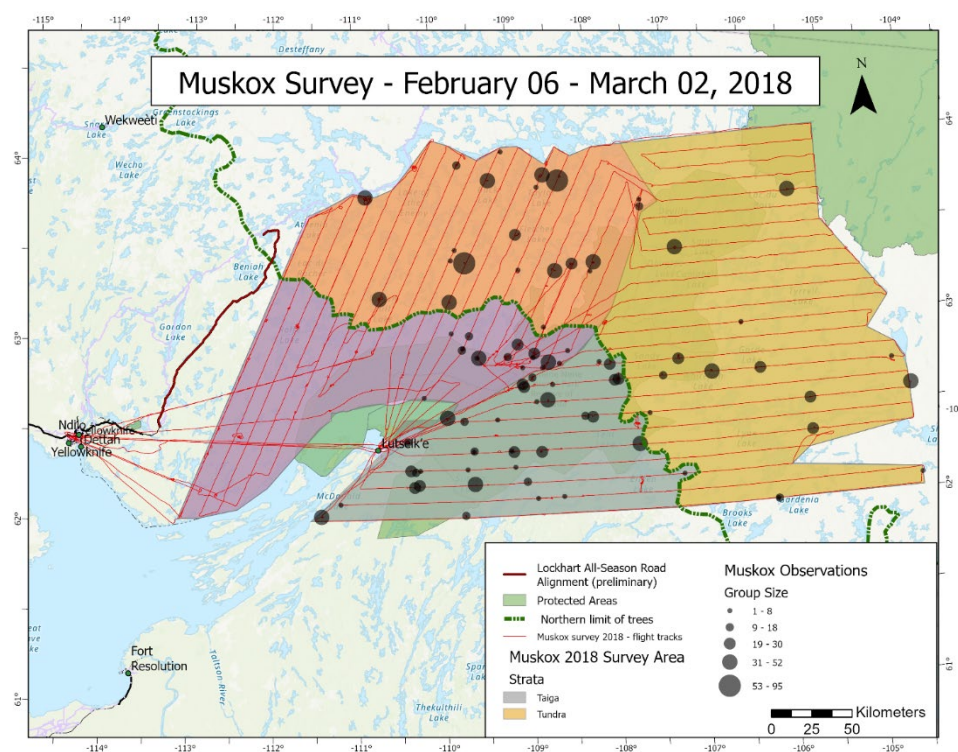


Figure 3. All muskox groups recorded (on-transect and incidental) during the 2018 aerial muskox survey - East Arm, Great Slave Lake.

2024 Muskox Observations

In 2024, a total of 2,387 muskoxen were recorded in 136 groups, with group sizes ranging from one to 76 individuals (Figure 4). Group size averaged 17.6 muskoxen, and median group size was 12. This includes 16 groups of muskoxen totaling 314 individuals that were recorded incidentally while ferrying to and from bases of operation and fuel caches, and between survey transects. When considering only those muskox groups observed while flying on transect, a total of 120 groups of muskoxen totaling 2,073 individuals were recorded.

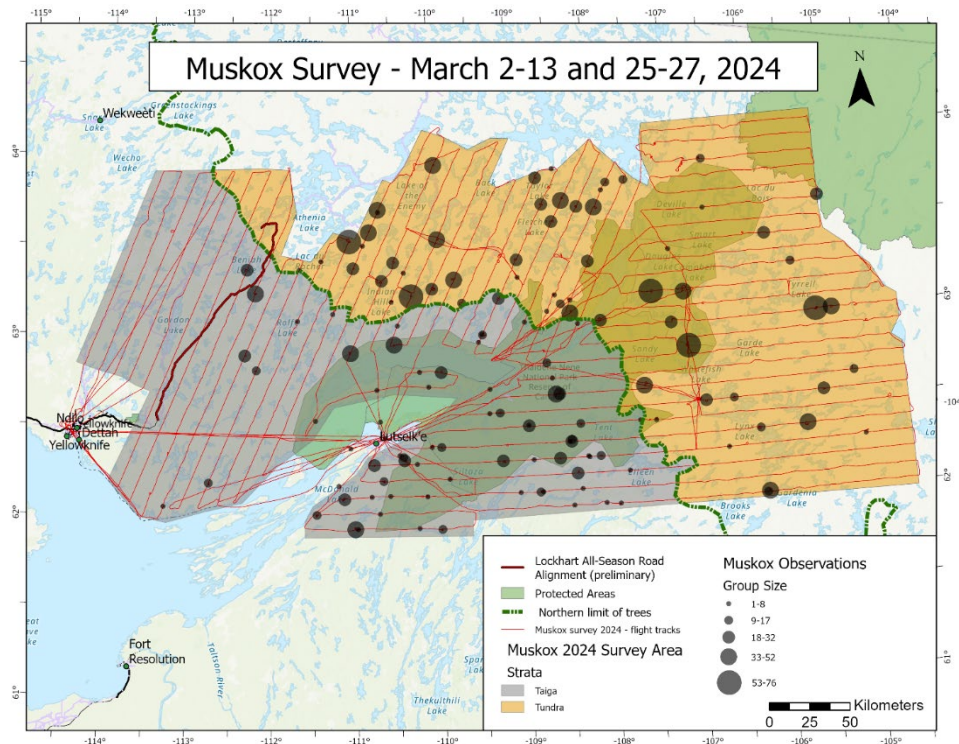


Figure 4. All muskox groups recorded (on-transect and incidental) during the 2024 aerial muskox survey - East Arm, Great Slave Lake.

Other Wildlife Species Incidentally Observed in 2024

Other species incidentally recorded during the 2024 aerial survey included barren-ground caribou, moose, wolf and wolverine (Table 1, Figure 5). Caribou group sizes were estimated by observers, and given that some groups were very large (the largest estimated group size was 1,500 individuals), the total number of caribou recorded should be considered a very rough estimate at best. Sixty-two moose were observed in 46 groups ranging in size from one to three individuals. There were three sightings of wolves totaling 15 individuals, which included two separate sightings of individual wolves, and one wolf pack with 13 individuals seen near the community of Łutsel K'e. Five separate sightings of individual wolverines were also recorded. One suspected wolf kill site was recorded, but there were insufficient remains at the site to determine which species had been killed.

Table 1. Other wildlife species incidentally observed during the 2024 aerial muskox survey - East Arm, Great Slave Lake.

Species	Number of Groups	Minimum Group Size	Maximum Group Size	Total Number of Individuals
Barren-ground Caribou	185	1	1,500	18,308
Moose	46	1	3	62
Wolf	3	1	13	15
Wolverine	5	1	1	5

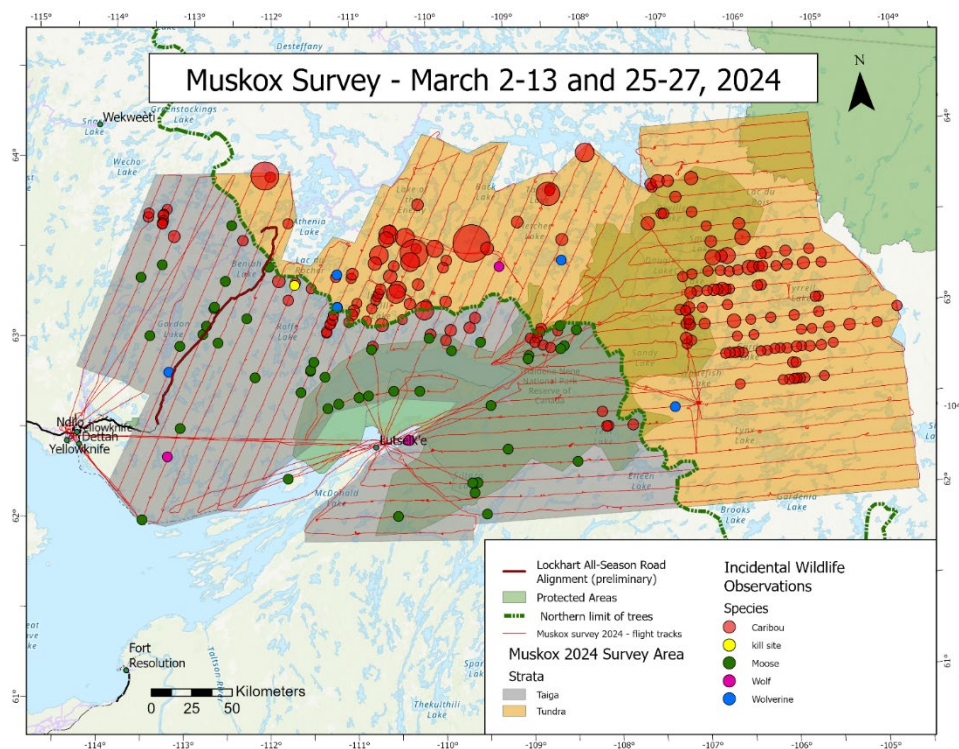


Figure 5. Other wildlife species incidentally observed during the 2024 aerial muskox survey - East Arm, Great Slave Lake. Symbol sizes are proportional to group size (range 1-1,500 individuals).

Summary of Data Used in Distance Analyses

Data used to estimate muskox density and abundance from the 2018 and 2024 surveys only considered muskox observations recorded “on transect” (Table 2). The 2018 survey covered an area of 79,758 km², with 43 transects flown totaling 7,607 km. The 2024 survey covered an area of 98,665 km², with 54 transects flown totaling 9,350 km. In both survey years, more groups of muskoxen were observed in the Taiga strata than the Tundra strata; however, muskox groups tended to be larger, and the total number of muskoxen counted was higher in the Tundra strata in both years. It is important to keep in mind that survey effort (total km flown on-transect) and the area surveyed were higher in the Tundra strata in both years (Table 2).

Table 2. Summary of survey effort (total km flown on transect), survey area size, number of muskox groups recorded (n), total number of muskoxen observed, and perpendicular detection distances (km) of muskox groups from flight lines during aerial surveys around the East Arm of Great Slave Lake in 2018 and 2024.

Year	Stratum	Effort (km)	Area (km ²)	Muskox Groups					Total Muskox Counted	Distance of Muskox Groups to Flight Lines (km)			
				n	Mean Group Size	s.d.	Min	Max		Mean	s.d.	Min	Max
2018	Taiga	2,532	28,855	42	15.8	13.0	1	52	662	0.54	0.4	0.01	1.40
	Tundra	5,075	50,903	33	23.2	21.5	2	95	765	0.80	0.7	0.01	2.83
	Total	7,607	79,758	75	19.0	17.5	1	95	1,427	0.65	0.6	0.01	2.83
2024	Taiga	4,177	45,665	66	11.6	11.4	1	48	767	0.44	0.3	0.00	1.31
	Tundra	5,174	53,000	54	24.2	19.3	1	76	1,306	0.91	0.8	0.00	4.36
	Total	9,350	98,665	120	17.3	16.6	1	76	2,073	0.65	0.6	0.00	4.36

Left and Right Truncation of the Detection Data

Histograms of muskox group detection distances did not suggest evidence of a blind spot near the aircraft in either the 2018 or 2024 data (Figure 6). Therefore, no left truncation (elimination of observations made close to the plane) was applied to the datasets. In both survey years, there were few detections made at distances greater than 2 km from the aircraft. Mean detection distances were greater in the Tundra strata than in the Taiga strata in both years (Table 2), likely reflecting substantially lower tree cover in the Tundra strata.

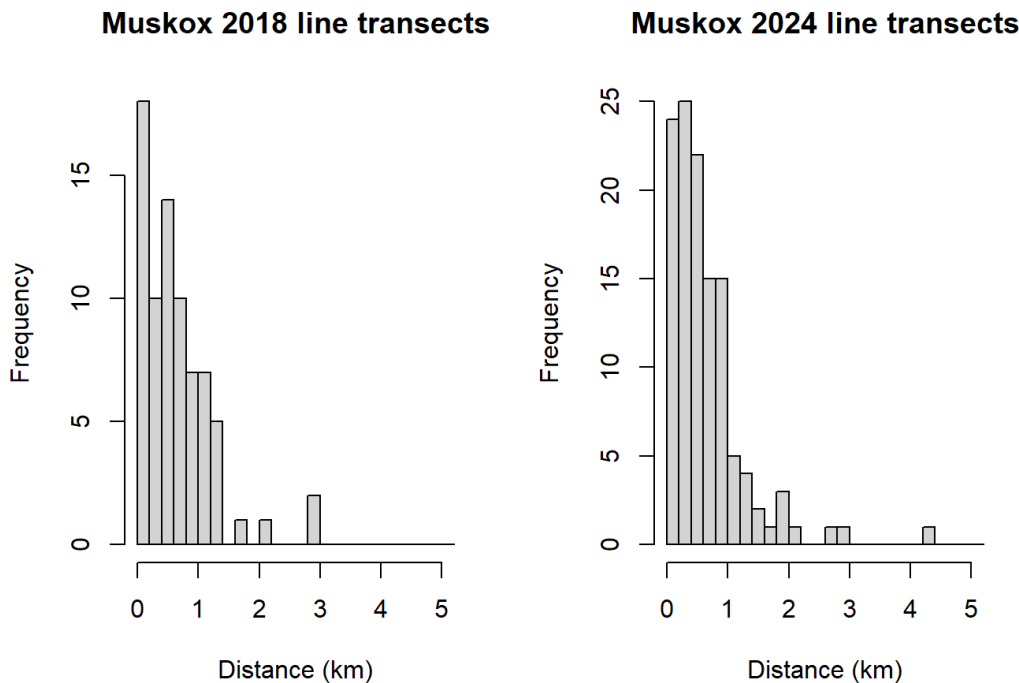


Figure 6. Frequency of perpendicular detection distances (km) of muskox groups from flight lines during 2018 and 2024 aerial surveys. Detection distances are binned into 200 m intervals.

Preliminary distance models based on the full datasets for 2018 and 2024 using a half-normal key without additional adjustment terms suggested that right truncation of the data around 2 km might be appropriate, as plots of the fitted detection functions indicated that detection probability of muskox groups fell below 0.1 beyond 2 km from the plane (Figure 7). For the 2018 dataset, a right truncation distance of 1.9 km was used to be consistent with the value used by Rentmeister (2024) in her analysis of the 2018 data. This resulted in retaining 72 of the 75 muskox groups recorded on-transect in 2018. For the 2024 dataset, a right-truncation distance of 2.0 km was used, which resulted in retaining 116 of the 120 muskox groups recorded on-transect. Although a right-truncation distance of 1.9 km was also tested for the 2024 dataset, it resulted in slightly poorer model fit (Cramér-von Mises test statistic = 0.08, p-value = 0.69) than a 2.0 km right-truncation distance (Cramér-von Mises test statistic = 0.07; p-value = 0.75).

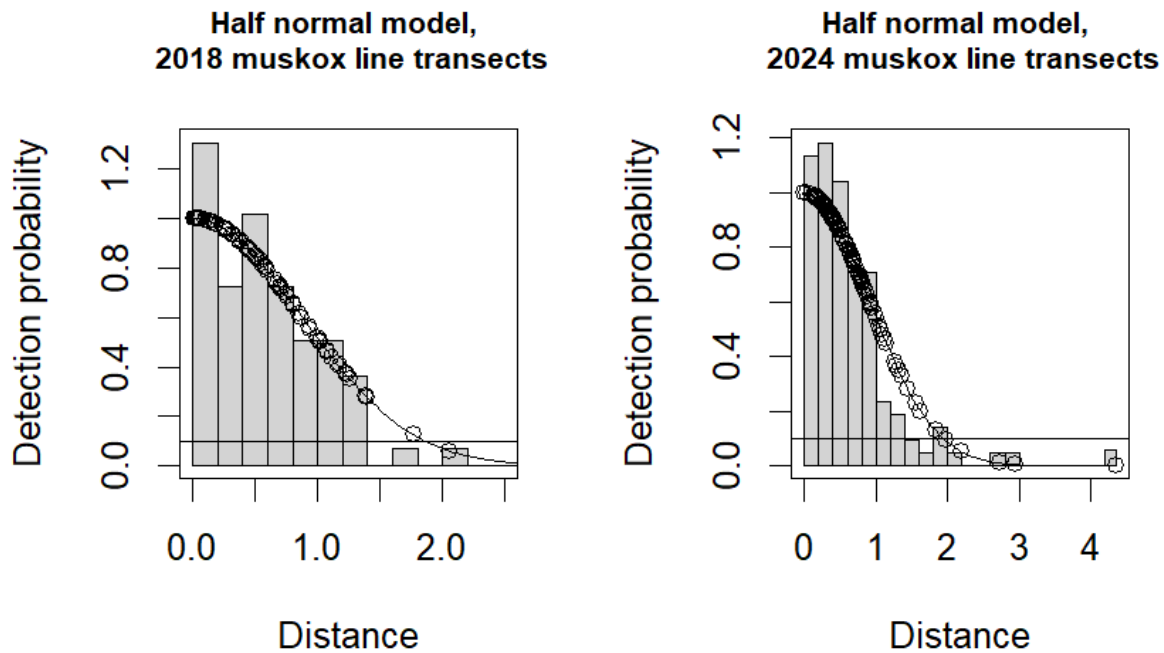


Figure 7. Plots of fitted detection functions (black line and open circles) and a histogram of observed detection distances (grey bars) using the full (on-transect) 2018 and 2024 muskox observation datasets. The horizontal line indicates a detection probability of 0.1.

Assessment of Different Key Functions and Adjustment Terms

Each combination of detection key function and applicable adjustment series was tested on the 2018 and 2024 right-truncated datasets, with the optimal number of adjustment terms determined automatically by AIC. The available key function/adjustment series combinations available in package ‘Distance’ are (based on Table 1 in Miller et al. 2019): half-normal/cosine; half-normal/hermite polynomial; hazard-rate/cosine; hazard rate/polynomial; uniform/cosine; and uniform/polynomial. Table 3 compares the fit of models based on AIC with these different key

function/adjustment series combinations applied to the right-truncated 2018 and 2024 muskox survey data. The degrees of freedom (df) for each model indicate the number of adjustment terms retained in each model. For the half-normal and uniform detection keys, a model without any additional adjustment terms would have a df=1 for the scale term. For the hazard-rate detection key, a model without any additional adjustment terms would have a df=2 for the scale term and shape parameter. For the 2018 data, a half-normal detection key without any additional adjustment terms best fit the data (all other models were >2 delta AIC from the top models; Table 3). For the 2024 data, all three detection keys provided a similar fit to the data (all were within <2 delta AIC of the best model; Table 3). A uniform key with a cosine adjustment with one term had the lowest AIC score; however, visual assessment of fitted detection functions against histograms of observed detection distances suggested that the hazard-rate model was more appropriate given the presence of a shoulder in the detection data (i.e., detection probability remained relatively constant out to a certain distance, then drops off) (Figure 8). Inspection of quantile-quantile (Q-Q) plots (Figure 9) and goodness-of-fit tests also suggested the hazard rate model had a slightly better fit to the data (Cramér-von Mises test statistic = 0.05, p-value = 0.90) than the uniform-cosine model (Cramér-von Mises test statistic = 0.11; p-value = 0.54). A hazard-rate detection key without adjustment terms was therefore used for the 2024 data to compare further models including covariates that might influence detection of muskox groups.

Table 3. Model comparison based on AIC of different combinations of detection function key and adjustment series using right-truncated 2018 and 2024 muskox survey data.

Survey Year	Key Function	Adjustment Series	df	AIC
2018	Half-normal	Cosine	1	54.93
		Hermite Polynomial	1	54.93
	Hazard-rate	Cosine	2	75.63
		Polynomial	2	75.63
	Uniform	Cosine	2	75.94
		Polynomial	2	77.55
2024	Half-normal	Cosine	1	89.89
		Hermite Polynomial	1	89.89
	Hazard-rate	Cosine	2	88.76
		Polynomial	2	88.76
	Uniform	Cosine	2	88.52
		Polynomial	3	89.93

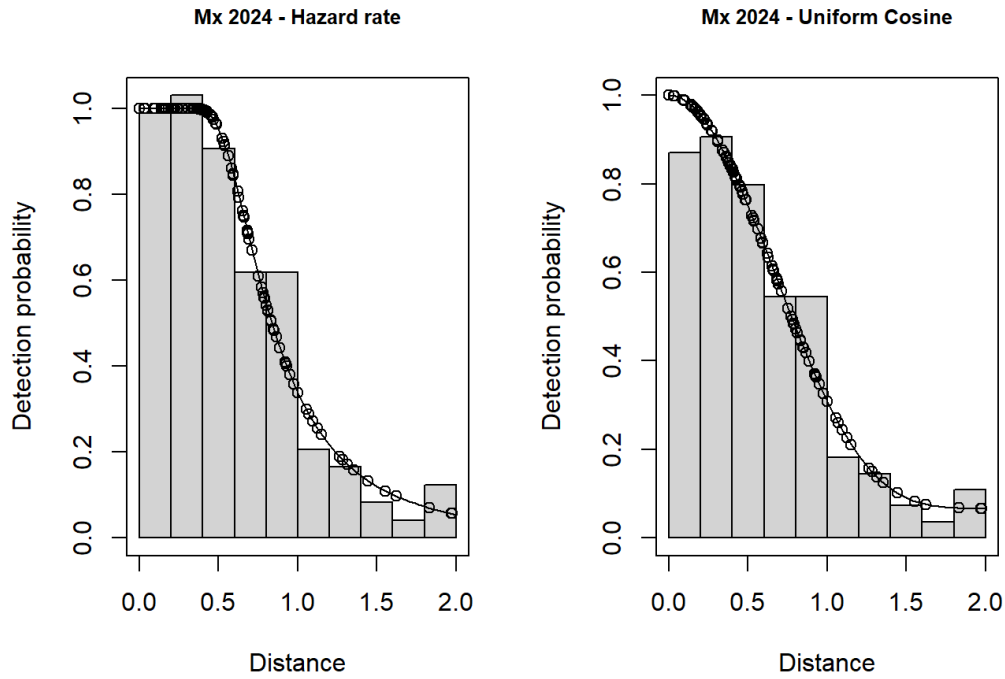


Figure 8. Comparison of detection functions (black lines with open circles) with a hazard-rate key (left panel) and uniform key with cosine adjustment (right panel) fitted to the 2024 right-truncated muskox (mx) survey data. The detection function is overlaid on a histogram of observed detection distances.

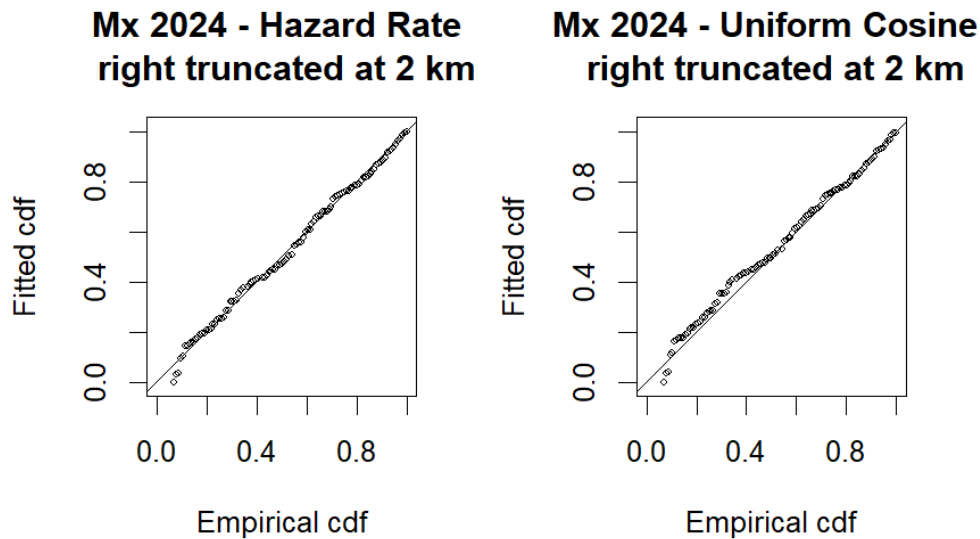


Figure 9. Quantile-quantile (Q-Q) plots comparing the fitted cumulative distribution function (cdf; y-axis) of the detection function to the distribution of the observed data (empirical cumulative distribution function [cdf]; x-axis). The left panel shows the Q-Q plot for the 2024 hazard-rate model and the right panel shows the Q-Q plot for the 2024 uniform-cosine model. Good models will have values close to the line $y=x$.

Covariates Influencing Muskox Detection

To assess the potential influence of factors affecting detection of muskox groups, five competing detection function models were compared for the 2018 muskox survey data, and seven competing models were compared for the 2024 survey data (Table 4). All 2018 detection models used a half-normal detection key without adjustment terms. All 2024 detection models used a hazard-rate key without adjustment terms.

Table 4. Candidate detection function models tested on the 2018 and 2024 muskox survey datasets to evaluate influence of factors influencing detection probability.

Candidate Models Tested	2018	2024
Naïve (~ 1 ; no detection covariates included)	$\ddot{u}$	$\ddot{u}$
Group size	$\ddot{u}$	$\ddot{u}$
Aircraft	$\ddot{u}$	$\ddot{u}$
Stratum (Taiga vs. Tundra)	$\ddot{u}$	$\ddot{u}$
Tree cover (%) [*]		$\ddot{u}$
Group size + Stratum	$\ddot{u}$	$\ddot{u}$
Group size + Tree cover		$\ddot{u}$

^{*} Percent (%) of tree cover was not recorded during the 2018 survey.

Influence of Detection Covariates – 2018 Muskox Survey

For the 2018 muskox survey data, the top-performing detection model had no detection covariates (“naïve” model); however, univariate models with strata and group size (‘size’) as detection covariates were within two ΔAICc of the top model, suggesting they were also good candidate models (Table 5). Group size had a slight positive influence on detection ($\beta_{\text{size}} \pm \text{se}$: 0.008 ± 0.008), and probability of detection was slightly higher in the Tundra strata than the Taiga strata ($\beta_{\text{Tundra}} \pm \text{SE}$: 0.227 ± 0.228).

Table 5. Comparison of support for candidate detection models with different detection covariates based on AICc using 2018 muskox survey data. Models used a half-normal detection key without adjustment terms, and detection data were right-truncated at 1.9 km.

Model	k	n	C-vM p-value	Average Detectability (SE)	AIC	ΔAIC	AICc	ΔAICc	Weight
~1	1	72	0.81	0.48 (0.05)	54.93	0.00	54.99	0.00	0.37
~stratum	2	72	0.68	0.47 (0.05)	55.67	0.73	55.84	0.85	0.24
~size	2	72	0.78	0.48 (0.05)	56.04	1.10	56.21	1.22	0.20
~size + stratum	3	72	0.64	0.47 (0.05)	57.20	2.26	57.55	2.56	0.10
~aircraft	3	72	0.77	0.47 (0.05)	57.44	2.51	57.80	2.81	0.09

Influence of Detection Covariates – 2024 Muskox Survey

The top model for the 2024 muskox survey data was a univariate model with percent tree cover (cover) as a detection covariate (Table 6). The bivariate model with percent tree cover and group size (size) was also within two ΔAICc of the top model, suggesting it was a strong candidate as well. Tree cover had a negative effect on detection probability in the univariate model ($\beta_{\text{cover}} \pm \text{SE}$: -0.009 ± 0.002) and when included in the bivariate model with group size ($\beta_{\text{cover}} \pm \text{SE}$: -0.011 ± 0.002). Unexpectedly, in this bivariate model, group size had a negative effect on detection probability ($\beta_{\text{size}} \pm \text{SE}$: -0.03 ± 0.06) but the large standard error for the coefficient suggested considerable uncertainty about its influence on detection probability. Although not a strong candidate model, when group size was included in a univariate model, it had a positive effect on detection probability ($\beta_{\text{size}} \pm \text{SE}$: 0.011 ± 0.007).

Table 6. Comparison of support for candidate detection models with different detection covariates based on AICc using 2024 muskox survey data. Models used a hazard-rate detection key without adjustment terms, and detection data was right-truncated at 2.0 km.

Model	k	n	C-vM		AIC	Δ AIC	AICc	Δ AICc	Weight
			p-value	Average Detectability (SE)					
~cover	3	116	0.90	0.49 (0.04)	74.23	0.00	74.44	0.00	0.56
~size + cover	4	116	0.87	0.50 (0.04)	75.71	1.49	76.07	1.63	0.25
~strata	3	116	0.80	0.47 (0.04)	76.68	2.46	76.90	2.46	0.16
~size + stratum	4	116	0.11	0.52 (0.03)	80.55	6.32	80.91	6.47	0.02
~size	3	116	0.86	0.46 (0.04)	86.55	12.32	86.76	12.32	0.00
~1	2	116	0.90	0.48 (0.04)	88.76	14.53	88.87	14.43	0.00
~aircraft	4	116	0.91	0.48 (0.04)	92.55	18.33	92.91	18.47	0.00

Muskox Abundance and Density Estimates – 2018 vs. 2024

Density (muskoxen/100 km²) and abundance estimate from the top-performing models (Δ AICc <2) are reported for each survey year in Table 7 to Table 10. For both survey years, muskox density and abundance estimates were slightly higher within the Taiga strata than within the Tundra strata across all top models, but 95% CIs around these estimates overlapped, suggesting the differences might not be statistically significant (a statistical test of these differences is provided in the final section of the results below).

Density estimates for the entire 2018 study areas from the top-ranking detection models ranged from 9.43 muskoxen/100 km² (95% CI: 6.15-14.47), based on the model that accounted for group size as a detection covariate, to 10.35 muskoxen/100 km² (95% CI: 6.91-15.50), based on the model that did not include covariates in the detection function (Table 7). **The model-averaged density estimate for 2018, considering all candidate models, was 10.07 muskoxen/100 km² (95% CI: 5.80-14.33; CV: 21.6%).**

Abundance estimates for the entire 2018 study area ranged from 7,525 muskoxen (95% CI: 4,906-11,543), based on the model that accounted for group size as a detection covariate, to 8,253 muskoxen (95% CI: 5,508-12,366), based on the model that did not include detection covariates (Table 8). **The model-averaged abundance estimate for 2018, considering all candidate models, was 8,029 muskoxen (95% CI: 4,630-11,430; CV: 21.6%).**

The top-ranking 2024 detection model that included tree cover as a covariate provided a density estimate of 9.54 muskoxen/100 km² (95% CI: 6.95-13.11) for the total survey area (Table 9), which was only slightly higher than the density estimate from the top model for 2018. The second ranked model that considered both group size and tree cover as detection covariates predicted a density of 9.81 muskoxen/100 km² (95% CI: 6.87-14.03) for the total survey area (Table 9). **The model-averaged density estimate for 2024, considering all candidate models, was 9.67 muskoxen/100 km² (95% CI: 6.42-12.92; CV: 16.5%).** Overlapping CIs for the 2018 and 2024

density estimates suggest there was not a significant increase in muskox density between the two survey years (Figure 10).

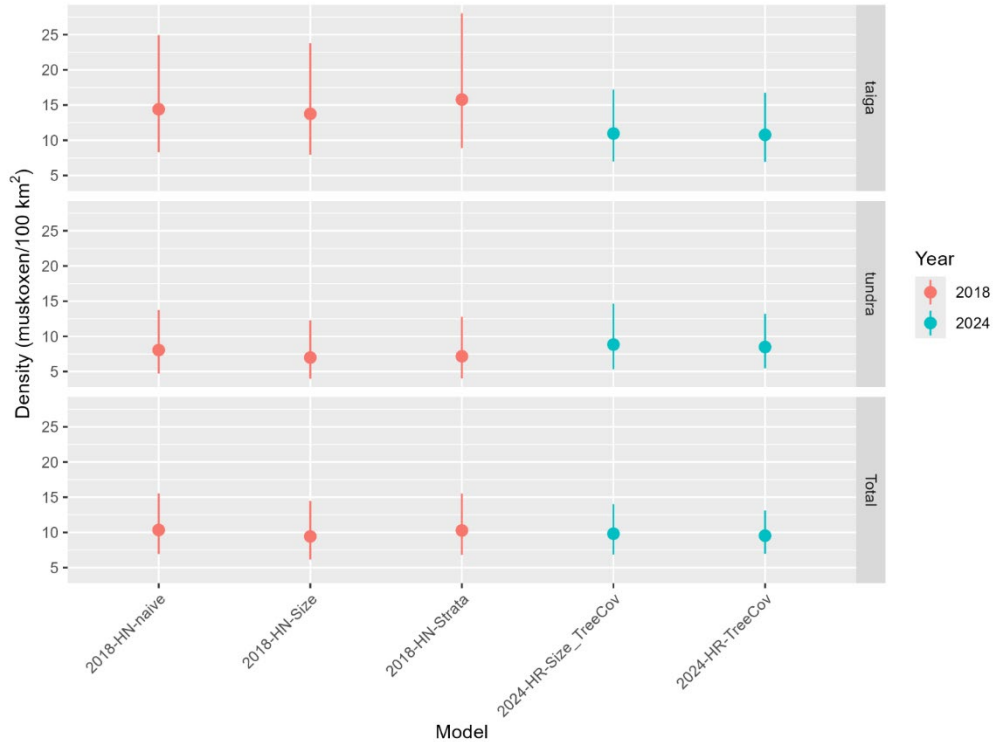


Figure 10. Muskoxen density estimates (muskoxen/100 km²) (points) and 95% CIs (vertical bars) for Taiga and Tundra survey strata, and ‘Total’ survey areas, from top detection models (<2 ΔAICc) for the 2018 and full 2024 survey areas.

Muskox abundance estimates for the total 2024 survey area ranged from 9,414 muskoxen (95% CI: 6,852-12,933) based on the univariate detection model that included tree cover, to 9,684 muskoxen (95% CI: 6,776-13,840), based on the bivariate model that included both tree cover and group size as detection covariates (Table 10). **The model-averaged abundance estimate for 2024, considering all candidate models, was 9,542 muskoxen (95% CI: 6,334-12,751; CV: 17.2%).** Although the point estimates for muskox abundance in 2024 are higher than those in 2018, it is important to keep in mind that the 2024 survey area was almost 20,000 km² larger than the 2018 survey area, meaning that the two abundance estimates are not directly comparable. Furthermore, the CIs for the estimates from the two years overlap, suggesting they are not significantly different (Figure 11).

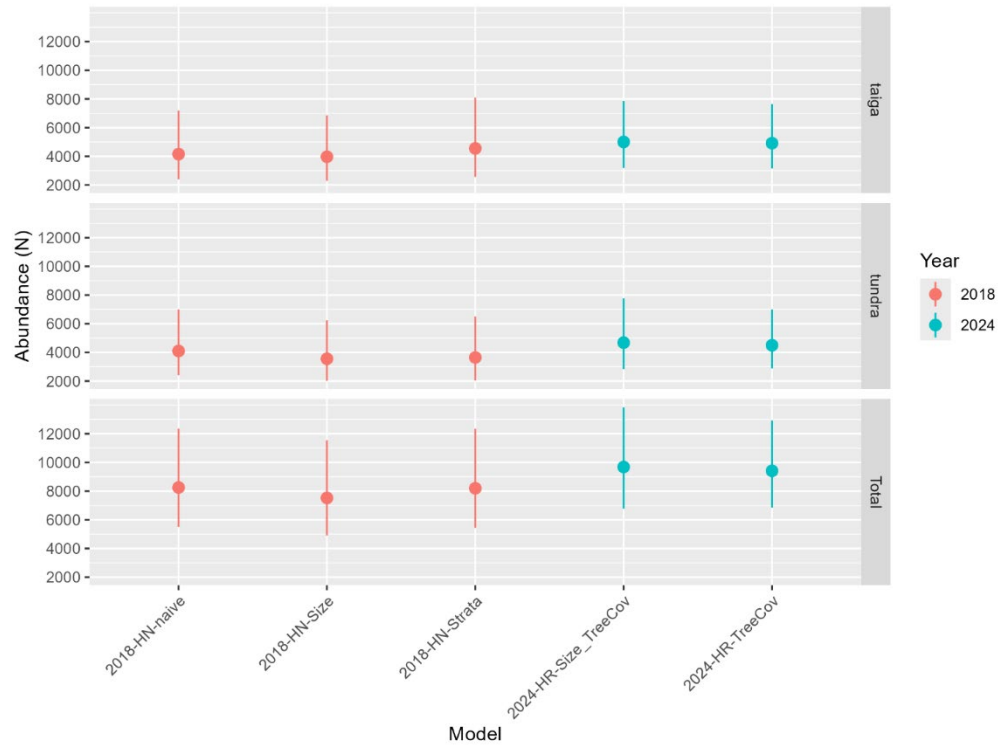


Figure 11. Muskox abundance estimates (points) and 95% CIs (vertical bars) from top detection models ($<2 \Delta AICc$) for Taiga and Tundra survey strata, and ‘Total’ survey areas, for the 2018 and full 2024 survey areas.

Table 7. Predicted muskox density (muskoxen/ km²) in 2018 from top-performing detection models (<2 Δ AICc), including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates. Estimates are provided for each stratum (Taiga vs. Tundra) separately and for the ‘Total’ study area.

Year	Key	Covariates	AICc	Stratum	Density Estimate (Muskoxen/100 km ²)	SE	CV	LCL	UCL
2018	Half-normal	~1	54.99	Taiga	14.40	3.98	0.28	8.31	24.95
				Tundra	8.05	2.19	0.27	4.72	13.75
				Total	10.35	2.13	0.21	6.91	15.50
2018	Half-normal	stratum	55.84	Taiga	15.78	4.60	0.29	8.88	28.05
				Tundra	7.16	2.13	0.30	4.02	12.78
				Total	10.28	2.15	0.21	6.82	15.49
2018	Half-normal	size	56.21	Taiga	13.75	3.80	0.28	7.95	23.78
				Tundra	6.99	2.01	0.29	3.98	12.26
				Total	9.43	2.06	0.22	6.15	14.47

Table 8. Predicted muskox abundance in 2018 from top-performing detection models (<2 Δ AICc), including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates. Estimates are provided for each stratum (Taiga vs. Tundra) separately and for the ‘Total’ study area.

Year	Key	Covariates	AIC	Stratum	Abundance Estimate	SE	CV	LCL	UCL
2018	Half-normal	~1	54.93	Taiga	4,155	1,149	0.28	2398	7,198
				Tundra	4,099	1,114	0.27	2400	6,999
				Total	8,253	1,701	0.21	5508	12,366
2018	Half-normal	stratum	55.67	Taiga	4,553	1,328	0.29	2561	8,093
				Tundra	3,646	1,082	0.30	2044	6,505
				Total	8,199	1,713	0.21	5440	12,358
2018	Half-normal	size	56.04	Taiga	3,969	1,096	0.28	2295	6,863
				Tundra	3,556	1,026	0.29	2026	6,242
				Total	7,525	1,645	0.22	4906	11,543

Table 9. Predicted muskox density (muskoxen/100 km²) in 2024 from top-performing detection models (<2 Δ AICc), including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates. Estimates are provided for each stratum (Taiga vs. Tundra) separately and for the ‘Total’ study area.

Year	Key	Covariates	AICc	Stratum	Density Estimate (Muskoxen/100 km ²)	SE	CV	LCL	UCL
2024	Hazard-Rate	cover	74.44	Taiga	10.77	2.40	0.20	6.92	16.74
				Tundra	8.49	1.90	0.22	5.45	13.21
				Total	9.54	1.54	0.15	6.95	13.11
2024	Hazard-Rate	size + cover	76.07	Taiga	10.95	2.50	0.21	6.97	17.21
				Tundra	8.83	2.29	0.26	5.32	14.65
				Total	9.81	1.79	0.18	6.87	14.03

Table 10. Predicted muskox abundance in 2024 from top-performing detection models (<2 Δ AICc), including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates. Estimates are provided for each stratum (Taiga vs. Tundra) separately and for the ‘Total’ study area.

Year	Key	Covariates	AICc	Stratum	Abundance Estimate	SE	CV	LCL	UCL
2024	Hazard-Rate	cover	74.44	Taiga	4,916	1,095	0.22	3,161	7,646
				Tundra	4,498	1,008	0.22	2,890	6,999
				Total	9,414	1,520	0.16	6,852	12,933
2024	Hazard-Rate	size + cover	76.07	Taiga	5,003	1,142	0.23	3,184	7,860
				Tundra	4,681	1,212	0.26	2,822	7,765
				Total	9,684	1,765	0.18	6,776	13,840

Muskox Abundance and Density Estimates – 2018 vs. Reduced 2024 Study Area

To provide a more direct comparison of muskox density and abundance estimates from the 2018 and 2024 surveys, the extent of the 2024 survey area was reduced to more closely match the 2018 survey area extent by excluding the nine new lines added in the western part of the survey area. The reduced 2024 survey covered an area of 82,349 km² (4.5% larger than the 2018 area), with 45 transects flown totaling 7,796 km (Figure 12). Figure 13 overlays the extent of the reduced 2024 survey area on top of the 2018 survey area for easier comparison.

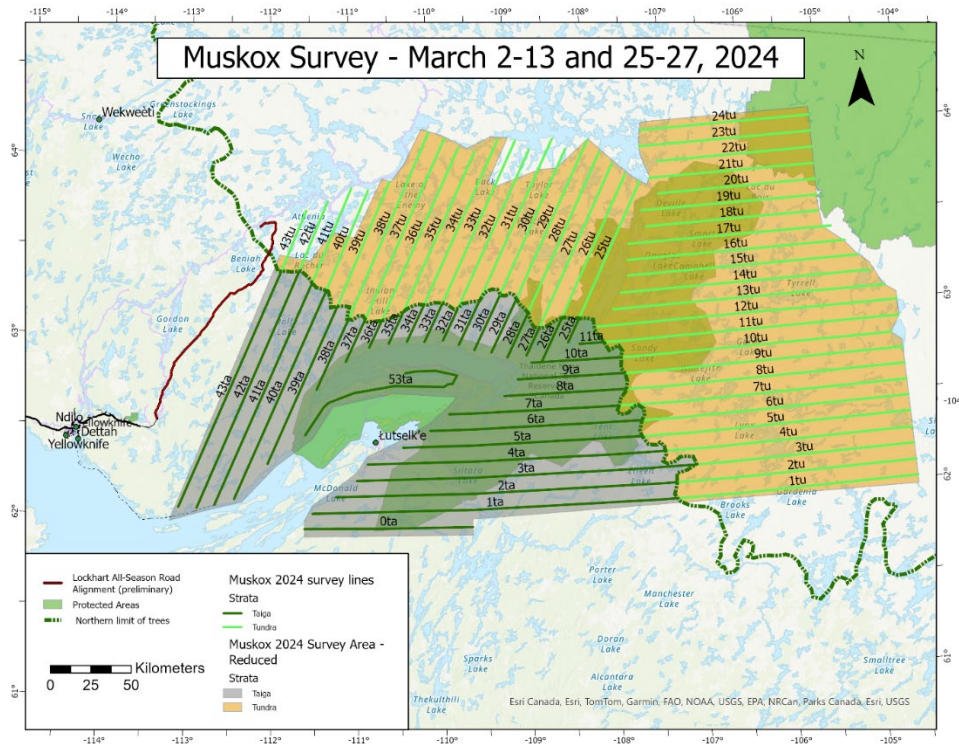


Figure 12. Reduced 2024 muskox survey area boundaries and transects used to make more direct comparison of density and abundance estimates to the 2018 muskox survey.

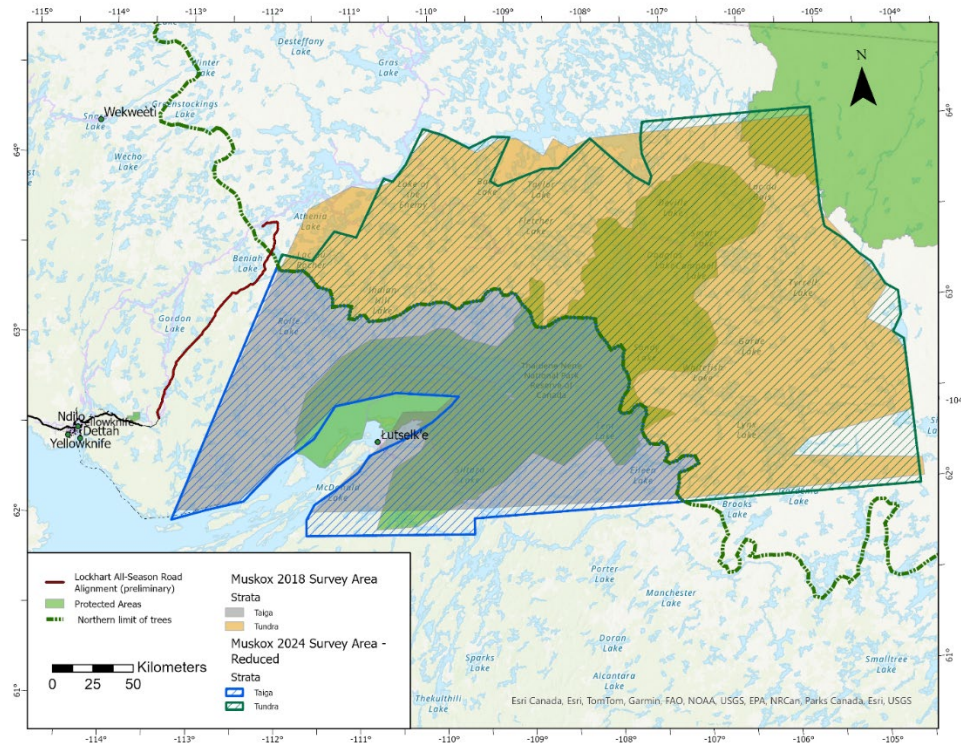


Figure 13. Comparison of 2018 and reduced 2024 muskox survey area extents and survey strata polygons.

The reduced 2024 survey area dataset included 116 muskox groups observed, and a total of 2,001 muskoxen counted on-transect. The same suite of candidate detection models with detection covariates was run using the reduced 2024 dataset, with a 2 km right truncation distance and hazard-rate detection key with no adjustment terms. Model rankings based on AICc were the same for the reduced 2024 dataset (Table 11) as they were for the full 2024 dataset (Table 6).

Table 11. Comparison of support for candidate detection models with different detection covariates based on AICc using the reduced 2024 muskox survey dataset. Models used a hazard-rate detection key without adjustment terms, and detection data was right-truncated at 2.0 km.

Model	k	n	C-vM p-value	Average Detectability (SE)	AIC	ΔAIC	AICc	ΔAICc	Weight
~cover	3	112	0.89	0.49 (0.04)	73.63	0.00	73.85	0.00	0.63
~size + cover	4	112	0.87	0.50 (0.04)	75.35	1.72	75.72	1.87	0.25
~stratum	3	112	0.75	0.48 (0.04)	77.62	3.99	77.84	3.99	0.09
~size + stratum	4	112	0.27	0.51 (0.04)	79.62	5.98	79.99	6.13	0.03
~size	3	112	0.78	0.47 (0.04)	85.88	12.25	86.10	12.25	0.00
~1	2	112	0.85	0.49 (0.04)	88.53	14.90	88.64	14.79	0.00
~aircraft	4	112	0.87	0.49 (0.04)	92.16	18.53	92.53	18.68	0.00

Density estimates from the top two models for the reduced 2024 dataset were similar at 11.09 muskoxen/100 km² (95% CI: 8.18-15.04) for the model with tree cover as a detection covariate, and 11.34 muskoxen/100 km² (95% CI: 8.04-16.00) for the model with tree cover and group size as covariates (Table 12). **The model-averaged density estimate for the reduced 2024 study area, considering all candidate models, was 11.13 muskoxen/100 km² (95% CI: 7.54-14.72; CV: 16.5%).**

Abundance estimates from the top two models for the reduced 2024 dataset ranged from 9,133 muskoxen (95% CI: 6,735-12,384), when accounting for tree cover as a detection covariate, to 9,339 muskoxen (95% CI: 6,619-13,177), when accounting for both tree cover and group size as detection covariates (Table 13). **The model-averaged density estimate for the reduced 2024 study area, considering all candidate models, was 9,168 muskoxen (95% CI: 6,212-12,125; CV: 16.5%).**

Muskox density (Figure 14) and abundance (Figure 15) point estimates for the 2018 survey area were lower than those for the reduced 2024 survey area, but 95% CIs around the estimates still overlapped substantially, suggesting that there might not be a statistically significant change in muskox abundance over the last six years. To evaluate whether muskox density differed significantly between strata within a given survey year, or among years for a given stratum, bootstrapping was used to compute uncertainty in the density estimates for each stratum and year combination with the “bootdht” function in R package ‘Distance’. The 2018 and 2024 reduced study area data were first combined into one flat file, and a new strata identifier was created using the combination of the Stratum (Taiga vs. Tundra) and Year (2018 vs. 2024). This resulted in four different strata (‘2018 Taiga’, ‘2018 Tundra’, ‘2024 Taiga’, ‘2024 Tundra’). A distance model was then fit to the combined 2018/2024 data using a half-normal key function without adjustments and the new strata as a detection covariate. The ‘differences.bootstrap’ function developed by Rextad (2025) with 250 bootstrap iterations was then used to produce a sampling distribution of the difference between pairs of density estimates from the different Year-Strata combinations. This function generates a histogram of the replicate density differences from the bootstrapping procedure and approximates the sampling distribution of the estimated density difference. A two-tailed *p*-value is calculated to test the significance of those differences. This procedure confirmed that muskox density estimates were significantly higher in the Taiga stratum than in the Tundra stratum in both survey years (two-tailed *p*-value for both years = 0.04; Figure 16). There was no significant difference in muskox density within either the Taiga (two-tailed *p*-value = 0.544) or Tundra strata (two-tailed *p*-value = 0.424) when comparing density estimates from the 2018 vs. 2024 (reduced area) surveys (Figure 16). This supports the overall conclusion that muskox density (and abundance) has not significantly increased between 2018 and 2024 when comparing similar survey extents.

Table 12. Predicted muskox density (muskoxen/100 km²) for the reduced 2024 survey area from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates. Estimates are provided for both the Taiga and Tundra strata, and the ‘Total’ survey area.

Year	Key	Covariates	AICc	Stratum	Density Estimate (Muskoxen/100 km ²)	SE	CV	LCL	UCL
2024	Hazard-Rate	cover	73.85	Taiga	15.11	3.07	0.20	10.08	22.66
				Tundra	8.66	1.95	0.22	5.55	13.50
				Total	11.09	1.71	0.15	8.18	15.04
2024	Hazard-Rate	size + cover	75.72	Taiga	15.29	3.19	0.21	10.10	23.17
				Tundra	8.95	2.32	0.26	5.39	14.86
				Total	11.34	1.99	0.18	8.04	16.00

Table 13. Predicted muskox abundance in the reduced 2024 survey area from top-performing detection models, including standard error (SE), coefficient of variation (CV) and lower and upper 95% CIs (LCL and UCL) around the estimates. Estimates are provided for both the Taiga and Tundra strata, and the ‘Total’ survey area.

Year	Key	Covariates	AICc	Stratum	Abundance Estimate	SE	CV	LCL	UCL
2024	Hazard-Rate	cover	73.85	Taiga	4,691	953	0.20	3,128	7,035
				Tundra	4,442	999	0.22	2,848	6,929
				Total	9,133	1,411	0.15	6,736	12,384
2024	Hazard-Rate	size + cover	75.72	Taiga	4,747	991	0.21	3,133	7,192
				Tundra	4,592	1,189	0.26	2,767	7,623
				Total	9,339	1,639	0.18	6,619	13,177

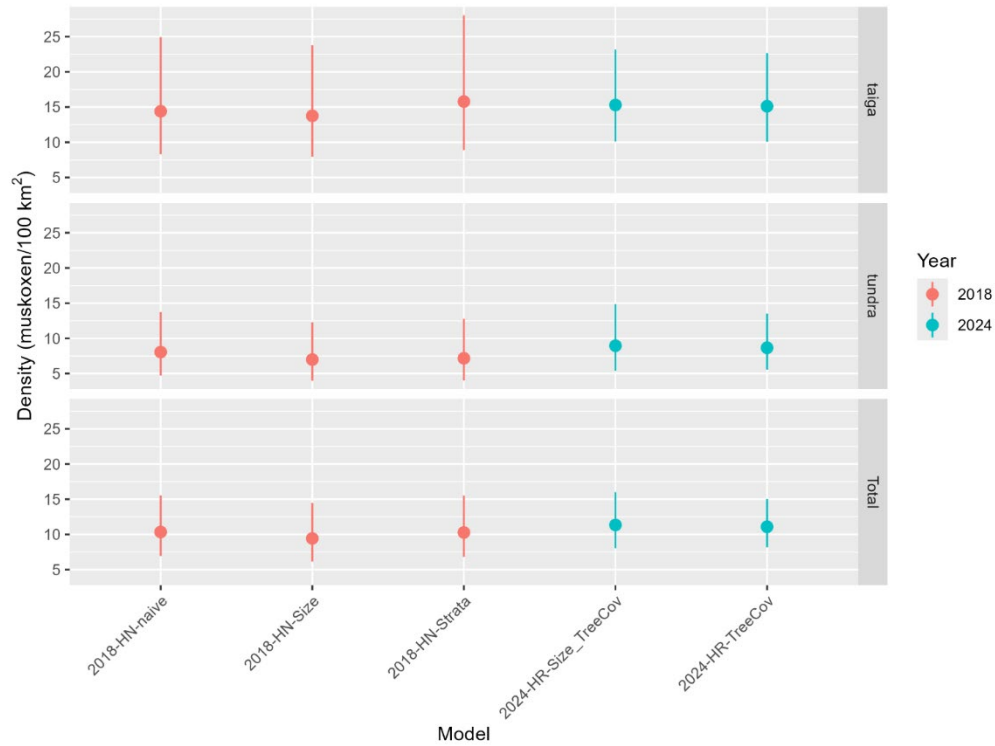


Figure 14. Muskoxen density estimates (muskoxen/100 km²) (points) and 95% CIs (vertical bars) for Taiga and Tundra survey strata, and ‘Total’ survey areas, from top detection models for the 2018 and reduced 2024 survey areas.

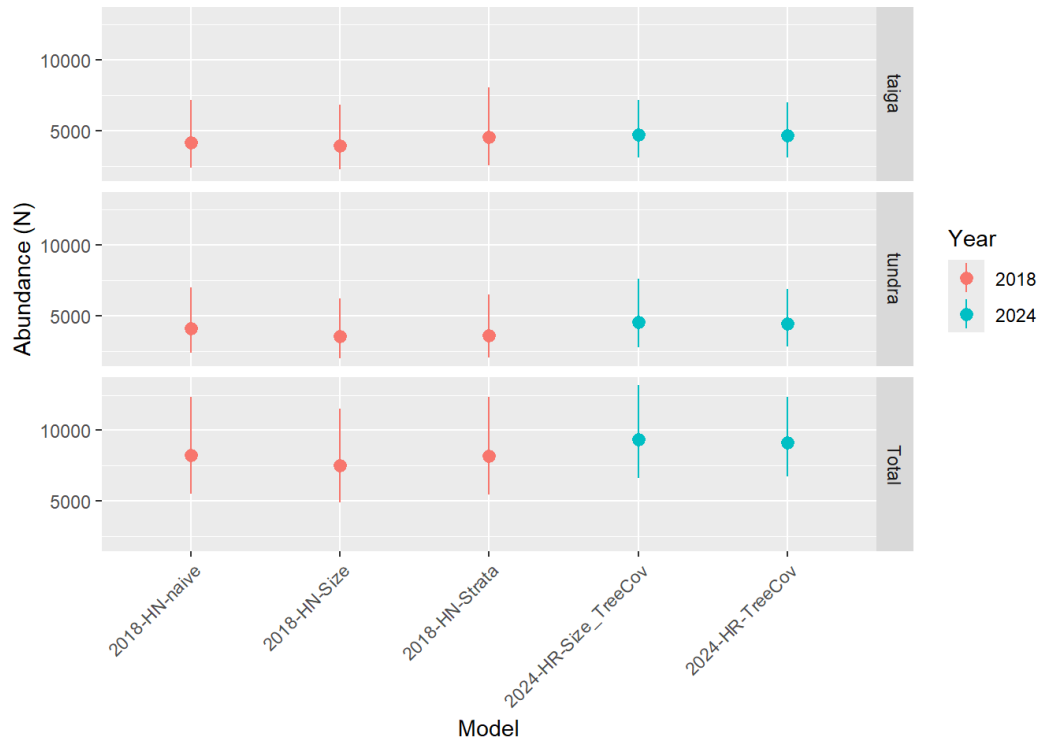


Figure 15. Muskoxen abundance estimates (points) and 95% CIs (vertical bars) from top detection models for Taiga and Tundra survey strata, and ‘Total’ survey areas, for the 2018 and reduced 2024 survey areas.

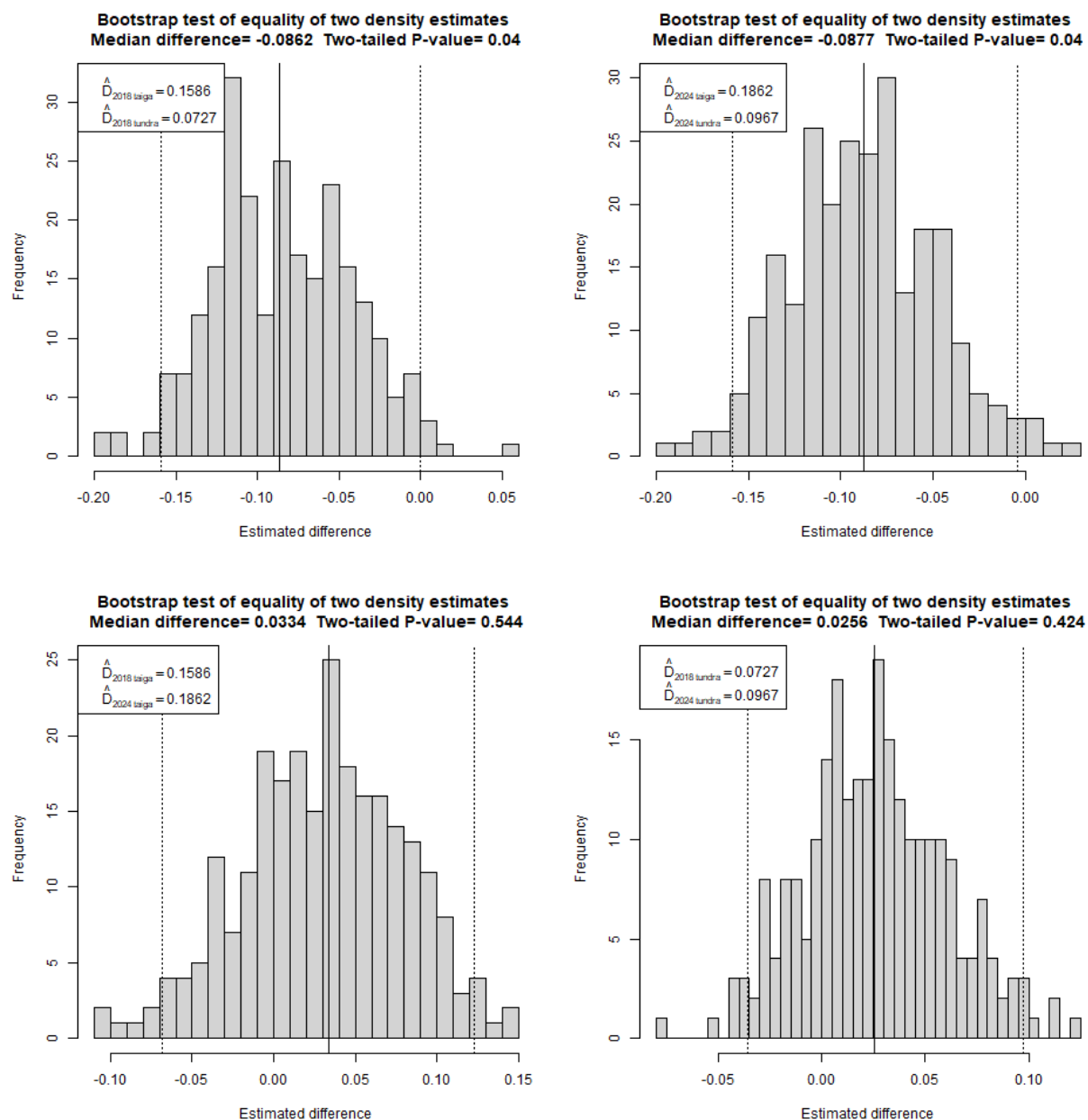


Figure 16. Comparison of muskox density estimates (muskoxen/km²) between strata (Taiga vs. Tundra) within years (top left pane: 2018; top right panel: 2024) and between survey years (2018 vs. 2024) within stratum (bottom left panel: Taiga; bottom right pane: Tundra) using a bootstrapping procedure. The solid vertical lines represent the median, and the dotted vertical lines depict the 95th percentiles around the estimated differences. Mean density estimates for each survey year-stratum combination are presented in the upper right legend box in each panel.

DISCUSSION

The 2024 aerial muskox survey represents the largest area surveyed in the North Slave region to date. Comparison of locations of muskox groups recorded during the 2018 (Figure 3) and 2024 surveys (Figure 4) suggests that the muskox population might be expanding their range westward (in the area between Yellowknife and the East Arm of Great Slave Lake), as there were muskox groups detected in 2024 along lines where none were detected in 2018, as well as some detections on the new western lines added in 2024. Two muskox groups were also detected along survey lines that intersected the preliminary alignment for the proposed LASR project, suggesting a potential for muskox interactions with the proposed road that warrant further consideration. The seven westernmost survey lines, however, did not have any muskox observations. It is not clear whether this is because the muskox population has yet to expand to that area, or if there are other factors that may be limiting their presence in that area. It is worth noting that muskoxen have been incidentally observed at Cameron Falls in 2018 (roughly 20 km east of Yellowknife; CBC News 2013) and to the west of Yellowknife near Behchokò in 2023. They have also been observed as far south as northern Saskatchewan and northern Alberta in 2012, 2019 and 2023 (CBC News 2023), indicating their potential to occasionally travel far outside their main areas of current distribution.

While the total number of muskoxen recorded during the 2024 survey was higher than in 2018, model-averaged muskox densities estimated from the detection models for the two surveys were similar (2018: 10.07 muskox/100 km² vs. 2024: 9.67 muskox/100 km²) and had overlapping CIs. This suggests there has not been an increase in the muskox population in the area around the East Arm of Great Slave Lake between 2018 and 2024. Abundance estimates (total number of muskoxen) for the 2018 and 2024 surveys were not as directly comparable because the survey area was increased by 18,907 km² in 2024. As such, it would be reasonable to expect a higher abundance estimate for a larger survey area, even if muskox density had not changed very much between 2018 and 2024. To address this, we also compared muskox density and abundance estimates from the 2018 survey to estimates from a reduced 2024 survey area that more closely matched the area surveyed in 2024. Here we found that the model-averaged muskox abundance estimate for the reduced 2024 study area (9,168 muskoxen) was higher than the model-averaged estimate for the 2018 survey (8,029 muskoxen); however, substantial overlap of the CIs around these estimates suggested there was too much uncertainty to conclude the increase was statistically significant. The bootstrap analysis comparing differences in density estimates between years within the same stratum (Taiga or Tundra) confirmed that muskox density (and therefore abundance as well) had not significantly changed between 2018 and 2024. The lower precision of the 2018 estimates (coefficients of variation (CV) for pooled [total] estimates were 21-22%) compared to 2024 (CV's: 15-18%) also limited our ability to detect significant differences between the two estimates. Preliminary findings from an aerial photographic muskox composition survey flown in late March-early April 2024, which overlapped the southeastern portion of the 2024 abundance survey area, noted that muskox abundance in that area may have decreased

relative to surveys of the same area in 2020 and 2022 (Adamczewski and Williams 2024). The latest calf:cow ratios and age structure of muskoxen obtained from this 2024 photo classification will help to confirm whether the population is showing signs of stabilizing or even decreasing.

Our estimates of muskox abundance from the 2018 survey data were very close to those obtained by Cluff (2018) but much higher than those estimated by Rentmeister (2024), both of whom used distance models to generate abundance estimates. Density and abundance estimated from distance-based sampling designs can be sensitive to the choice of key function, adjustment terms and covariates included in the detection function, which may have contributed to differences and similarities among these estimates. We used the perpendicular distances of muskox observations to flight lines measured by Cluff (unpublished data) for the 2018 data in our analysis and also used similar study area polygons for the survey strata; however, we corrected some errors we found in the measures of transect lengths surveyed and did not include muskox groups observed when ferrying between transects. Our overall abundance estimates from the naïve model (8,253 muskoxen) and the model including stratum as a detection covariate (8,199 muskoxen) were very similar to Cluff's (2018) pooled (total) estimate of 8,098 muskoxen from a model that included stratum as a covariate. Cluff (2018) did not report which key function he used. In contrast, Rentmeister's (2024) top detection model for the 2018 survey used a uniform key function with no detection covariates and predicted an abundance of 6,111 muskox. Other plausible models (within two $\Delta AICc$ of the top model) reported by Rentmeister (2024) that used a half normal key function predicted abundances between 5,748 and 6,470 muskoxen. Similar to Cluff (2018), Rentmeister (2024) included muskox observations made when ferrying between transects. Differences between Rentmeister's (2024) estimates for the 2018 data and the ones presented in this report may be due to differences in the data used in the analyses. Rentmeister (2024) independently re-measured all of the perpendicular distances of the muskox observations to the flight lines and made adjustments to the study area boundary to exclude large water bodies such as Artillery Lake and the East Arm (including islands) of Great Slave Lake. This resulted in a smaller study area and hence may explain why her abundance estimates were lower than ours for 2018. These differences illustrate why it is also important to report estimated muskox densities in addition to abundance, as density may provide a better measure to compare results from surveys that used different boundaries.

The fact that models including percent tree cover were the top models in 2024 suggests that tree cover has an important influence on the likelihood of detecting muskox groups and should continue to be recorded in future surveys. While this variable was not recorded in 2018, a model that included survey stratum was among the top 2018 detection models, and a comparison of percent tree cover recorded in the Taiga vs. Tundra strata from the 2024 data (see [Appendix B, Figure B4](#)) suggests that this stratification reflected differences in tree cover in 2018.

The extent and configuration of areas surveyed for muskox around the East Arm of Great Slave Lake has evolved over time (Gunn et al. 2024), which makes comparisons of muskox abundance estimated from these different surveys challenging if we want to make inferences about population

trend. It would be valuable to ensure that the area surveyed in 2018 continues to be covered in the future surveys using the same transect lines. While the overall survey area could be expanded, as we did in 2024, it is always possible to sub-sample to an area similar to 2018 to allow more direct comparisons for population trend analysis. Furthermore, muskox abundance survey boundaries should incorporate the full extent of aerial photo composition survey boundaries. This would help to ensure that insights gained from the composition of muskox groups (age and sex structure) can be applied to interpret population trends observed within the broader abundance survey area.

Given that the results of these muskox abundance surveys are being used to inform management decisions including muskox hunting tag allocations, the study area could be extended further south and west in future years to better capture areas of high muskox density below the treeline and to cover a larger portion of the U/MX/01 wildlife management zone that is open to Resident and Non-Resident muskox harvest, including islands in the East Arm of Great Slave Lake. As illustrated in Figure 17, only a small portion of U/MX/01 was covered by the 2024 muskox abundance survey. To increase coverage of U/MX/01, it would be beneficial to collaborate on future surveys with the South Slave regional ECC office.

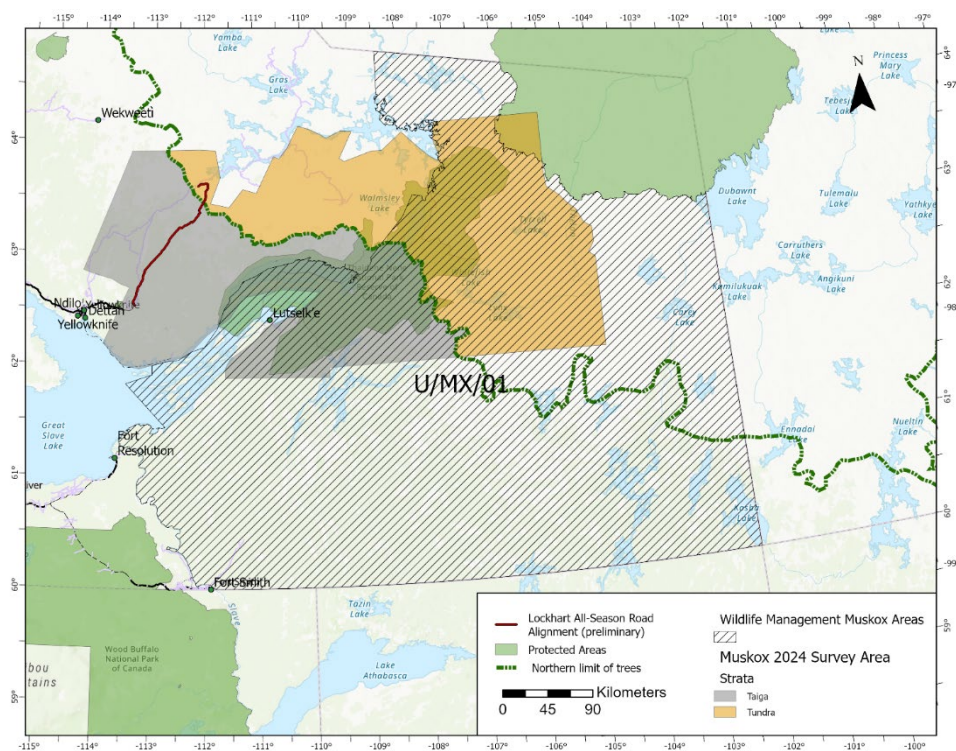


Figure 17. Extent of the 2024 muskox survey area relative to the U/MX/01 wildlife management zone, which is open to Resident and outfitter muskox harvest in the southeast NWT.

Future work could consider extrapolating the 2024 muskox density estimates for the Taiga and Tundra strata to obtain an abundance estimate for the entire area of U/MX/01 that occurs above and below the treeline could be considered. Analyses could also be done to build on the work

done by Rentmeister (2024) and use density surface modeling (Miller et al. 2013) incorporating the 2024 muskox survey data. This approach involves splitting transects into continuous segments (e.g. 5 km long segments), and then using environmental covariates measured for each segment, such as elevation or land cover, to predict density estimates for each segment while accounting for detectability (Miller et al. 2013). The density surface models can then be used to develop a continuous spatially explicit muskox density map that extends beyond the transects to cover the entire study area. Predictions from these models could be further extrapolated to a larger area, if caution is used in their interpretation (Miller et al. 2013, Bouchet et al. 2019), for example in areas where values of the environmental covariates used as predictors are outside of the range of those encountered in the transect segments surveyed.

ACKNOWLEDGEMENTS

We would like to thank Nick Wilson and Judy Williams at GNWT-ECC who assisted with mapping the survey transects; Dean Cluff for his guidance about designing the survey; and Derek Drinnan, Sergei Mjatelski and Dave Olesen, who piloted their aircraft safely and effectively. We appreciate the keen eyes of our observers Charlie Catholique (Łutsel K'e Dene First Nation (LKDFN)), Gabriel Enzoe (LKDFN), Joseph Parsch (LKDFN), Aileen Drybones (LKDFN; Thaidene Nënë (TDN) Guardians); Tas-Tsi Catholique with LKDFN for helping to coordinate observers in Łutsel K'e and Danielle Thompson (Government of the Northwest Territories, Department of Environment and Climate Change (ECC)) for providing funding to compensate observers. For the flights based out of Yellowknife, we would like to thank the following observers: Janik'ah (Jericho) Camsell (Tłıchǫ), Orna Phelan (North Slave Metis Alliance (NSMA), Dylan Coumont (NSMA), Darren Marlow (Yellowknife Dene First Nation (YKDFN)), Jonathan Mackenzie (YKDFN), Arianne Depot-Bernier (ECC) and Bethany Nesbitt (ECC). Thank you to Mason Elwood, Dave Ott and the De Beers Group at Gahcho Kue mine for their remote logistical support. The survey was funded by the Department of Environment and Climate Change.



Photo 1. Survey aircraft (Cessna 180 and Cessna 185) refueling at a fuel cache on Whitefish Lake. Survey crew for the portion of the survey based out of Łutsel K'e consisted of pilots Derek Drinnan and Sergei Mjatelski, ECC navigators James Hodson and Stefan Goodman, and observers Charlie Catholique, Gabriel Enzoe, Joseph Parsch, and Aileen Drybones.

LITERATURE CITED

- Adamczewski, J., K. Olesen, D. Olesen, J. Williams, D. Cluff and J. Boulanger. 2021. Late Winter 2018 Muskox Photo Composition Survey, East Arm of Great Slave Lake. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No. 296. 41pp.
- Adamczewski, J. and Williams, J. 2024. Late-Winter 2024 East Arm Muskox Photo Composition Survey: Field Report June 2024. Environment and Natural Resources, Government of the Northwest Territories. 3pp.
- Bouchet, P., D.L. Miller, J. Roberts, L. Mannocci and L. Thomas. 2019. From Here and Now to There and Then: Practical Recommendations for Extrapolating Cetacean Density Surface Models to Novel Conditions. Technical Report 2019-01 v1.0, Centre for Research into Ecological and Environmental Modelling (CREEM), University of St Andrews, 59pp.
- Buckland, S.T, D.R. Anderson, K.P. Burnham, D.L. Borchers and L. Thomas. 2001. Introduction to Distance Sampling. Oxford University Press, Oxford.
- Burnham, K.P. and D.R. Anderson. 2003. Model Selection and Multi-model Inference: A Practical Information-Theoretic Approach. Springer-Verlag.
- CBC News. 2013. "Muskox seen near Yellowknife" October 18, 2013. www.cbc.ca/news/canada/north/muskox-seen-near-yellowknife-1.2125282
- CBC News. 2023. 'Am I actually seeing this?': Muskox spotted in Fort Chipewyan, Alberta. November 07, 2023. www.cbc.ca/news/canada/north/muskox-in-fort-chipewyan-1.7020509
- Center for Research into Ecological and Environmental Modelling. 2024. Analysis of Animals in Groups. Introductory distance sampling training materials. <https://distancesampling.org/online-course/09-clusters/clusterslanding.html>
- Cluff, D. 2018. 2018 Muskox Survey – North Slave Region. Survey Report Briefing (letter). Environment and Natural Resources, Government of the Northwest Territories. 3pp.
- Government of the Northwest Territories [GWNT]. 2024. NWT Summary of Hunting and Trapping Regulations. 49pp.
- Gunn, A., B. Fournier, J. Williams and J. Adamczewski. 2024. Technical Status Report for Muskoxen (*Ovibos moschatus*) in the Northwest Territories. Government of the Northwest Territories, Environment and Climate Change. Manuscript Report No. 315. 119pp.
- Mazerole, M.J. 2023. AICcmodavg: Model selection and multi-model inference based on (Q)AIC(c). R package version 2.3.3.
- 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(11): 1001-1010.

- Miller, D.L., E. Rexstad, L. Thomas, L. Marshall and J.L. Laake. 2019. Distance Sampling in R. Journal of Statistical Software, 89: 1-28.
- R Core Team. 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, AT. Available at: www.R-project.org/
- Rentmeister, C. 2024. Variation in Mainland Northwest Territories Late-winter Muskox (*Ovibos moschatus*) Density Estimations and Habitat Associations Above and Below Treeline. M.Sc. Thesis. Wilfrid Laurier University. 141pp.
- Rexstad, E. 2025. Detecting Density Estimate Differences. Website: <https://distancesampling.org/Distance/articles/web-only/differences/differences.html>
- Thomas, L., S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R. Bishop, T.A. Marques and K.P. Burnham. 2010. Distance Software: Design and Analysis of Distance Sampling Surveys for Estimating Population Size. Journal of Applied Ecology, 47(1): 5-14.
- Wickham, H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

APPENDIX A: SAMPLE PHOTOS FROM THE 2024 MUSKOX AERIAL SURVEY – EAST ARM OF GREAT SLAVE LAKE

Photo credits: GNWT/S. Goodman, ECC



Photo 2. Aerial photo of muskoxen in sparsely treed habitat in the Taiga stratum.



Photo 3. Aerial photo of muskoxen in the Tundra stratum.



Photo 4. Aerial photo of muskoxen in the Tundra stratum.



Photo 5. Aerial photo of muskoxen in the Tundra stratum.



Photo 6. Aerial photo of muskoxen in moderately treed habitat in the Taiga stratum.



Photo 7. Aerial photo of muskoxen in sparsely treed habitat in the Taiga stratum.



Photo 8. Aerial photo of muskoxen in moderately treed habitat in the Taiga stratum.



Photo 9. Aerial photo of muskoxen in the Tundra stratum.



Photo 10. Aerial photo of muskoxen in densely treed habitat in the Taiga stratum.

APPENDIX B: SUPPLEMENTARY FIGURES

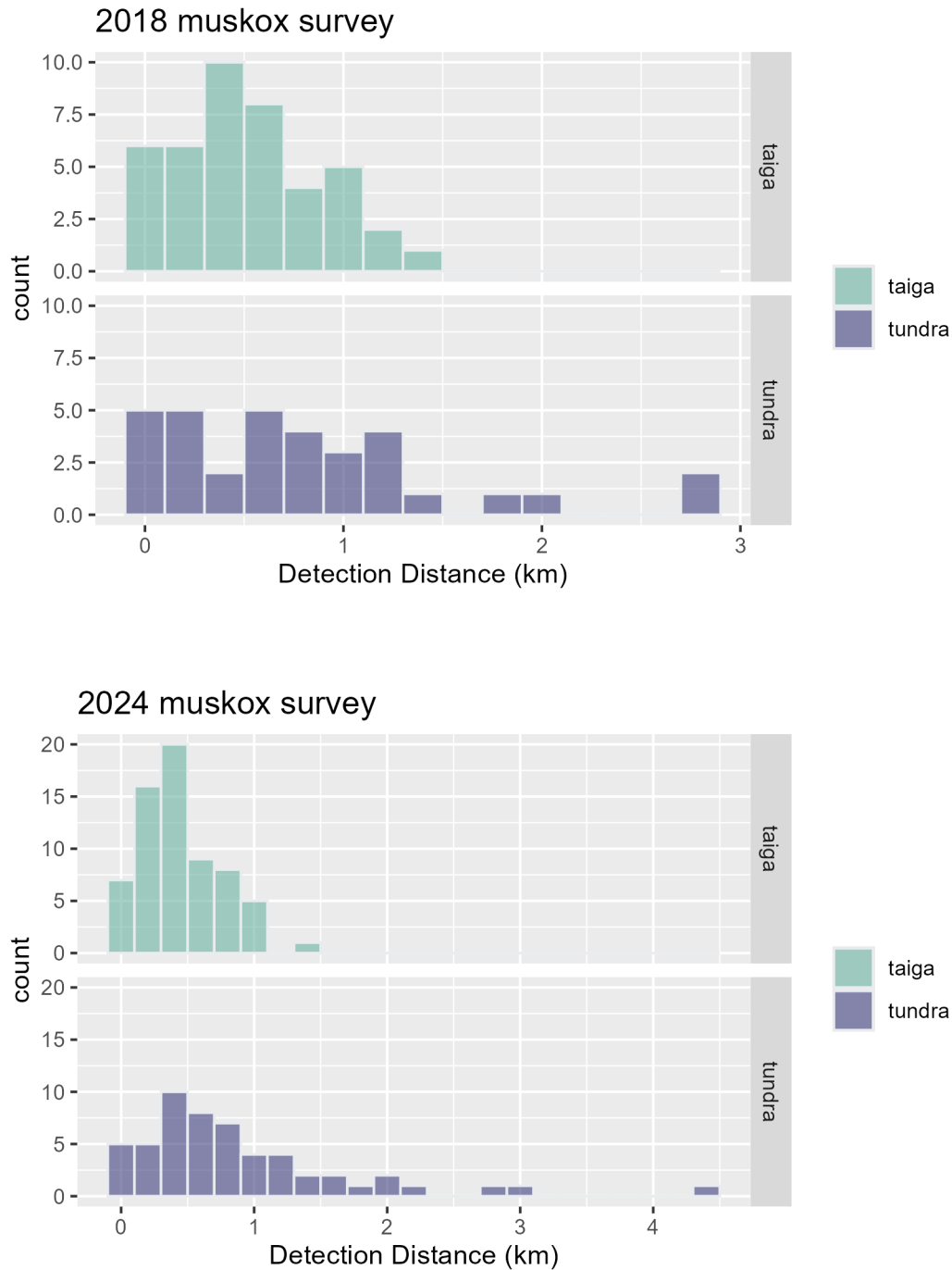


Figure B1. Histograms of the number of muskox groups detected at different distances from the survey line within Taiga vs. Tundra strata in 2018 (top panel) and 2024 (bottom panel).

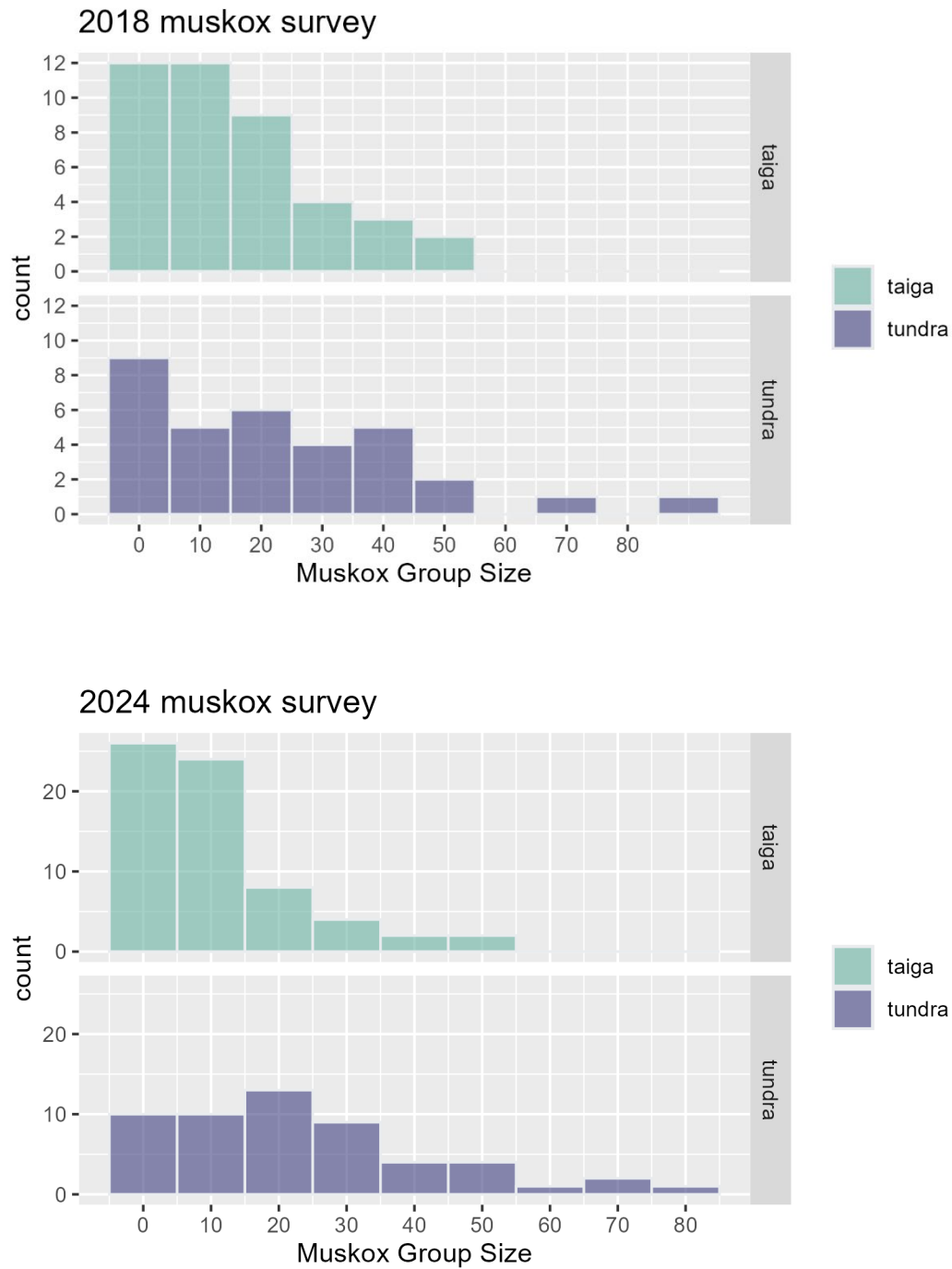


Figure B2. Histograms of the number of muskox groups detected by group size within Taiga vs. Tundra strata in 2018 (top panel) and 2024 (bottom panel).

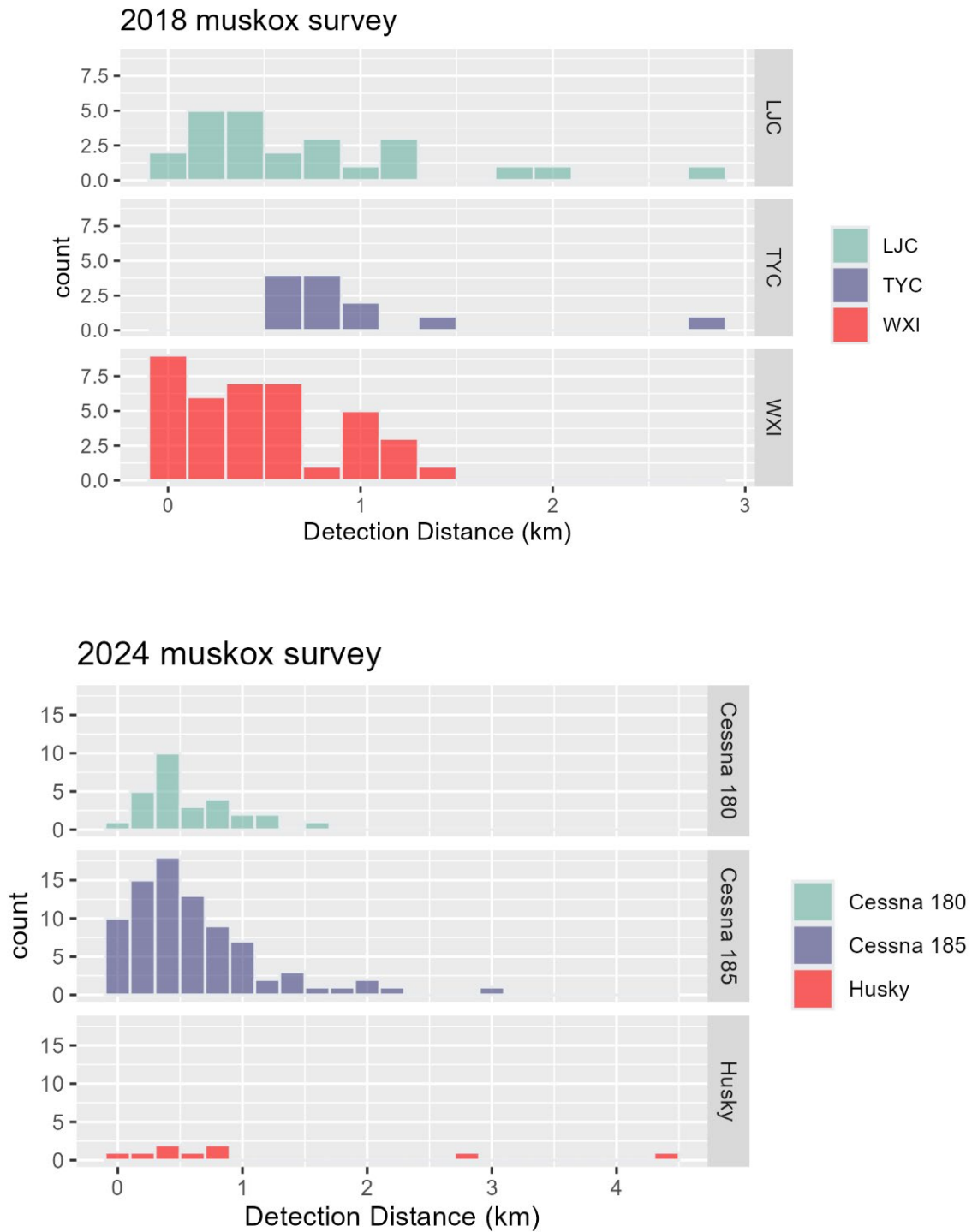


Figure B3. Histograms of the number of muskox groups detected at different distances from the survey lines by aircraft callsign in 2018 (top panel) and aircraft type in 2024 (bottom panel).

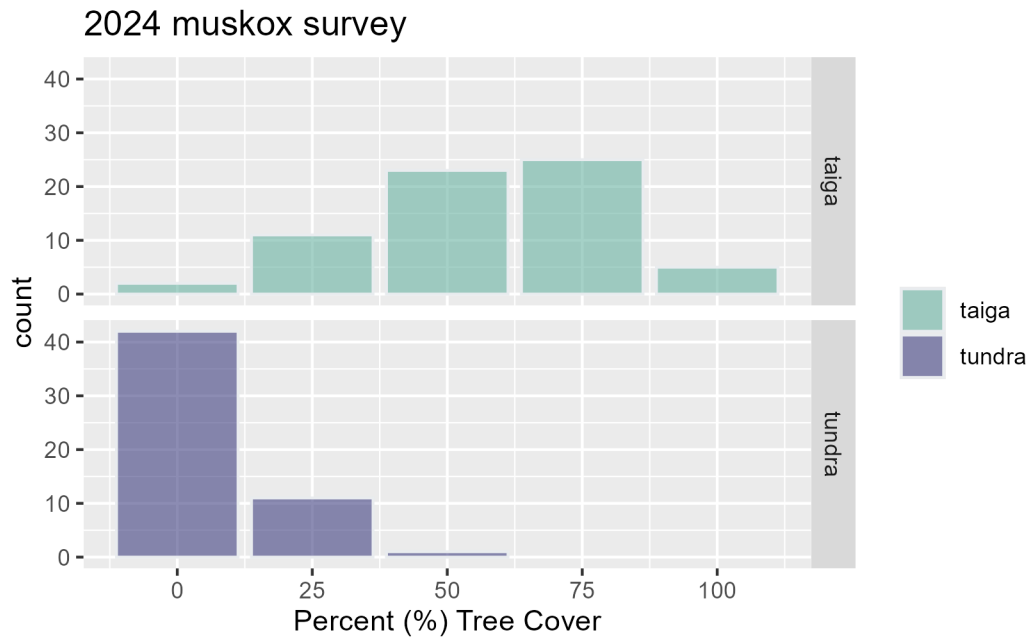


Figure B4. Histograms of the number of muskox groups detected within different percent (%) tree cover categories in the Taiga vs. Tundra strata in 2024.