

# Estimating Abundance of the Qamanirjuaq Mainland Migratory Barren-Ground Caribou Subpopulation - June 2022

## FILE REPORT

Government of Nunavut  
Department of Environment  
Technical Report Series – No: 01-2023

*Mitch Campbell*

*Department of Environment, Nunavut Wildlife Research Division, Arviat, NU*

*John Boulanger*

*Integrated Ecological Research, Nelson, BC*

*John Ringrose*

*Department of Environment, Nunavut Wildlife Research Division, Pond Inlet, NU*

*&*

*David S. Lee*

*Department of Wildlife and Environment, Nunavut Tunngavik Inc., Ottawa, ON*

**14<sup>th</sup> June 2024**

**Disclaimer:**

*The conclusions and recommendations discussed within this report represent those of the authors and do not necessarily reflect the position of the Government of Nunavut.*







## ABSTRACT

Modern mainland migratory caribou calving ground photo surveys generally rely on the assessment of females (and where appropriate, breeding females) combined with fall composition surveys, to estimate and track herd abundance and trend. From June 2008 through June 2017, assessments of the mainland migratory Qamanirjuaq herd abundance and trend, have followed similar methods. In June 2022, we set out to estimate the abundance and trend of females in the Qamanirjuaq herd of barren ground caribou which were then used as one component to generate a whole herd estimate using fall composition studies. In June 2008, the Government of Nunavut estimated 215,049 (95% CI=180,770-249,328; CV=8.1%) adult female caribou on the Qamanirjuaq annual core calving ground, yielding a whole herd estimate of 344,078 (95% CI=287,208-400,948; CV=8.1%) adult caribou. In June 2014, the survey estimated 163,066 (95% CI=136,317-189,815; CV=8.2%) adult female caribou with a whole herd estimate of 264,718 (95% CI=220,634-308.802; CV=8.3%) adult caribou. The 2014 results confirmed a significant decline (DF=71.3; T=-2.23; P=0.029) between survey periods, indicating a 23% decline over the 6-year period. Following up on these observed declines, the herd was again surveyed in June 2017, which generated an estimate of 178,423 (95% CI=150,468-206,377; CV=7.6%) adult female caribou, and a whole herd estimate of 288,244 (95% CI=242,121-334,367; CV=7.8%) adult caribou, suggesting a non-significant decreasing trend with a yearly  $\lambda$  estimate of 0.98 (CI=0.94-1.01). The June 2022 (this report) abundance survey generated an estimated 156,540 adult female caribou (95% CI=116,635-210,099; CV=13.8%), which yielded a whole herd estimate of 252,892 (95% CI=188,050-340,092; CV=13.9%) adult caribou. The total number of caribou (including bulls and yearlings) estimated on the calving ground was 262,272 (95% CI=227,910-296,634; CV=6.4%) in June 2014 and 252,060 (95% CI=220,721-283,398; CV=6.1%) in June 2017, compared to 213,079 (95% CI=166,781-272,229; CV=11.5%) estimated on the

calving ground in June 2022. The overall survey results suggest that the herd appears to be relatively stable. Comparison of the 2022 to the 2008 estimate directly, indicates a significant decline. However, an analysis of regression between 2008 and 2022 is not significant. The mean of the whole herd estimate of the June 2022 survey is 35,352 adult and yearling caribou below that observed in June 2017. Though not statistically significant, this reduction in the mean estimate highlights the importance of continued monitoring of the herd. As indicated, periodic re-assessments of herd abundance are necessary to ensure that any declines can be detected and addressed by co-management partners as outlined within the Nunavut Agreement. Of equal importance is the protection of critical range to ensure healthy seasonal range remains available and accessible to Qamanirjuaq caribou. This is of primary importance to mainland migratory barren-ground caribou such as the Qamanirjuaq herd when recovering from cyclical or major declines in abundance.

**Key Words:** Calving Ground, Photographic Survey, Mainland Migratory Caribou, Kivalliq Region, Barren-Ground Caribou, Qamanirjuaq Herd, Nunavut, *Rangifer tarandus groenlandicus*, Population Survey.

# TABLE OF CONTENTS

<b>1.0 INTRODUCTION.....</b>	<b>7</b>
<b>2.0 STUDY AREA.....</b>	<b>13</b>
<b>3.0 METHODS .....</b>	<b>17</b>
<b>3.1 Visual Surveys.....</b>	<b>17</b>
3.1.1 <i>Double Observer Pair (DOP) Visual Method.....</i>	21
3.1.2 <i>Systematic Reconnaissance Survey .....</i>	24
3.1.3 <i>Visual Abundance Surveys .....</i>	28
3.1.4 <i>Photographic Abundance Surveys .....</i>	30
3.1.5 <i>Double Observer Pair Visual Survey Analysis .....</i>	30
3.1.6 <i>Modelling of sighting probability variation.....</i>	33
3.1.7 <i>Data recorder observations.....</i>	34
3.1.8 <i>Analysis of trend.....</i>	35
<b>3.2 Composition Surveys .....</b>	<b>36</b>
3.2.1 <i>Calving.....</i>	36
3.2.2 <i>Fall/Rut.....</i>	39
<b>3.3 Spatial studies.....</b>	<b>42</b>
<b>4.0 RESULTS .....</b>	<b>43</b>
<b>4.1 Layout of Survey Strata .....</b>	<b>43</b>
<b>4.2 Allocation of Survey Effort .....</b>	<b>49</b>
<b>4.3 Survey Layout Used for Estimates .....</b>	<b>52</b>
<b>4.4 Analysis of Survey Data .....</b>	<b>56</b>
4.4.1 <i>Visual survey double observer pair surveys.....</i>	56
4.4.2 <i>Model selection .....</i>	62
4.4.3 <i>High density photo and visual survey estimates.....</i>	65
4.4.4 <i>Composition surveys to determine proportions of females .....</i>	69
<b>4.5 Estimates .....</b>	<b>70</b>
4.5.1 <i>Estimates of total caribou on the calving ground.....</i>	70
4.5.2 <i>Estimates of breeding females and other cohorts on the core breeding ground.....</i>	71
4.5.3 <i>Extrapolated estimate of total herd size .....</i>	72
4.5.4 <i>Estimates of trend.....</i>	74

<b>4.6 Changes in Annual Calving Extents .....</b>	<b>79</b>
<b>5.0 DISCUSSION.....</b>	<b>84</b>
<b>6.0 MANAGEMENT CONSIDERATIONS .....</b>	<b>88</b>
<b>7.0 ACKNOWLEDGMENTS .....</b>	<b>91</b>
<b>8.0 LITERATURE CITED.....</b>	<b>93</b>

## 1.0 INTRODUCTION

The Qamanirjuaq Caribou Herd is the largest herd in the western arctic, occupying an estimated annual range of 300,000 km<sup>2</sup>. Caribou are an extremely important form of food security, and are socially and culturally important to the well being of the indigenous peoples of Nunavut, Northwest Territories, Manitoba, and Saskatchewan. The most recent estimates of caribou use (harvest) suggest Kivalliq Inuit utilize over 8,000 Qamanirjuaq caribou per year, followed by Manitoba Dene utilizing an estimated 2,000 caribou per year, and Saskatchewan and NWT range-based communities harvesting an unverified number of caribou per year. Both Saskatchewan and NWT aboriginal harvesters are thought to utilize approximately 500 to 1,000 animals annually (InterGroup, 2013). Within Nunavut, NWT, Manitoba, and Saskatchewan, indigenous harvesters are not required to report their barren-ground caribou harvest, resulting in insufficient data to quantify the harvest across the entire annual range of the Qamanirjuaq herd. Given these limitations, we relied on the 2004 Nunavut Wildlife Harvest study, and anecdotal reports gathered by the Beverly and Qamanirjuaq Caribou Management Board (BQCMB), to approximate the harvest (Priest and Usher, 2004). In total, an estimated 11,000 Qamanirjuaq caribou are harvested annually, which would produce an annual dollar equivalent of over fifteen (15) million dollars in food value to indigenous harvesters. These values likely represent an underestimate as there remains uncertainty around the actual number of caribou that are harvested. Within Nunavut, internet sales of caribou meat to other Nunavut communities are occurring but is not currently tracked or reported. Regardless of the accuracy of the estimated subsistence harvest, any decline in productivity, or increase in mortality herd wide, would have a significant impact on thousands of indigenous peoples across the Qamanirjuaq range.

A satellite telemetry program initiated in 1993 has supported the creation of a comprehensive location and activity database for the Qamanirjuaq herd. This

database has been providing biologists, Hunter and Trapper Organizations (HTOs), Regional Wildlife Organization (RWOs), and inter-jurisdictional and jurisdictional management boards with the only source of western scientific based information examining the Qamanirjuaq herds use of their annual range.

Recent movements (within the last 5 years) of Qamanirjuaq caribou cows have indicated some shifts in calving-grounds, migratory corridors, spring staging areas, and summer range in the vicinity of resource development infrastructure. Additionally, Qamanirjuaq winter range over the last ten years has shown considerable overlap with the Bathurst and Beverly populations of barren ground caribou (Campbell et al. 2012-A; Campbell et al. 2014).

Trend analysis of the Qamanirjuaq herd across the June 1994, 2008, 2014, and 2017 calving-ground photographic surveys indicates a declining trend (Boulanger et al. 2018; Campbell et al. 2015-A; Campbell et al., 2010). Prior to the recorded peak in Qamanirjuaq herd abundance in the mid-1990s, the Qamanirjuaq herd showed signs of decline in the early 1950's (Parker, 1972). These early findings led to an increase in scientific studies attempting to understand the underlying mechanisms responsible for the observed declines (Heard, 1985; Parker, 1972). Research interest and efforts reached a peak between the mid 1970's and late 1980's until the results of a June 1982 survey showed that the downward trend had reversed and herd abundance was increasing (Gates, 1985). This unexpected increase in abundance was not surprising to local hunters as the local knowledge of the time disagreed strongly with the late 1970s survey estimates.

Abundance surveys of the Qamanirjuaq Herd have documented considerable change from late 1970s to present. Abundance survey findings suggest the herd dropped from an estimated 43,800 caribou in 1976 to a historical low of 39,000 adult and yearling caribou in June 1980 (Heard, 1981; Gates, 1983). These earlier surveys, however, were visual only, carrying concerns that at high densities, characteristic of the Qamanirjuaq concentrated calving ground, single observer visual estimates could be imprecise. To correct this problem, Biologists developed the June barren-ground caribou calving photographic survey method first deployed on the Qamanirjuaq herd

in June 1983. The new photographic method indicated increases in abundance over the 1970's single observer visual methods and has been used since. By 1988 the herd was estimated to have increased to 221,000 (SE = 72,000), and by 1994, to 495,665 (SE = 105,426), the highest recorded abundance for the herd. By June 2008 the Qamanirjuaq subpopulation was estimated to be 344,078 (SE = 44,861) adults and yearlings (Russell, 1990; Williams, 1995; Campbell et al., 2010) which represented a significant decline from the June 1994 estimate.

From June 1983 to present, estimates of Qamanirjuaq herd size have been based on a combination of aerial photography and visual assessments of the calving ground, where the numbers of breeding cows are counted and herd abundance extrapolated using fall composition counts (**Table 1**). Up until 1994 the herd appeared to have been growing. Evidence of a decline was first detected In June 2008, at which time the Government of Nunavut estimated 344,078 (95% CI=287,208-400,948; CV=8.1%) adult caribou. A second survey flown in June 2014 estimated 264,718 (95% CI=220,634-308,802; CV=8.3%) adult caribou. The reduction in abundance between June 2008 and June 2014 was significant (DF=71.3; T=-2.23; P=0.029) suggesting a 23% decline over the 6 years between estimates. A survey flown in June 2017, estimated 288,244 (95% CI=242,121-334,367; CV=7.8%) adult caribou. Total number of caribou (adults and yearlings) estimated on the calving ground in 2017 was 262,272 (SE=16,746) in June 2014 and 252,060 (SE=15,493). Weighted log-linear regression of the adult female estimates from 2008, 2014, and 2017 suggest a non-significant decreasing trend with a yearly  $\lambda$  estimate of 0.98 (CI=0.94-1.01) further indicating a longer-term declining trend of 2% (CI=-6% to +1%) per year. Using a regression simulation approach for the 2008, 2014, and 2017 surveys, Boulanger et al. (2018) were further able to demonstrate that the majority of trend estimates suggested a negative trend ( $\lambda < 1$ ). The mean  $\lambda$  estimate in this case was 0.975 (percentile 95% CI=0.95-1.00) which is similar to that obtained from regression analysis.

Community-based information has also raised considerable concern for the future of the herd across the Kivalliq region due to recent unpredictable movements of the herd across its spring, calving, and summer range in addition to a thriving inter-territorial

meat sales market largely between the Kivalliq and Baffin Regional communities. These concerns were heightened with a documented drop in relative densities of calving Qamanirjuaq caribou between reconnaissance surveys flown in June 2008, 2010 and 2012.

Table 1. A survey history of the Qamanirjuaq Herd showing estimates and the methods used to derive estimates. Photographic survey methods provide the most reliable results and are generally used when relative densities are high.

Year	Total Herd Size			Source
	Y <sub>h</sub>	SE	CV	
1968	63,000			Parker, 1972 (Visual Calving-ground Survey)
1976	43,800			Calef & Hawkins, 1981 (Visual Calving-ground Survey)
1977	44,095	n/a	n/a	Heard, 1981 (Visual Calving-ground Survey)
1980	39,000	n/a	n/a	Heard & Calef, 1986 (Visual Calving-ground Survey)
1982	180,000	n/a	n/a	Heard & Calef, 1986; Gates, 1985 (Visual Calving-ground Survey)
1983	230,000	59,000	0.258	Heard and Jackson, 1990; Thomas, 1998; Williams, 1995 (Calving-ground Photo-Survey)
1985	272,000	142,000	0.523	Heard and Jackson, 1990; Thomas, 1998; Williams, 1995 (Calving-ground Photo-Survey)
1988	221,000	72,000	0.328	Heard and Jackson, 1990; Thomas, 1998; Williams, 1995 (Calving-ground Photo-Survey)
1994	495,665	105,426	0.213	Unpublished data; Thomas, 1998 (Calving-ground Photo-Survey)
2008	344,078	48,861	0.081	Campbell, Nishi, & Boulanger, 2010 (Calving-ground Photo-Survey)
2014	264,718	21,913	0.088	Campbell, Boulanger, & Lee. 2015 (Calving-ground Photo-Survey)
2017	288,244	22,438	0.078	Campbell, Boulanger, & Lee. 2018 (Calving-ground Photo-Survey)

The present work was designed to re-assess the abundance and trend of the Qamanirjuaq mainland migratory barren-ground caribou subpopulation. We designed the survey to meet the following 4 objectives: 1) Obtain an estimate for the number of females on the calving ground with a coefficient of variation of <15%; 2) Determine the trend in herd abundance since 2008; 3) Estimate the ratio of breeding females to the total number of females at peak of calving as an indicator of productivity; 4) Delineate the spatial extent of the annual calving ground and compare this to historical calving ground use.

## 2.0 STUDY AREA

Using annual location data collected from satellite and GPS collars between 1993 and 2013 we estimated the Qamanirjuaq caribou herd range to cover an estimated 310,000 km<sup>2</sup>, (**Figure 1**). The annual range is large with its northern extents starting from the southern shores of Baker Lake and Chesterfield Inlet (latitude 57 degrees north), extending south to northeastern Saskatchewan and northern Manitoba. The Qamanirjuaq range is bounded to the east by the Hudson Bay coastline and to the west by longitude 105 degrees. The annual range covers four jurisdictions NWT, Manitoba (Man), Saskatchewan (Sask), and Nunavut (NU), and includes seven communities; Brochet Man., Tadoule Lake Man., Black Lake Sask., Wollaston Lake Sask., Arviat NU, Whale Cove NU, Rankin Inlet NU, Baker Lake NU, and Chesterfield Inlet, NU. Most of the annual range including the calving and post-calving range, as well as the spring and fall migration corridors, lie entirely within Nunavut, while the early- mid- and late-winter ranges extend into all four jurisdictions.

The Qamanirjuaq caribou annual range extends from the northern Arctic ecozone at its northeastern edge through the southern Arctic ecozone into its largest expanse in the taiga shield ecozone and ending with its southern tip within the boreal shield ecozone and at its southeastern tip within the Hudson plain ecozone (Environment Canada, 2009, **Figure 2**). Though the herd occupies five different ecozones, it rarely ranges into the northern arctic ecozone and are more commonly observed within the southern arctic ecozone during spring and summer. Dominant seasonal range within the southern arctic ecozone include spring migratory, calving, post-calving and portions of the early summer range. The Taiga Shield covers the largest portion of the Qamanirjuaq herds annual range making up most of the herds late summer, fall migration, fall rut, early winter, and late winter seasonal ranges while the Hudson Plains and Boreal shield are less commonly used across most years (Campbell et al. 2012: Environment Canada, 2001; Wiken, 1986).

The Southern and Northern arctic ecozones are dominated by open tundra largely made up of graminoid, herbaceous shrub, and ericaceous shrub habitats, with lichen mats common across aggregate glacial deposits, beach ridges, and rocky ridges. The Taiga Shield is dominated by open lichen woodlands with interspersed grasslands and shrubby habitats, While the Hudson plains and Boreal shield ecozones are more dominated by closed conifer and mixed forest, arboreal lichens, with interspersed grasslands and shrubby habitats.

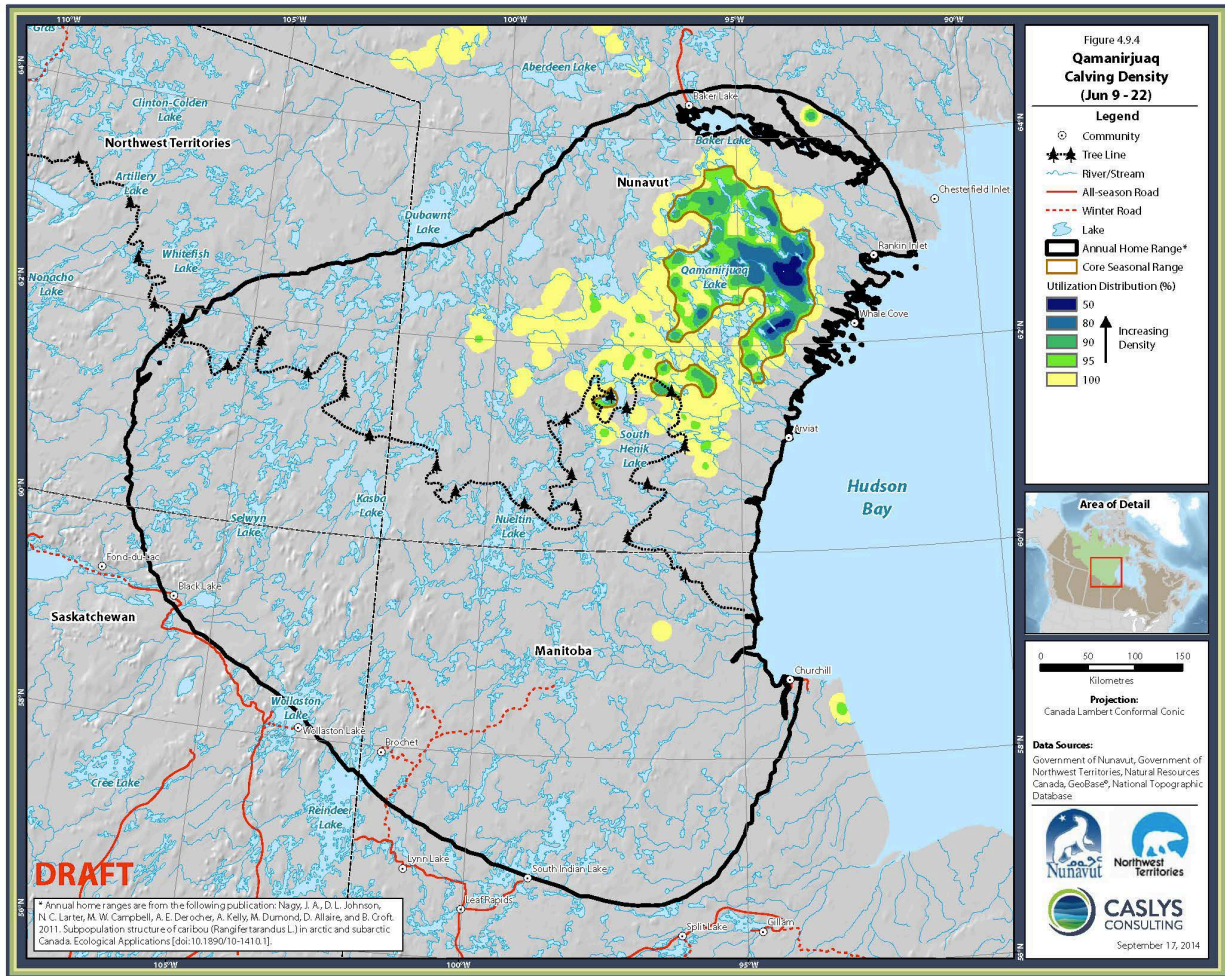


Figure 1. The annual range extents (bold black line) and annual concentrated calving area (dark blue, green, and yellow) of the Qamanirjuaq barren-ground caribou herd. Range extents were calculated using a kernel analysis of satellite and GPS collar data collected between November 1993 and April 2013 (Campbell et al. 2014).



## **3.0 METHODS**

The 2022 Qamanirjuaq barren-ground caribou double observer pair (DOP) visual and photographic calving ground survey was based out of the community of Rankin Inlet, Nunavut, with periodic refueling stops in the community of Arviat, 300 km south of Rankin. The survey was structured into five main components: 1) Systematic reconnaissance DOP visual survey, 2) DOP visual abundance survey, 3) Photographic abundance survey, 4) Density-based abundance strata composition surveys and 5) fall composition surveys. The systematic reconnaissance survey was initiated when GPS collar movement rates reached or fell below 5 km/day. The purpose of the reconnaissance survey was to develop strata to delineate discrete areas of similar breeding female and non-breeding female relative densities, commonly termed very low, low, medium and high. These delineated strata were then flown during the abundance phase of the survey using degrees of flying effort that would grade from high percent coverage in the highest density strata, to lower percent coverage within lower density strata. Aerial photography was utilized within the highest density strata where, in past surveys, densities have been found to be too high for accurate visual counts. The DOP visual abundance survey and the concurrent stratum-based composition surveys were used to estimate the total number of females and breeding females on the annual concentrated calving grounds, while fall composition survey results were used to extrapolate female abundance to whole herd estimates by incorporating the male to female ratio.

### **3.1 Visual Surveys**

Two high-wing, twin engine, turbine, DeHavilland Twin Otter aircraft were used for both the reconnaissance and visual abundance surveys across the entire survey study area. Left and right observation strip widths were established using streamers attached to the wing struts (**Figure 3**). To configure the strip widths ( $w$ ) on aircraft struts we used Norton-Griffiths (1978) formula:

$$w = W * h/H$$

Where:

***W*** = the required strip width;

***h*** = the height of the observer's eye from the tarmac; and

***H*** = the required flying height

Based on decades of aerial wildlife survey work and analysis, the strip width was configured out to 400 meters at 122 meters above ground level (AGL) on each of the left and right aircraft struts, for a total transect width of 800 meters. All aircraft were equipped with radar altimeters to ensure an altitude of 122 meters AGL was maintained accurately while on transect. During the reconnaissance survey, caribou were classified where and when possible as adult with or without antlers, adult with or without calf, female, yearling, or bull.

The DOP method implemented during all phases of the June 2022 reconnaissance and abundance surveys is very similar to the strip transect method used in pre-2008 calving ground surveys with the exception of the addition of a second pair of observers. The double observer pair method allows for the comparison of caribou sightability between front observer pairs (primary observers) and rear observer pairs (secondary observers). Due to the high densities of observations typically encountered during barren-ground caribou surveys, we utilized a cooperative modification to the method between same side observers. This modification allows same side observers to discuss their observation as long as ample time is given to ensure each observer has actually seen

the same group. For every observation, we collected additional information (co-variates) including visibility, ground speed, percent snow cover, elevation indices, and percent cloud cover to help estimate caribou sightability and resulting most representative statistical models used to assess abundance and associated reliability. Off-transect observations were optional during the abundance phase of the survey so that observers could maintain their primary focus on effectively searching the 400-meter strip of ground between the strut markers, also termed the observation bin.

To increase data entry speed without reducing accuracy, and to reduce the time required to perform preliminary analysis of reconnaissance data for abundance survey stratification, a digital data entry system, termed the “Aerial Wildlife Survey – Observation Collector” (AWS-OC), was utilized for this survey (Campbell et al. 2012). The software was developed by the Government of Nunavut, Wildlife Research Division, in collaboration with Integrated Ecological Research, Caslys Consulting Ltd, and Nunavut Tunngavik Inc (NTI), in 2011, and originally deployed on the June 2011 Beverly mainland migratory barren-ground caribou calving ground abundance survey (Campbell et al. 2012). Since its original launch, improved hardware, and some enhancements to the AWS-OC software had been undertaken prior to its deployment in June 2022 (Boulanger et al. 2018). The AWS-OC software operates with Windows editions 7 through 10 and was developed specifically for use in both independent and dependent double-observer pair aerial caribou surveys, including distance-sampling applications, to facilitate the collection of field data, and the subsequent management of the resultant observation dataset. This tablet-based system allows for the instantaneous entering of caribou group waypoints (observations) directly into a digital database. Data entry time was cut by approximately 50% over standard hand written datasheets, with the added benefits of continuous back up onto a USB drive into a digital database with no additional data entry required.

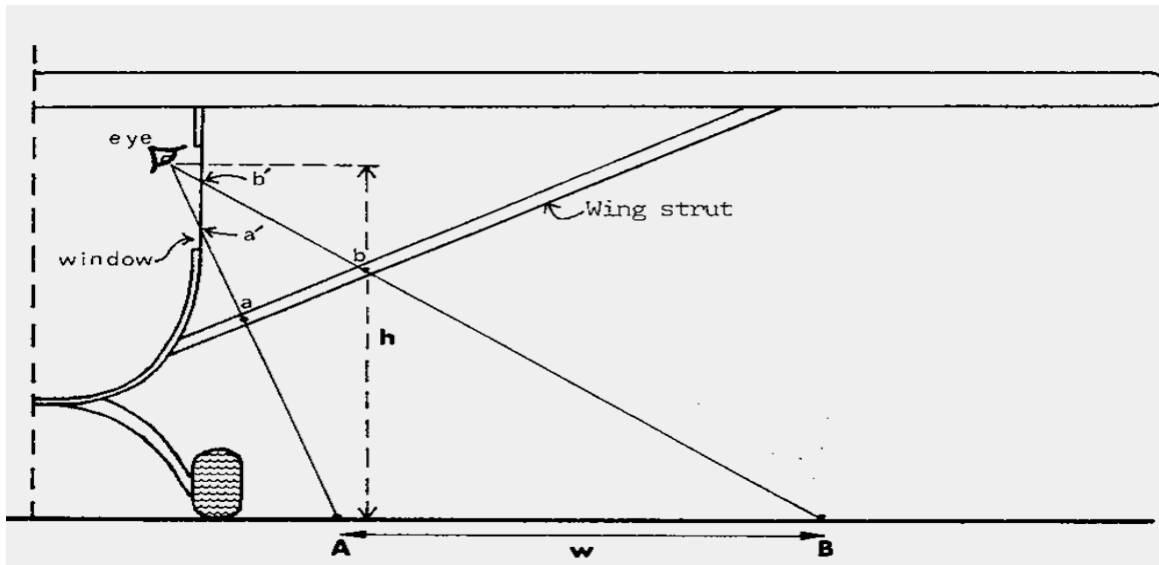


Figure 3 Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978).  $w$  is marked out on the tarmac, and the two lines of sight  $a' - a - A$  and  $b' - b - B$  established. The streamers are attached to the struts at  $a$  and  $b$ , whereas  $a'$  and  $b'$  are the window marks.

### **3.1.1 Double Observer Pair (DOP) Visual Method.**

The double-observer pair method was designed to increase the accuracy and precision of wildlife observations during visual surveys using both fixed wing and rotary wing aircraft. This method involves two pairs of observers on each of the left- and right-hand sides of the aircraft. Two “primary” or front observers who sit in the more forward seats over the wing struts and two “secondary” or rear observers who sit behind the primary observers (**Figure 4**). By design the method adheres to five basic steps:

- 1) The primary observer called out all groups of caribou (number of caribou and location) he/she saw within the 400-meter-wide strip transect before they passed halfway between the primary and secondary observer (approximately at the wing strut). This included caribou groups that were between approximately 12 and 3 o’clock for right side observers and 9 and 12 o’clock for left side observers (**Figure 4**). The main requirement was that the primary observer be given time to call out all caribou seen before the secondary observer called them out;
- 2) The secondary observer called out whether he/she saw the caribou that the first observer saw and observations of any additional caribou groups. The secondary observer waited to call out caribou until the group observed passed half way between observers (between 3 and 6 o’clock for right side observers and 6 and 9 o’clock for left side observer);
- 3) The observers discussed any differences in group counts to ensure that they had called out the same groups or different groups and to ensure accurate counts of larger groups;
- 4) The data recorder, one in front of the left side observers and the second in front of the right-side observers, categorized and recorded counts of each caribou group into “front only”, “rear only”, and “both”, while recording predetermined co-variates; and
- 5) The left two observers and right two observers switched places approximately half way through each survey day (i.e. during refueling or within a stratum) to address

observer ability and sightability differences between the front and rear seats. The recorder noted the names of the front and rear observer for all observations.

The sample unit for the survey was “*groups of caribou*” not individual caribou. Recorders and observers were instructed to consider individuals to be those caribou that were observed independent of other individual caribou and/or groups of caribou. If sightings of individuals were within close proximity (within an estimated 200 meters) to other individuals then the caribou were considered a group.

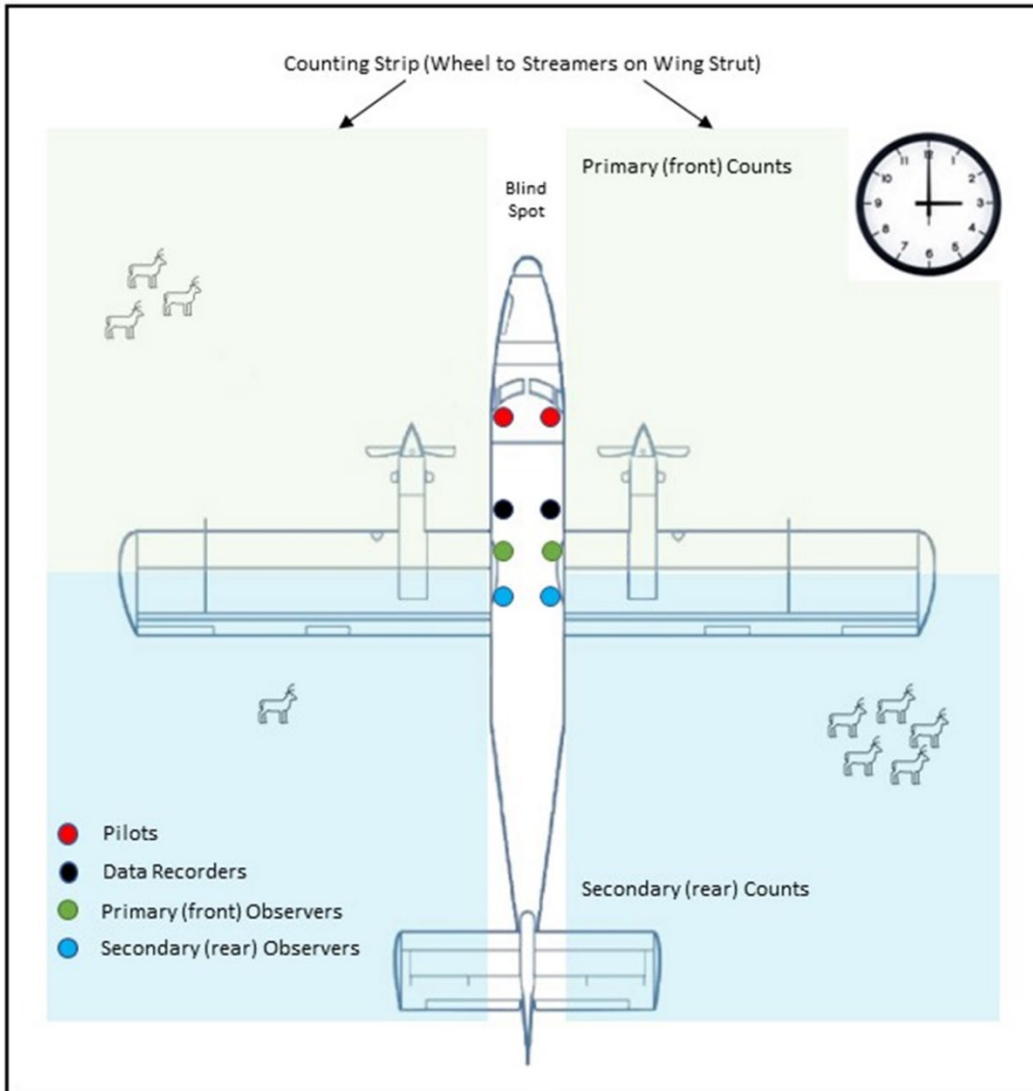


Figure 4. Observer position for the double observer pair method deployed on this survey using Twin Otter aircraft. The rear (secondary) observer (blue shaded area) calls caribou not seen by the front (primary) observer after the caribou have passed the main field of vision of the front observer (light green shading). The small hand on a clock is used to reference relative locations of caribou groups (e.g., “Caribou group at 3 o’clock” would suggest a caribou group 90° to the right of the aircrafts longitudinal axis.).

### **3.1.2 Systematic Reconnaissance Survey**

The systematic reconnaissance survey was designed to estimate relative densities and delineate aggregations of females and breeding females (hard antlered cows or cow/calf pairs) for the purposes of stratifying the calving ground for the subsequent photo and visual abundance surveys. We used the observed locations of hard-antlered cows, newborn calves and aggregations of bulls and yearlings to delineate the spatial extent of the annual calving ground (Heard and Jackson, 1990; Thomas, 1998; Williams, 1995; Bergerud et al. 2008). The systematic reconnaissance survey of the annual calving ground was flown June 6<sup>th</sup> and 7<sup>th</sup>, 2022. Some additional reconnaissance was flown June 9<sup>th</sup> following the completion of the abundance phase and along known spring migratory corridors to ensure distributions of breeding females were not missed.

The reconnaissance survey was based on a systematic array of transects running north-south (**Figure 5**) and spaced at 10-kilometer intervals. Each transect was further divided into adjoining 10 kilometer transect segments, with each segment identified by a unique alpha-numeric code assigned to the transect station defining its northern end. The reconnaissance survey used these pre-determined transect segments (defined as one 10 km segment between two transect stations) to bin caribou observations for the purposes of calculating relative density within the segment. A rigid set of criteria governed when the 10 kilometer transect segments were flown. Criterion controlling when and where transect segments would be flown varied slightly across the calving distribution.

As the historic distribution of the Qamanirjuaq herd consistently displayed a distinct northern boundary along the leading edge of known migratory extents, while the southern, eastern, and western extents showed more inter-annual variability. For these reasons, rules controlling when to discontinue a transect varied between the northern extent of the distribution and that of the southern, eastern and western. Consecutive transect segments were flown north along the reconnaissance grid until no females and/or breeding females (hard antlered cows or cow/calf pairs) were observed within the ten-kilometer segment being flown. To further define the northern limit of breeding and non-breeding cows, parallel ten kilometer transect segments, adjacent to the

additional northern segment, would also be flown. Along the more southerly “trailing edge” of the observed caribou distribution, the reconnaissance survey continued two full transect segments (including those segments directly east and west) beyond any surveyed segment where fewer than 2 breeding females/females were observed. On the western extents where caribou densities were in excess of 5 animals per ten kilometer transect segment and/or breeding female densities below 2 per transect segment, additional western transects would be flown at 20 km spacing between transects rather than ten, to increase area coverage and to ensure aggregations of breeding females/females were not missed. We intermittently continued the reconnaissance along known spring migratory corridors to ensure distributions of females/breeding females were not missed (**Figure 6**).

Following the systematic reconnaissance but prior to the initiation of the visual and photographic surveys, all tabulated observations were entered in to ESRI GIS software to calculate relative densities of breeding females using a tool utility. The relative density tools were built in ESRI’s Model Builder (v9.1) utility and loaded into Arc Toolbox. The tools allowed us to calculate the relative density of observed caribou locations along the reconnaissance transects and associated transect segments and display these results on a map. We used vector-based analysis methods based on the following steps: 1) The survey transect segments were buffered by a user-specified width (i.e., 800 meters) yielding polygons that were 8 km<sup>2</sup> (i.e., 0.80 km wide x 10 km long); 2) The survey observations points were intersected with the derived buffer polygons; 3) The density was calculated for each polygon by dividing the number of 1+ year-old caribou by the area of the buffer polygon (#1+ year old caribou/km<sup>2</sup>); 4) The relative density (#obs/km<sup>2</sup>) is then thematically displayed on a map based on pre-defined classes or bins. The resulting graphics were then used to stratify the breeding female/female distributions into High, Medium, low, and very low-density strata to prepare for the abundance phase of the survey.

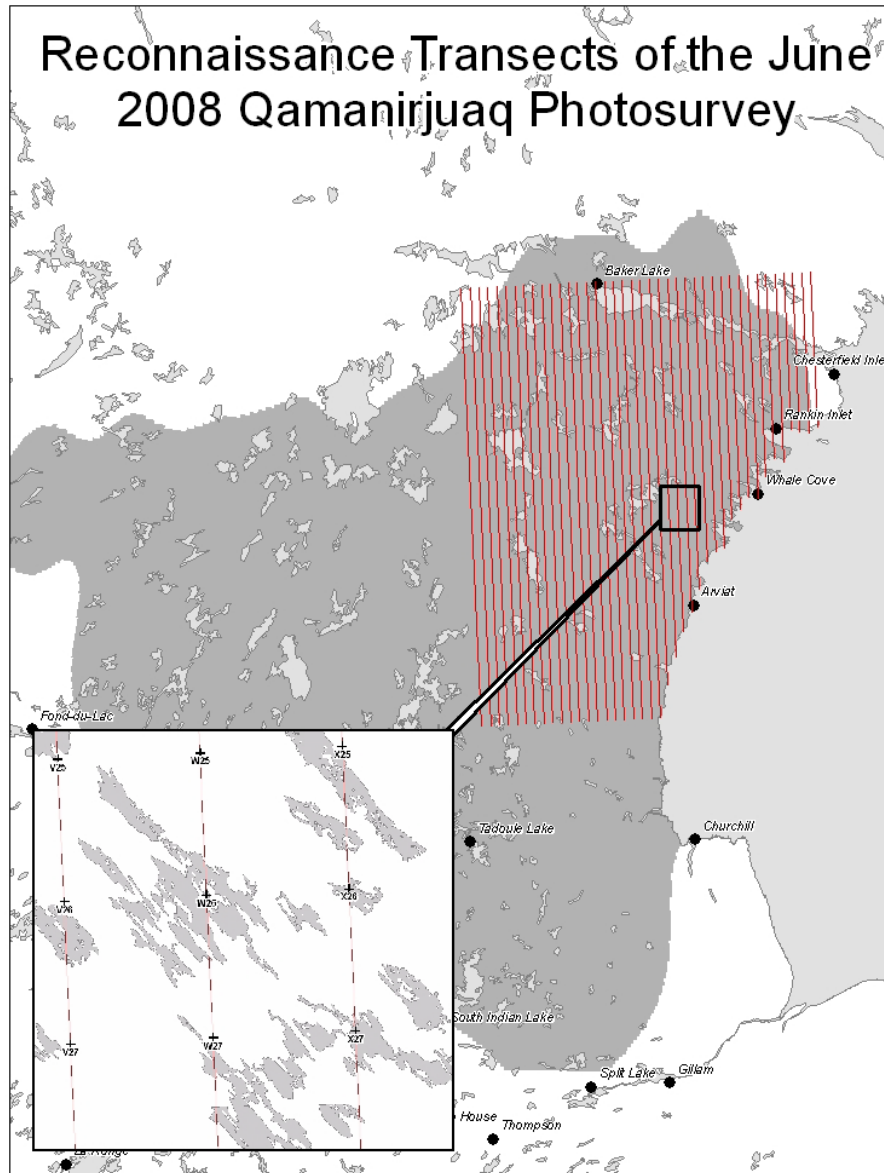


Figure 5. Potential reconnaissance transects and transect stations designed to cover the known extent of calving for the Qamanirjuaq barren-ground caribou herd in June 2022. These same transects were used in all consecutive surveys flown from June 2008 to present. Not all lines shown in this figure were flown during the 2022 survey.

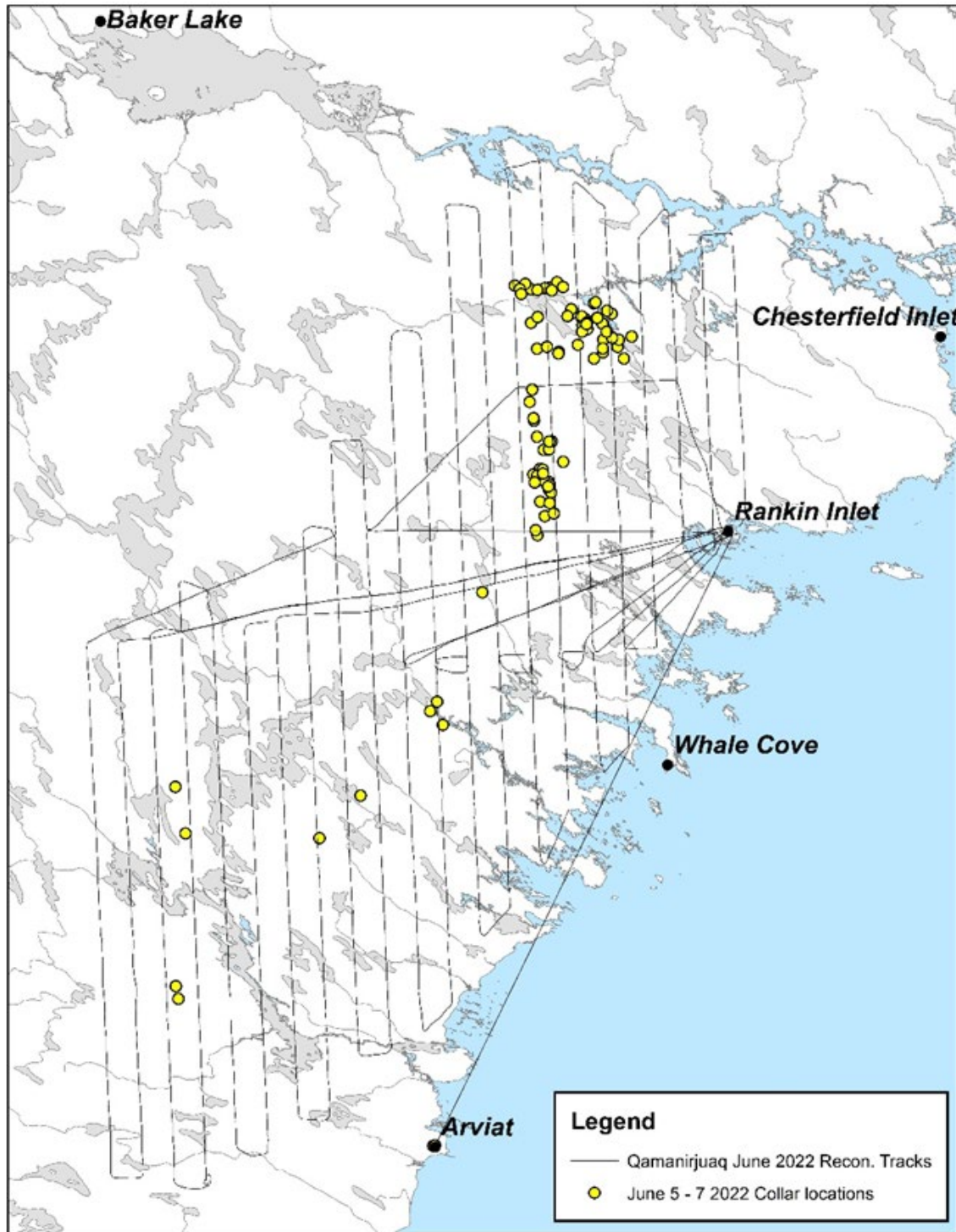


Figure 6. Qamanirjuaq Caribou Herd June calving-ground reconnaissance survey flown June 6<sup>th</sup> and 7<sup>th</sup>, 2022. Yellow dots show all collared Qamanirjuaq caribou cow locations over the same period.

### 3.1.3 Visual Abundance Surveys

The visual abundance survey was conducted within 4 low to medium density strata all located entirely within the breeding female/female distribution identified using reconnaissance survey results (**Figure 7**). Stratum boundaries were visually aligned with the relative density graphic to capture transect segments of similar density. All visual strata were surveyed immediately following the completion of the systematic reconnaissance of breeding female/female distributions.

The visual survey followed the same methods as the systematic reconnaissance survey with the exception of transect allocation, coverage, and alignment. Transects within each of one medium density (vis-1), one medium-low density (vis-4), and two low density (vis-3+4) strata were aligned at right angles to the longitudinal axis of the stratum to maximize the total number of transects (N). Transect spacing was allocated based on relative densities calculated within each individual stratum (**Figure 7**). Within the medium density stratum transects were placed three kilometers apart providing approximately 30% coverage, while within low and very-low density strata, transect spacing was set at 3.17 km and 10 km yielding 30% and 9% coverage respectively.

Visual survey data collected within each stratum were analyzed using Jolly's Method 2 for unequal sample sizes (Jolly 1969 *in* Norton-Griffiths 1978). Only counts of adults were used for the final population estimates. Lake areas were not subtracted from the total area calculations used in density calculations.

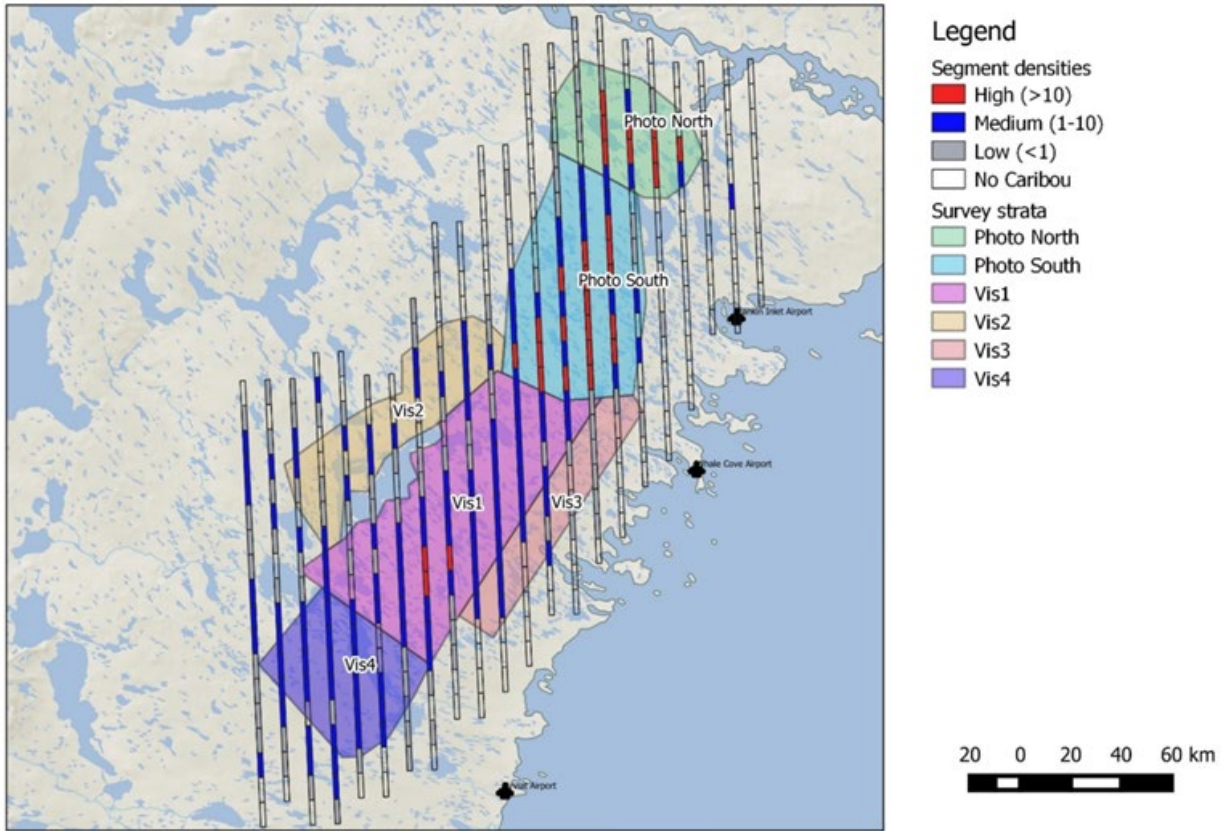


Figure 7. Reconnaissance transects with transect station relative densities overlaying strata derived using reconnaissance relative abundance segment estimates. Data collected, and strata derived during the 2022 Qamanirjuaq calving ground photographic abundance survey.

### **3.1.4 Photographic Abundance Surveys**

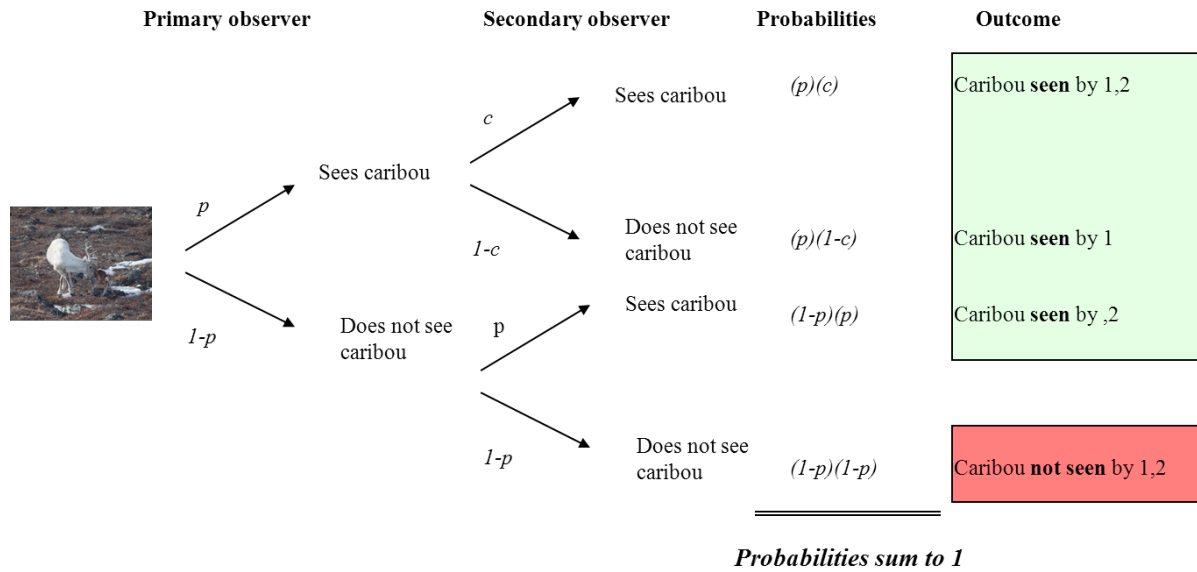
Aerial photography provides more accurate abundance estimates of large mammals due to its ability to remove in-flight observer error and bias, and replace it with more controlled interpretation after the fact. This advantage is significantly increased when caribou relative densities exceed 10 to 15 caribou per kilometer squared, a point at which in flight observer error can become substantial. The photographic component of the survey used a single engine low wing Piper Malibu turbine aircraft. The aircraft was equipped with a radar altimeter and a digital camera with forward motion compensator. The photographic component of the 2022 Qamanirjuaq calving ground survey was designed to capture relative densities of adult and yearling female and breeding female caribou in excess of ten caribou per kilometer squared as close to the completion of the systematic reconnaissance survey as possible. The photographic abundance survey was completed June 8<sup>th</sup>, 2022. As in the visual survey, transect spacing within the high-density photo strata was allocated based on proportional densities and available resources (Heard, 1987). During the June 2022 survey effort, high density transect coverage ranged from 45% to 54% coverage over the photo-north and photo-south photographic strata respectfully. Approximately 4,000 photos were taken within delineated photographic abundance strata, representing an estimated 900 linear kilometers of flying.

### **3.1.5 Double Observer Pair Visual Survey Analysis**

Removal models in the *mrds* package were used to estimate and model sighting probabilities. In this context, double observer sampling can be considered a 2-sample mark-recapture trial in which some caribou are seen (“marked”) by the (“session 1”) primary (front) observer of which some are also seen by the secondary (rear) observer (“session 2”). The second observer may also see caribou that the first observer did not see. This process is analogous to mark-recapture except that caribou are sighted and resighted rather than marked and recaptured. A group of caribou rather than the

individual caribou was the sample unit given that the sighting probabilities of caribou within a group were not independent.

In the context of dependent observer methods, the sighting probability of the secondary observer was not independent of the primary observer. To accommodate this, removal models were used which estimated  $p$  (the initial probability of sighting by the primary and secondary observer) and  $c$  (the probability of sighting by the secondary observer given that it had been already sighted by the primary observer). Note that resighting probability ( $c$ ) is not equivalent to the initial sighting probability of a caribou ( $p$ ). Also, the removal model assumed that the initial sighting probability of the primary and secondary observers was equal. Therefore, observers were switched midway in each survey day, and covariates were used to account for any differences that were caused by unequal sighting probabilities of primary and secondary observers (as discussed later). The combined probability that a group of caribou was seen by at least one of the observers ( $p^*$ ) was therefore  $1-(1-p)(1-p)$ . **Figure 8** provides a conceptual argument for how  $p^*$  is estimated. It is  $p^*$  that is then used to estimate the overall sightability of caribou and adjust counts for caribou not sighted.



**Figure 8.** Conceptual diagram of how the probability of both observers not sighting a caribou group is estimated, and how the probability that at least one of the observers sees the caribou group ( $p^*$ ) is estimated. The green boxes correspond to outcomes where caribou are seen and the red box corresponds where both observers do not see a caribou group. Mark-recapture methods are used to estimate sighting probabilities for the primary observer 1 and primary observer 2 (using data from when each observer is situated as the primary observer). Using these probabilities, the probability that a caribou is not seen can be estimated. In a method analogous to flipping a coin, each observer will see or not see a caribou as described by  $p$  (caribou seen) or  $1-p$  (caribou not seen). Each of these outcomes can then be multiplied to obtain the probabilities for both observers combined. Because the two observers do communicate, the events are not independent and therefore the re-sighting probability of the secondary observer has to be adjusted (to  $c$ ) using behavioral response removal models when the caribou was called out by the primary observer. However, since the probabilities sum to 1 it is possible to estimate the overall probability that the caribou group is sighted ( $p^*$ ) as one minus the probability that none of the observers saw the caribou  $(1-p_{ob1})(1-p_{ob2})$  (the red box) or by summing the probabilities in the green box.

Estimates of caribou within survey strata, and associated variance, were estimated using the mark-recapture distance sampling (MRDS) package (Laake et al. 2012) in program R program (R Development Core Team 2009). In MRDS, a full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, Laake et al. 2008b) was used therefore making it possible to derive double observer strip transect estimates. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002) with the “S2” encounter rate estimator (Fewster et al. 2009). Estimates from MRDS were cross checked with strip transect estimates (that assume sightability=1) using the formulas of Jolly (1969) (Krebs, 1998). Data was explored graphically using the ggplot2 (Wickham, 2009) R package. GIS operations were conducted using the simple features (Pebesma, 2018) R package and QGIS software (QGIS Foundation 2020).

### ***3.1.6 Modelling of sighting probability variation***

One assumption of the double observer method is that each caribou group observed had an equal probability of being sighted. To account for differences in sightability we also considered the following sightability covariates in the MRDS analysis (**Table 2**). Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. Previous analyses (Campbell et al. 2012, Boulanger et al. 2014a) suggested that the size of the group of caribou had a strong influence on sighting probabilities and therefore we considered linear and log-linear relationships between group size and sightability (**Table 2**). Cloud and snow cover, recorded by data recorders, were recorded as ordinal rankings as they changed across any given observation entry. We suspected that sightability was most likely lowest in mixed snow cover conditions and therefore we considered both categorical and linear models to describe variation in sightability caused by snow cover. Cloud cover, or the lack there of, could also influence sightability by causing glare, flat light, or variable lighting. We used the same basic strategy to model cloud cover variation and snow cover variation. Survey phase (reconnaissance or visual abundance survey) was also considered.

Table 2. Covariates used to model variation in sightability for double observer analysis.

Covariate	Acronym	Description
observer pair	obs	each unique observer pair
group size	size	size of caribou group observed
	Log(size)	Natural log of group size
snow cover	snowF	snow cover (0,25,75,100)
	snowc	continuous
cloud cover	cloudcat	cloud cover (0,10,25,75,100)
	cloud	continuous
Strata	Strata	Strata
Survey phase	Phase	Recon or visual

The fit of models was evaluated using the Akaike Information Criterion (AIC) index of model fit. The model with the lowest  $AIC_c$  score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson, 1998). The difference in  $AIC_c$  values between the most supported model and other models ( $\Delta AIC_c$ ) was also used to evaluate the fit of models when their  $AIC_c$  scores were close. In general, any model with a  $\Delta AIC_c$  score of less than 2 was worthy of consideration.

### 3.1.7 Data recorder observations

Data recorder observations, where data recorders saw caribou that were not observed by observers, were recorded for all of the observer pairs. Data recorder observations do not necessarily need to be included in analyses given that the method allows for observers to miss caribou and therefore the fact that a small percentage of caribou are only seen by data recorders is not surprising. In the context of the dependent double observer method, use of data recorder observations presents some challenges. First, observations from the data recorder are partial; the data recorder only records observations that he/she observes but are not observed by either other observer which

limits the ability to use data recorder observers as a unique third observer. In this context, data recorder observations supplement the secondary observer in “testing” the primary observer.

One approach to include data recorder observations is to pool the secondary observer and data recorder as a single observer. The main potential issue caused by this approach is that it will increase the difference in detection probabilities between the primary and secondary observer regardless of observer position therefore violating the assumption of equal detection probabilities between observers. This could be thought of as always having one primary and 2 secondary observers that have a combined higher detection probability. Because the removal estimator considers observer order, this approach could potentially cause a negative bias in detection probabilities with a subsequent positive bias in abundance estimates. This scenario would likely correspond to cases when both observers have reasonable sighting probabilities. Another scenario, that likely occurred, was where both observers were weak and not including data recorder observations substantively reduced observations leading to a negative bias in estimates. In this case, observer probabilities are low and cannot be estimated using the double observer data alone. To detect this potential scenario, we estimated detection probabilities with and without data recorder observations under that rationale that these pairs could be identified by large differences in detection probabilities with data recorder observations included and excluded. In this case observations from these pairs were potentially included in the analysis with the secondary and data recorder observations pooled.

### ***3.1.8 Analysis of trend***

As an initial step estimates were compared using a t-test (Zar, 1996) with variances and degrees of freedom calculated using the formulas of (Gasaway et al. 1986). This comparison gave an initial indication of change in population size, but did not consider the survey interval between two surveys.

Estimates of trend were derived using ratios of estimates for pooled and post stratified estimates. A simulation approach that assumed log-normal distributions of estimates

was used to test for significance between successive estimates as well as confidence limits on overall (gross) change and yearly change in estimates. Confidence limits were then derived based on the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentile of the resulting distributions of gross change (GC) and annual change (with  $\lambda = GC^{(1/\text{survey interval})}$ ).

Weighted regression analysis was also used to estimate trend from the time series of data (Brown and Rothery 1993). Each estimate was weighted by the inverse of its variance to account for unequal variances of surveys, and to give more weight to the more precise surveys.

## **3.2 Composition Surveys**

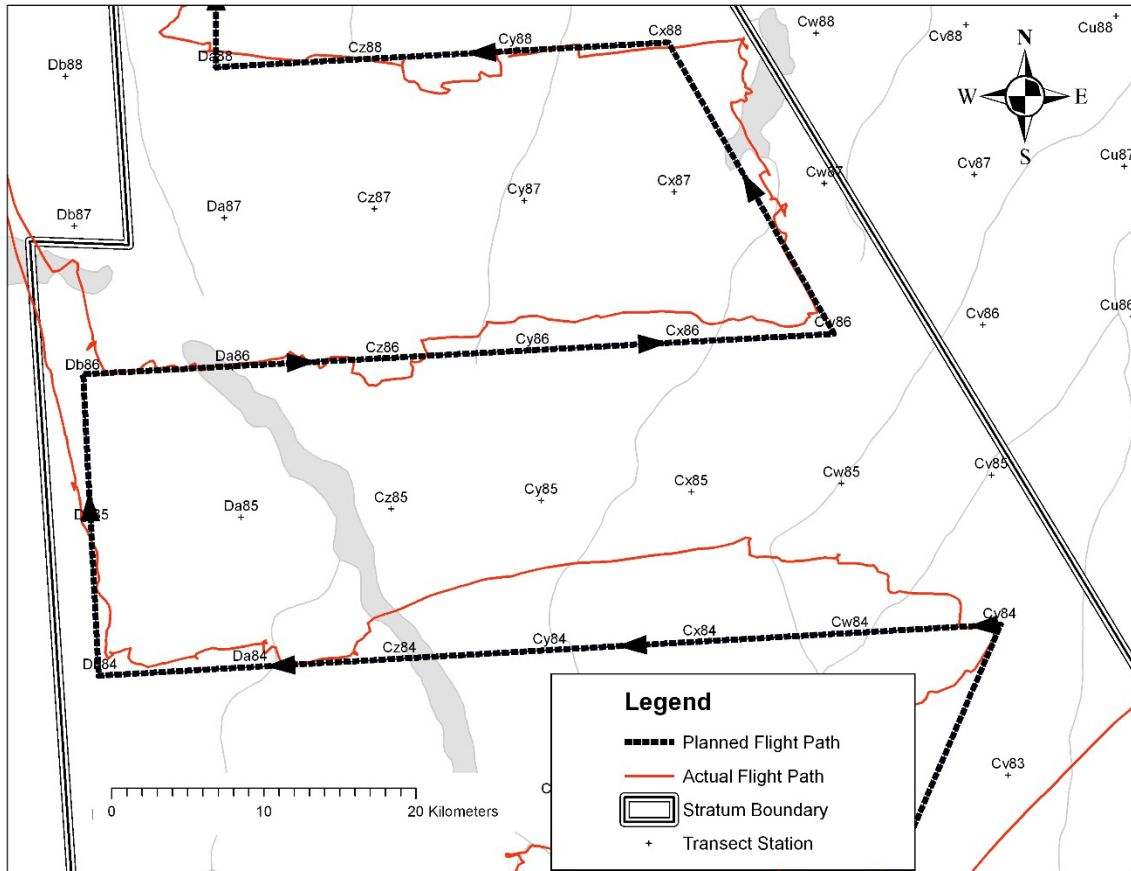
### **3.2.1 Calving**

Composition studies were conducted concurrently with the abundance phase photographic and visual surveys that immediately followed study area stratification. Caribou were classified as yearlings ( $\geq 1.0$  but  $< 1.1$  years of age termed 1+ years of age in this document), bulls, cows with calves ( $< 1$  month old) and 0, 1, or 2 antlers, cows with udders and 0, 1, or 2 antlers, and udderless cows with 0, 1, or 2 antlers. Breeding cows were tallied as cows with calves, cows with udders, and udderless cows with antlers. Adult udderless cows with no antlers were classified as non-breeding females while all remaining adult females were classified as breeding females. All remaining caribou were classified as either yearlings or bulls. The proportion of breeding and non-breeding females was then determined using these categorizations. Bootstrap methods were used to obtain variance estimates for all strata. In this case, 1,000 resampling's of the data were used and the mean and standard deviation from resampling were used as point estimates with associated standard error as a proportion of breeding females, non-breeding females, calves, yearlings and bulls (Manly, 1997).

Composition survey effort was allocated as consistently as possible within each stratum. Selection of flight paths were based on fuel cache locations and caribou aggregations but consistently used the reconnaissance transect station locations in an attempt to maintain consistent coverage throughout the strata being sampled. GPS waypoints were recorded for all groups of caribou where they were first encountered.

June composition surveys were timed to begin concurrently with abundance photographic and visual surveys to ensure minimal movement between strata. Sampling was structured to begin at a fuel cache then proceeded to a predetermined transect station within a maximum of two (2) kilometers of the strata corner/boundary. From this station a Bell 206 Long Ranger aircraft would proceed to the next nearest transect station to the north and/or south, priority sampling the next nearest caribou group including individual caribou (**Figure 9**). At times, observed groups of caribou “pulled” the aircrew from the pre-planned flight path at which time the aircrew would stop sampling caribou groups that were seen greater than 10 kilometers (half the distance between reconnaissance transects) perpendicular to the original flight path. From this point, only caribou groups observed within this ten-kilometer buffer would be sampled and an attempt to rejoin the original flight path made. During re-positioning flights from the stratum to the fuel caches, caribou encountered within a maximum of 2 km inside of target stratum boundaries were classified opportunistically and variation of flight paths was held to within 2 km to conserve fuel and reduce deviation from the planned flight paths and fuel caches.

Estimates of the proportion of females and breeding females were then multiplied by the double observer pair estimate of all adult caribou and yearlings for each stratum to obtain an estimate of the number of non-breeding and breeding females within the survey study area extents. Variances were obtained for the combined estimate using the delta method (Seber, 1982; Williams et al., 2002) assuming no correlation between the two estimates.



**Figure 9.** Strata composition flight lines vs. planned routes. Deviations were the result of observed caribou groups away from flight paths. The next nearest group would be classified up to a maximum of 10 km (half way between adjacent transects) perpendicular to the planned flight path.

### 3.2.2 *Fall/Rut*

The purpose of a Qamanirjuaq fall-rut composition survey is to determine the proportion of females in the population at a time of year when all age and sex classes come together into large mixed groups for the breeding season (rut). Though a combined estimate of breeding and non-breeding females, used in this report, is the most precise, and as such, represents the best indicator of population trend, for management and conservation education purposes, an estimate of total population size is desirable.

The Qamanirjuaq caribou fall composition survey was flown out of Arviat Nunavut, Tadoule Lake Manitoba, and Lac Brochet Manitoba, between October 15<sup>th</sup> and 20<sup>th</sup> 2014 (**Figure 10**). The survey itself used the locations of 20 Telonics GPS III and IV collars to locate aggregations of caribou and establish search patterns. All caribou groups encountered between and in the immediate vicinity of collared adult female caribou were classified and tracks followed to locate other groups. All collar locations were searched a minimum of twenty kilometers to the north, east, south and west of the outer most collar locations, with exceptions made when adjacent areas included boulder fields, large lakes, the Hudson Bay coast, or were restricted due to fuel limitations. Fresh tracks in snow were used in all areas to locate new groups. The search of an area represented by collared caribou cows would terminate following the cessation of fresh tracks or when a possibility of double sampling occurred. GPS tracks were also used to ensure the same groups were not re-sampled, which at times required the skipping of groups where there was a risk of mixing. Once the area around a collar or cluster of collars was thoroughly searched, the survey would proceed to the next nearest collar to begin a similar search pattern. In total, 121 groups, or 8,856 individual Qamanirjuaq caribou were classified.

To estimate the total population size, the number of non-breeding and breeding females estimated in June 2022, was divided by the product of the proportion of females in the population as determined during the 2014 fall composition studies. The proportion of females in the population assumed a 50:50 sex ratio for yearlings. We suggest that the proportion of females estimated on the calving ground is a better estimator of herd size and trend as the proportion of females pregnant, used to extrapolate a whole herd

estimate from breeding females alone, is based on dated information and for the Qamanirjuaq population, not sampled since fall 2014. It should be noted that inter-annual variation in sex ratio does occur though large changes in herd sex ratio would be considered atypical for these large mainland migratory herds (Gunn et al. 2005; Sober, 1982).

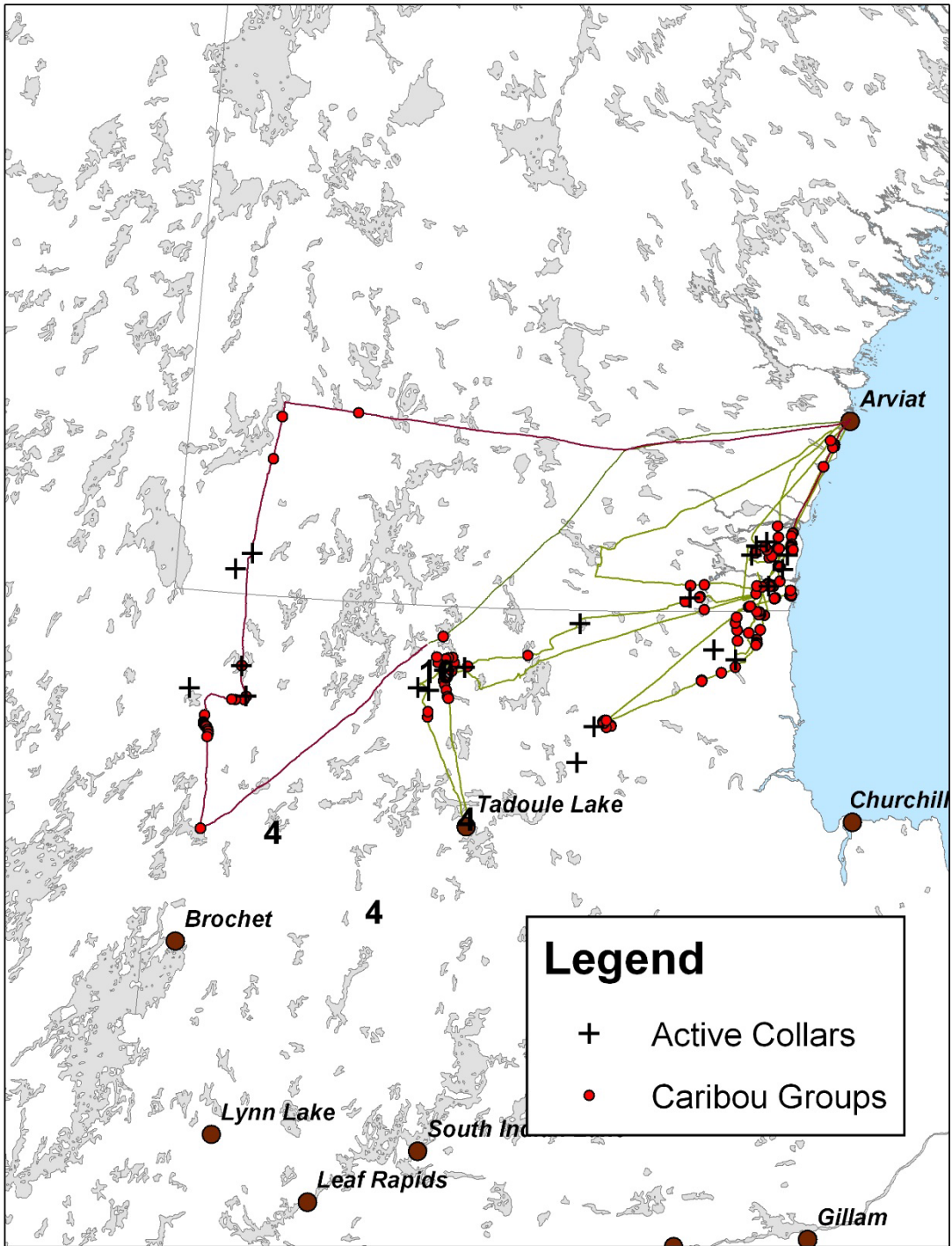


Figure 10. Qamanirjuaq fall composition flight tracks and caribou group locations, October 15 – 20<sup>th</sup>, 2014 (numbers indicate alternate fuel caches).

### **3.3 Spatial studies**

Utilization distributions were generated for the calving season using telemetry data collected for Qamanirjuaq caribou between 2000 and 2022. Data were resampled to daily locations to address differences in sampling frequencies between collars and only locations collected between April 15<sup>th</sup> and July 3<sup>rd</sup> were considered in the analysis. All telemetry locations were attributed with a season based on the following date ranges: spring migration (April 15 – June 8), calving (June 9 – June 22), and post-calving (June 23 – July 3<sup>rd</sup>). To account for variation in the calving dates between individuals and years, each collar was reviewed and the start and end dates for the calving season were adjusted based on changes in movement pattern. Once the calving date ranges had been refined, a kernel density estimation (KDE) approach was used to generate utilization distributions for a series of data subsets to illustrate changes in calving distributions for Qamanirjuaq through time. The first calving time series examined changes in distribution over four years: 2008, 2014, 2017, and 2022. For each of the four years, the calving data were extracted and used to generate a KDE using a fixed bandwidth value of 9.5 km. The fixed bandwidth value is the average of the individual bandwidths calculated for each year using Silverman (1986). A fixed bandwidth was selected over the individual values to balance the differences in sample sizes between the four time periods. The second time series examined changes in distributions between five-year periods: 2003-2007, 2008-2021, 2013-2017, and 2018-2022. As with the single year time series, KDEs were generated for each five-year subset using a fixed bandwidth of 12.6 km. The final time series examines annual changes in calving distributions using KDEs generated for each year from 2004 to 2022. As there were fewer than 30 locations for the calving season for years 2000 to 2003, the locations for these years were pooled to provide a more representative sample of calving distributions for this period. A fixed bandwidth of 12km was used to generate the annual kernel density utilization distributions.

## 4.0 RESULTS

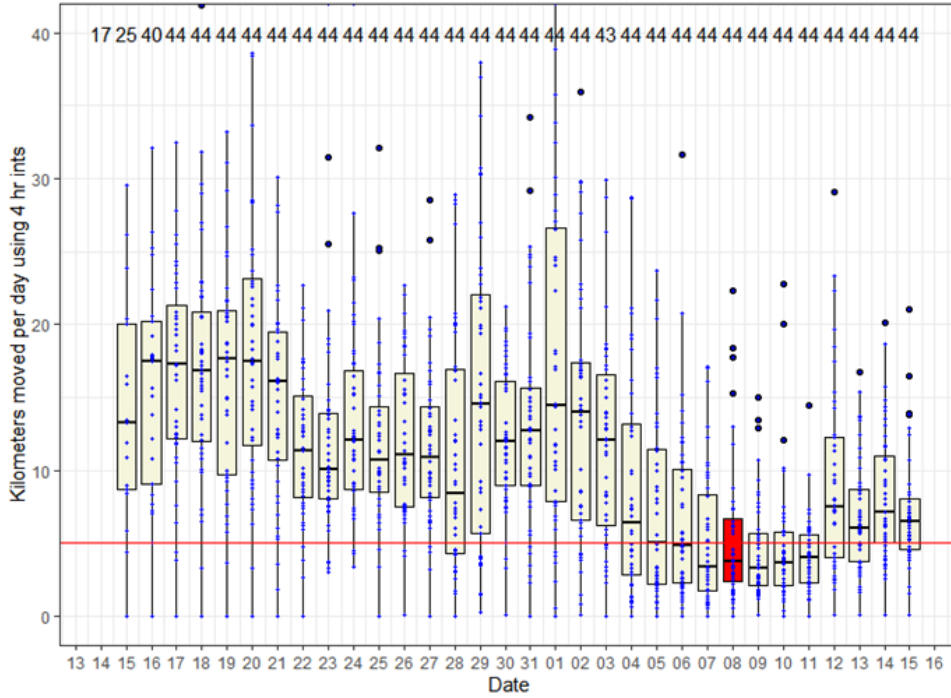
### 4.1 Layout of Survey Strata

Survey strata were designed based on reconnaissance survey flight density observations, and the movements of 44 collared female caribou. The threshold for the peak of calving was based upon observations of cow/calf proportions and/or when movement rates declined to less than 5 km per day for collared cows (**Figure 11**).

The Qamanirjuaq June 2022 abundance survey was the shortest on record, largely due to the relatively small geographic area within which the spring migration occurred, geographically tight aggregations of females on the calving ground, and excellent weather. The survey took a total of 5 days to complete, 2 days for the reconnaissance survey, one day for the photographic survey, two days for the visual abundance survey, and 3 days for the composition survey (**Table 3**).

Survey strata were laid out based on reconnaissance survey segment densities (**Figure 12**) and the initial fixed wing composition of caribou observed within reconnaissance segments (**Figure 13**). Unlike June 2017, the main migration path of collared caribou cows occurred within a narrow corridor inland from, but parallel to, the Hudson Bay coast, as initially determined using adult cow collar locations, later verified during the reconnaissance survey (**Figure 14**). High densities of adult female caribou were observed within the northern extents of the 2022 Qamanirjuaq herd annual concentrated calving area which were stratified into photographic strata. Further south of these higher female densities were the visual strata, mainly composed of non-breeding females, yearlings, and bull caribou. As the majority of observations and their associated densities fell below the 10 caribou/km<sup>2</sup> threshold, photographic methods were not required. Further to reconnaissance observations, the movements of collared caribou indicated that the caribou moved to the northwest in the photo stratum then circled back

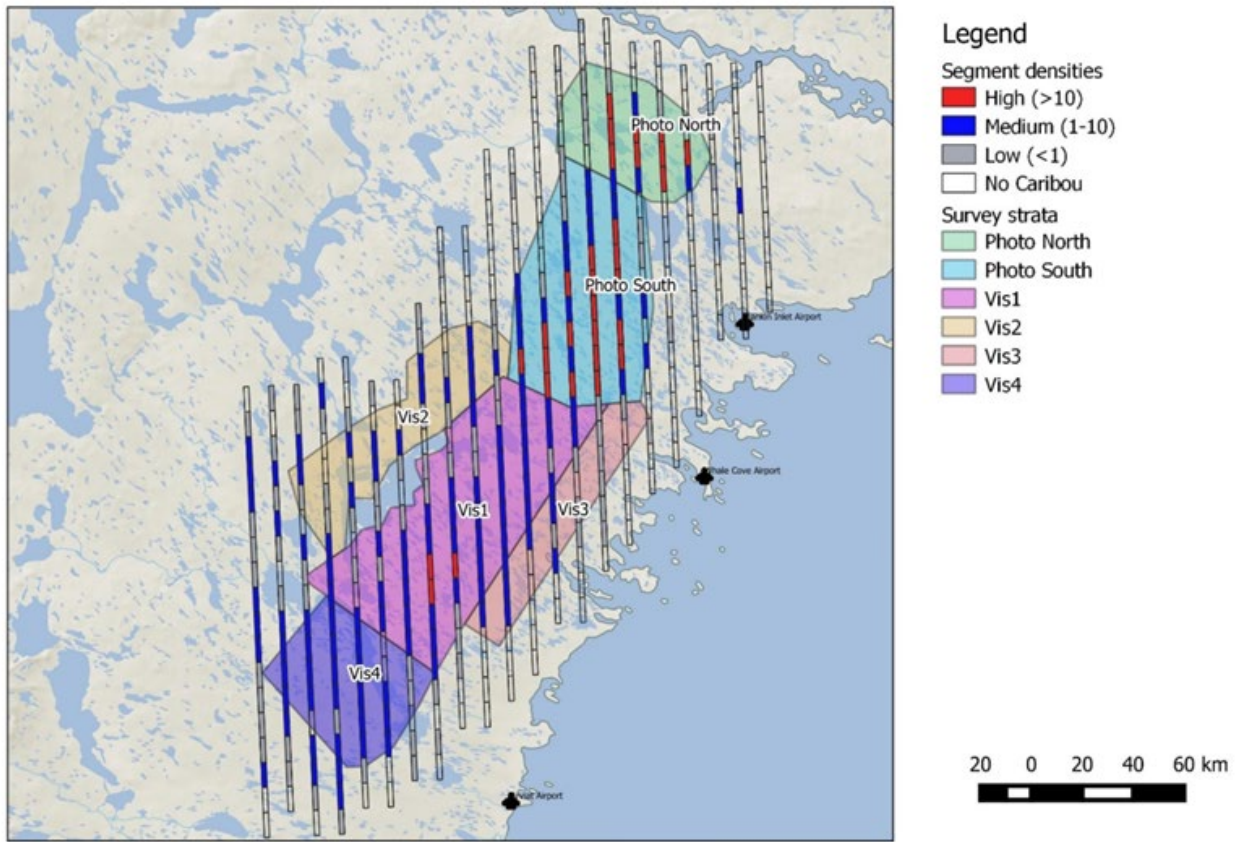
to the northeast. The photo north stratum was extended to the northwest to capture this movement as well as guard against movement to the northwest which occurred during the 2017 photo survey (**Figure 15**). The lines in this area were considered a buffer and preliminary with the potential of eliminating them if movement did not occur.



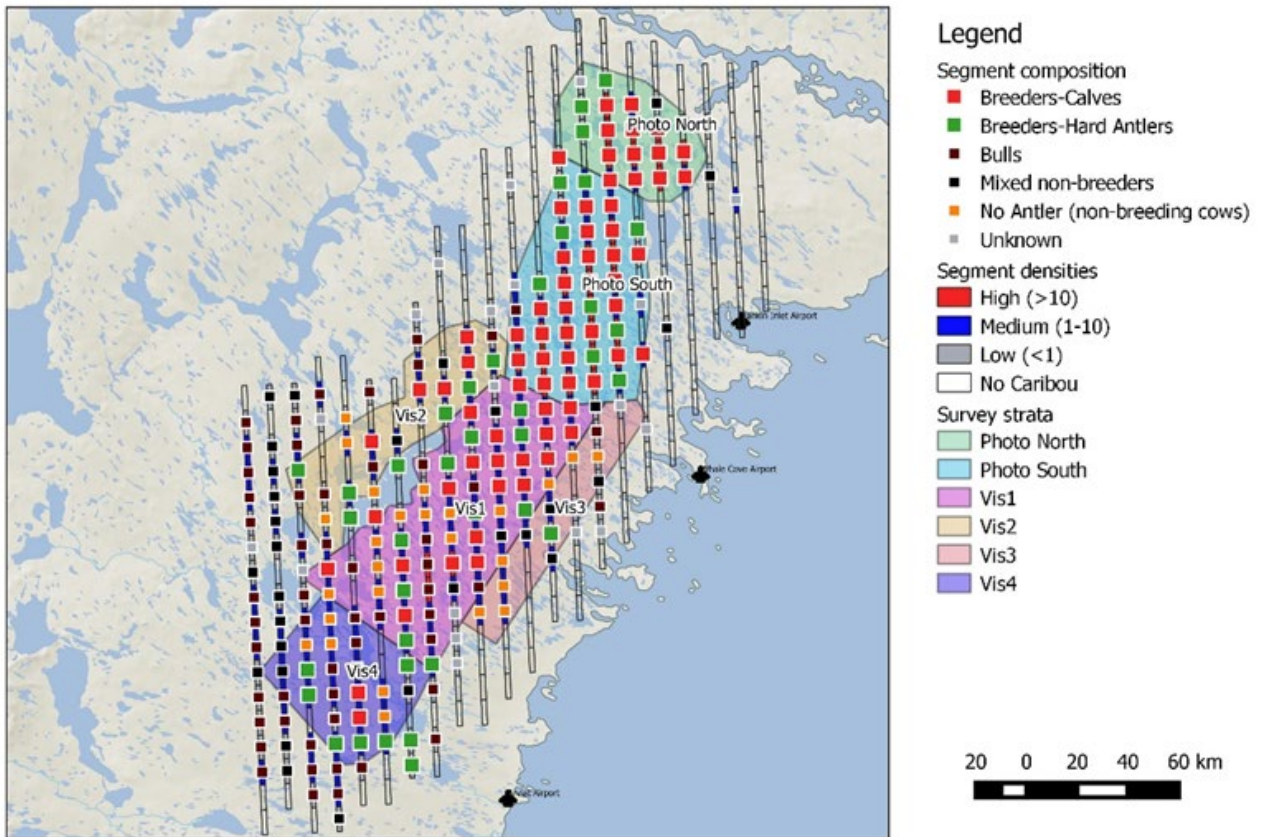
**Figure 11.** Collar movement rates of Qamanirjuaq cows during the June 2022 Qamanirjuaq calving ground photo survey. Sample sizes of collars are given above each boxplot. The boxplot for the primary date that the photo survey occurred is highlighted in red.

**Table 3.** Survey Initiation and completion dates for the June 2022 Qamanirjuaq Calving Ground Photographic Survey.

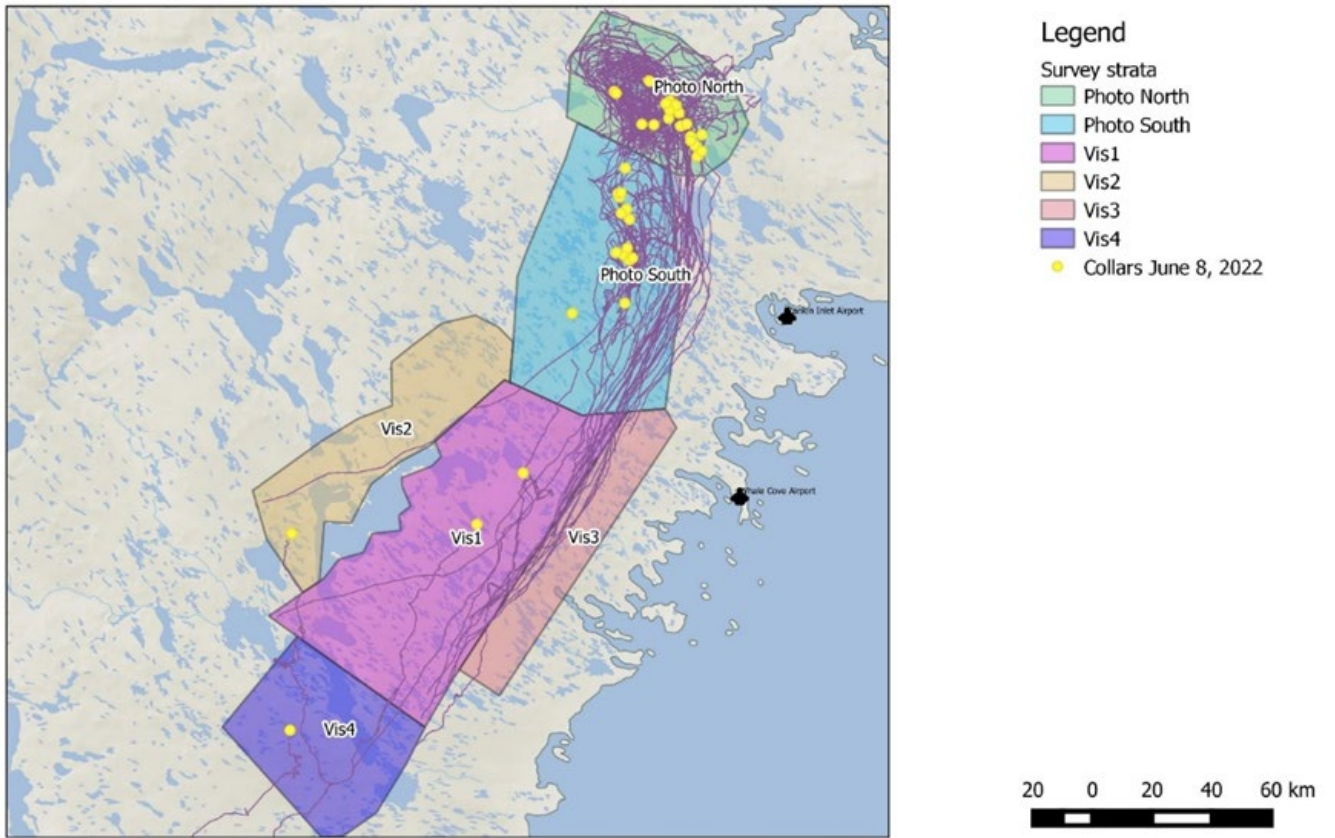
Survey Activity	Jun-06	Jun-07	Jun-08	Jun-09	Jun-10
Systematic Reconnaissance	X	X			
Visual Abundance			X	X	
Photographic Abundance			X		
Abundance Strata Composition			X	X	X



**Figure 12.** June 2022 Qamanirjuaq reconnaissance survey segment density.



**Figure 13.** June 2022 Qamanirjuaq reconnaissance survey segment composition overlaid on segment densities as shown in Figure 12.



**Figure 14.** Qamanirjuaq June 2022 calving-ground survey collar movements from May 15 to the beginning of aerial survey observations June 8, 2022 (yellow points).

## 4.2 Allocation of Survey Effort

Following stratification, preliminary estimates of density were derived for each stratum which were then used to allocate the number of transects flown per strata (**Table 4**). Allocation for the photo strata was based on a limit of 5,000 to 6,000 photos total. Given that survey weather was favorable, we set a target GSD (Ground Surface Density or Ground Sampling Distance) level of 7 which would be equivalent to an estimated 5,000 photos to complete all photographic strata (**Figure 15**). A GSD 7 would provide individual photographs within which the distance between two consecutive pixel centers, as measured on the ground, would be 7 cm. We also set an approximate limit of 1,600 km of flying on transect which amounts to slightly over a day of flying for a single photo plane. Allocations suggested higher coverage for the Photo-north stratum given that the mean density was higher than the Photo-south stratum, however, the Photo-south stratum was approximately twice the size of the Photo-north strata and therefore received more transect km’s of flying.

**Table 4** The June 2022 Qamanirjuaq calving-ground abundance survey transect allocations based on reconnaissance observations and achieved GSD levels within photographic (high density) strata.

Strata	area	Recon estimates			Allocation (GSD 7)				Actual flown		
		Density	N	CV	SE-based	N-Based	% effort	Coverage	Transects	Km	Coverage
North	2121.3	12.9	27,470	64.0%	23	24	45.5%	47.1	19	664	44%
South	4131.8	7.4	30,502	35.5%	17	16	54.5%	22.7	20	958	33%
										1,622	

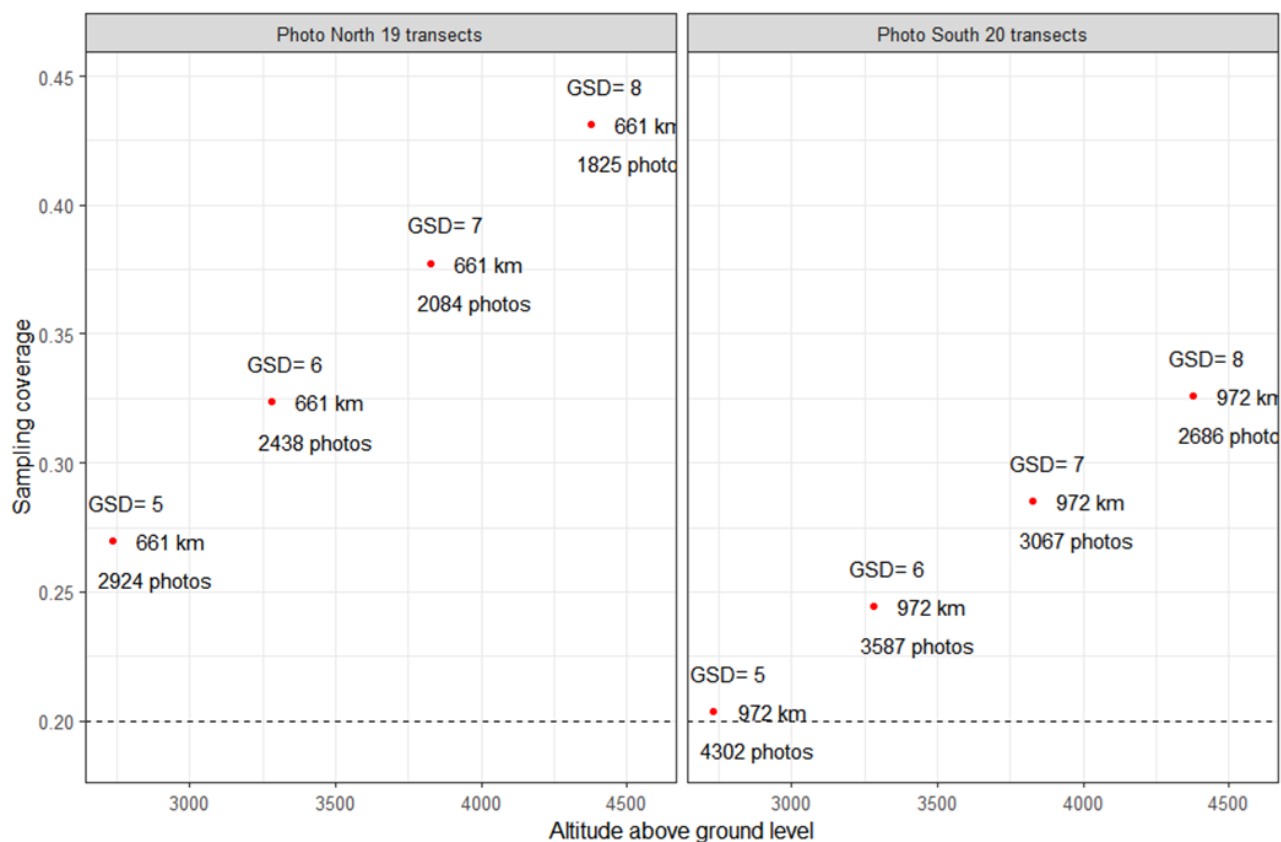
Graphically, it can be seen that the desired resolution, coverage, and photo numbers would be achieved at either a GSD 7 or 8, with GSD 8 more desirable as it would require

fewer photographs (**Figure 15**). Given a stable high-pressure system in the survey area we judged these targets were reasonable.

The remaining strata were surveyed visually with allocations based upon the total number of kilometers that the two survey planes could fly in two days of flying assuming two trips per day with ferrying to survey strata factored into the calculations (**Table 5**). This amounted to 3,000 kilometers of flying on transect (including ferrying in-between transects). The Vis-1 strata had the highest densities of caribou outside of the photographic strata and likely the highest proportion of both breeding and non-breeding female caribou within non-photographic (Visual) strata and therefore it received higher coverage than other visual stratum. The Vis-4 stratum had higher densities, however, it was composed of mainly non-breeders and therefore received slightly lower coverage than visual 1.

**Table 5.** Allocations of visual strata based on 3,000 km’s of flying on transect.

Strata	area	Recon estimates					Allocation			Actual flown	
		Density	N	CV	SE-based	N-based	%Effort	Coverage SE	Coverage N	transects	km
Vis1	5496.8	3.4	18,906	14.2%	39	33	72.4%	28.2%	24.0%	35	1,611
Vis2	2570.9	1.5	3,797	28.6%	23	21	13.6%	16.6%	15.0%	20	487
Vis3	1713.0	1.2	2,130	36.2%	20	22	6.5%	14.6%	15.6%	20	311
Vis4	2453.8	2.3	5,691	11.0%	5	12	7.5%	7.0%	17.4%	12	519
											2,928



**Figure 15.** Strata coverage and number of photos estimated at different aircraft altitudes during the June 2022 Qamanirjuaq calving-ground photo-survey.

### **4.3 Survey Layout Used for Estimates**

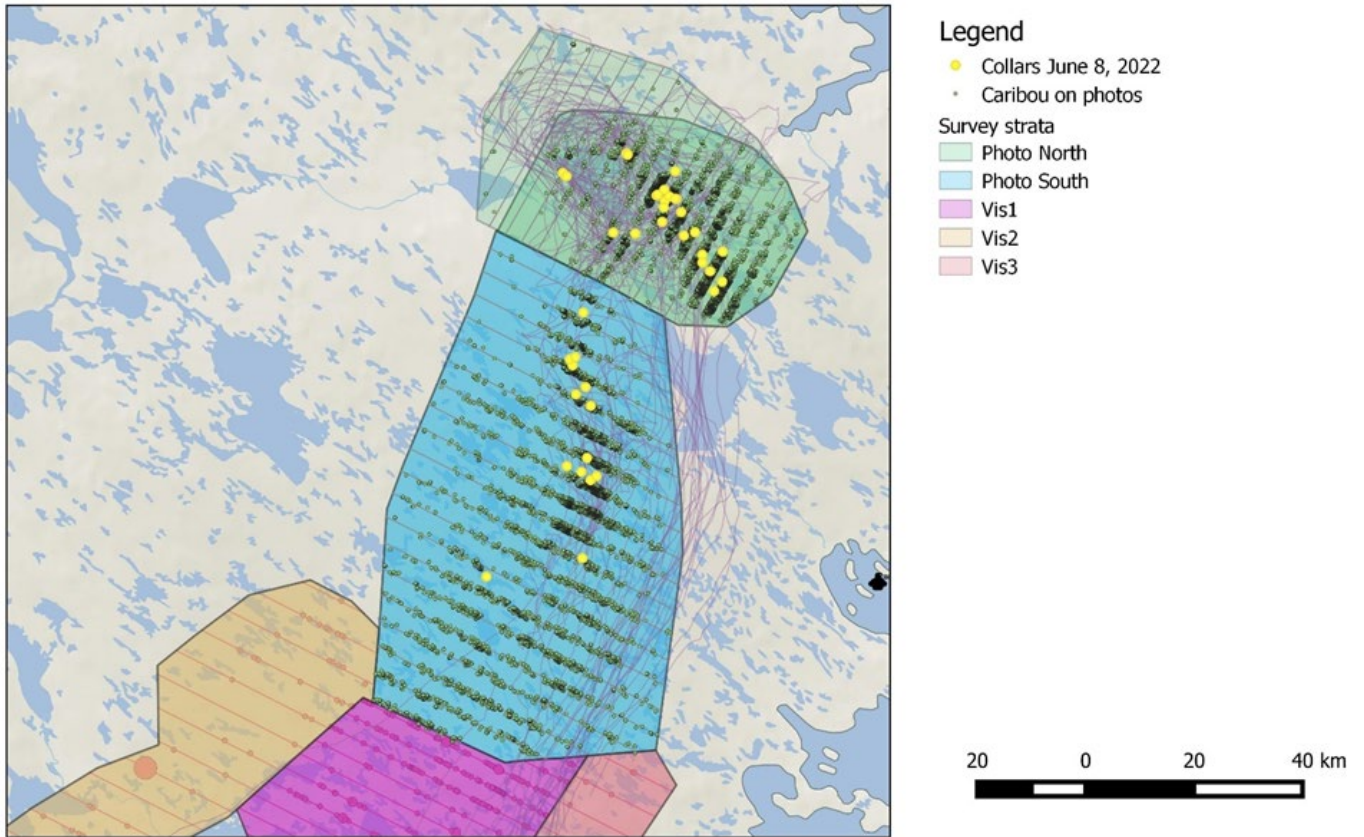
The Photo-north stratum was expanded west to buffer for potential west movement of caribou, and to capture the migration path of caribou to their annual core calving area (**Figure 16**). Inspection of the distribution of caribou on the photos revealed that caribou had moved east out of the western extents of the stratum that were initially set up as a western buffer. These lines contained few (65) caribou on transect and were therefore not representative of this high-density photographic stratum. As a result, the western most transects were removed to account for this movement within the photo-north stratum (**Figure 16**).

**Table 5** summarizes the dimensions and sampling effort for each of the strata sampled. The area surveyed in each stratum was estimated by the total transect kilometers flown multiplied by the strip width of the survey (0.8 km for visual and with variable widths for photo stratum). Coverage was estimated as the area surveyed divided by the strata area. Naïve density for stratum was then estimated as the total count of caribou divided by the area surveyed. From this, it can be seen that the density of caribou on the high-photographic strata were much higher than the visual stratum.

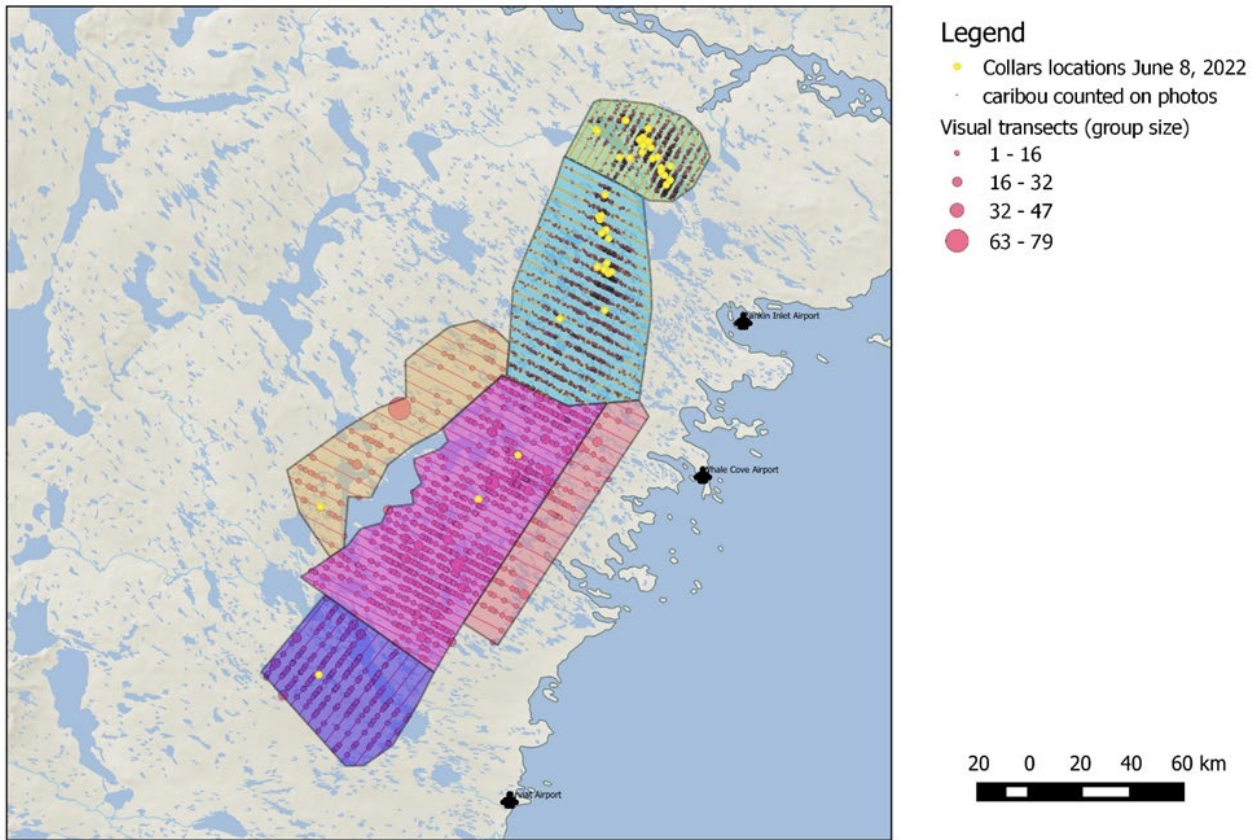
A preliminary estimate of abundance can be gained by dividing the caribou counted by coverage (**Table 6**). This estimate is preliminary for visual surveys given that estimates are not corrected using double observer methods. However, the preliminary estimate demonstrates that the actual means of obtaining strata estimates is relatively simple. It is just the estimate of caribou counted divided by the proportion of each strata sampled (the coverage). A plot of visual and photo survey results (**Figure 17**) suggests that the high-north photo stratum delineated the core group of female caribou as defined by caribou counted on photos as well as satellite collar locations and proportions. The migration trail was then sampled by the photo south and visual transects.

**Table 6.** Summary of sampling and count-based results by strata. Preliminary N is estimated based on the number of caribou counted on transect divided by survey coverage.

Strata	Strata area (km <sup>2</sup> )	Transects	Area surveyed	coverage	Caribou counted	Density on transect	Preliminary N
<u>Photo strata</u>							
Photo North	1585.0	15	664.0	41.9%	41,314	62.22	98,601
Photo South	4390.4	20	1383.4	31.5%	24,945	18.03	79,190
<u>Visual strata</u>							
Vis1	5496.8	35	1288.5	23.4%	5,323	4.13	22,748
Vis2	2570.9	20	389.4	15.1%	435	1.12	2,881
Vis3	1713.0	20	248.8	14.5%	425	1.71	2,931
Vis4	2453.8	12	415.5	16.9%	1,066	2.57	6,308



**Figure 16.** The 2022 Qamanirjuaq June calving-ground survey reduced photo north stratum (darker green area) in comparison to full photo-north stratum (Light green area).



**Figure 17.** Summary of photo and visual survey with group sizes indicated for visual surveys and densities of individual caribou shown for photo data (light green and blue areas), for the 2022 Qamanirjuaq June calving-ground survey.

## 4.4 Analysis of Survey Data

### 4.4.1 Visual survey double observer pair surveys

The majority of caribou were seen as single caribou or small groups with few larger group sizes observed. The relative proportion of caribou not seen by both observers was highest in group sizes of 3 or less with both observers seeing the majority of group sizes that were greater than 3. Compared to previous surveys (Campbell et al. 2012), the proportion of caribou seen by both observers was high suggesting that overall sightability was high (**Figure 18**).

During the reconnaissance surveys the core of the calving ground was surveyed which led to observations of larger group sizes (**Figure 19**). This area was surveyed using the photo plane for the abundance phase of the survey and therefore the number of larger groups was lower during the abundance phase. The main focus of the analysis was to estimate sightability for the visual survey phase. For this reason, the reconnaissance survey data set was filtered to only include group sizes of 80 or less caribou which was similar to the range of group sizes observed in the visual survey. Photo strata counts increased the precision of group counts within high density aggregations, and visual strata had significantly lower densities and associated smaller group sizes. Additionally, the visual counting of areas of very-high caribou densities generally leads to a breakdown in establishing the defined 200-meter separation between groups as observers often combine groups due to the longer time it takes to count more caribou. Because of this, large groups often flow into one another yielding higher group sizes. Because the main focus of the analysis was to estimate sightability for the visual survey phase, the recon survey data set was filtered to only include group sizes of 80 or less which was similar to the range of group sizes observed in the visual survey.

Overall, there were 6 unique pairs of observers during the visual portion of the survey. Of these pairs, 5 of them switched position from primary to secondary during the survey (**Table 7**). One pair (pair 0) only occurred during the reconnaissance survey and did not switch and for this reason was not used in the analysis. Pair 2 was composed of 4

individuals given that the 2<sup>nd</sup> pairing only had 12 sightings preventing modelling of sighting probabilities. Data recorder observations mainly occurred for pair 1.

Table 7. Summary of observer pairings used in the double observer analysis.

Pair	Observers		Observation type/frequencies				
	front	rear	Both	Front	Rear	Data recorder	Total
0	JR	OS	63	11	0	0	74
1	DM	OS	413	15	125	60	613
1	OS	DM	82	6	0	16	104
2	DL	JV	441	31	9	8	489
2	JV	DL	104	5	25	5	139
2	DL	LI	9	0	0	0	9
2	LI	DL	0	2	1	0	3
3	JB	LI	574	7	14	8	603
3	LI	JB	227	5	13	2	247
4	JE	RT	80	20	7	0	107
4	RT	JE	486	13	47	1	547

A graphical representation of detections suggests most detection differences occurred when group sizes were low (**Figure 18**). Pair 1 had a higher relative frequency of missed observations than other pairs, however, some differences also existed between other pairs (**Figure 19**).

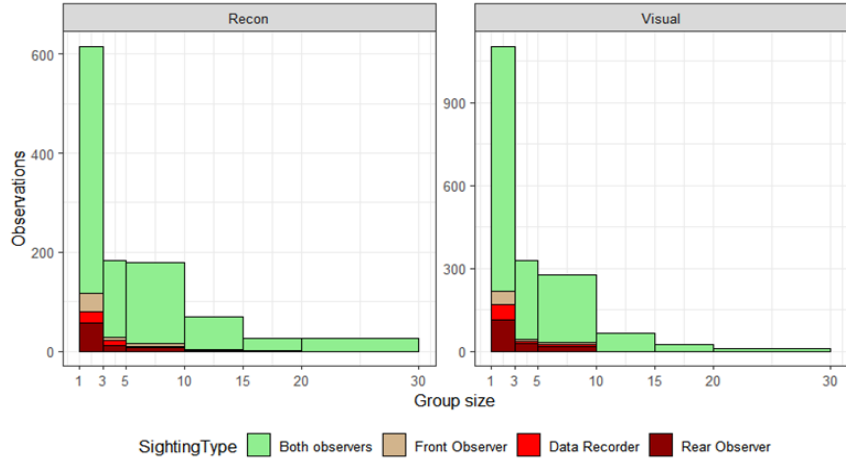
The pooled data from observer pairs (**Table 8**) suggested slight differences in proportions of caribou sighted as indicated by the proportion of caribou only observed by the secondary observer. Graphically, it can be seen that there is minimal difference between detection probabilities when data recorder observations are included except for pair 1 (**Figure 20**).

Though the reconnaissance survey phase saw variable cloud conditions, in general, survey conditions were ideal with 0% cloud during the abundance phase (**Figure 21**). Proportion of missed observations was slightly higher when cloud cover was 50% or greater during the recon survey phase, though consideration must also be given to observer experience, which would increase with every successive flying day. Snow

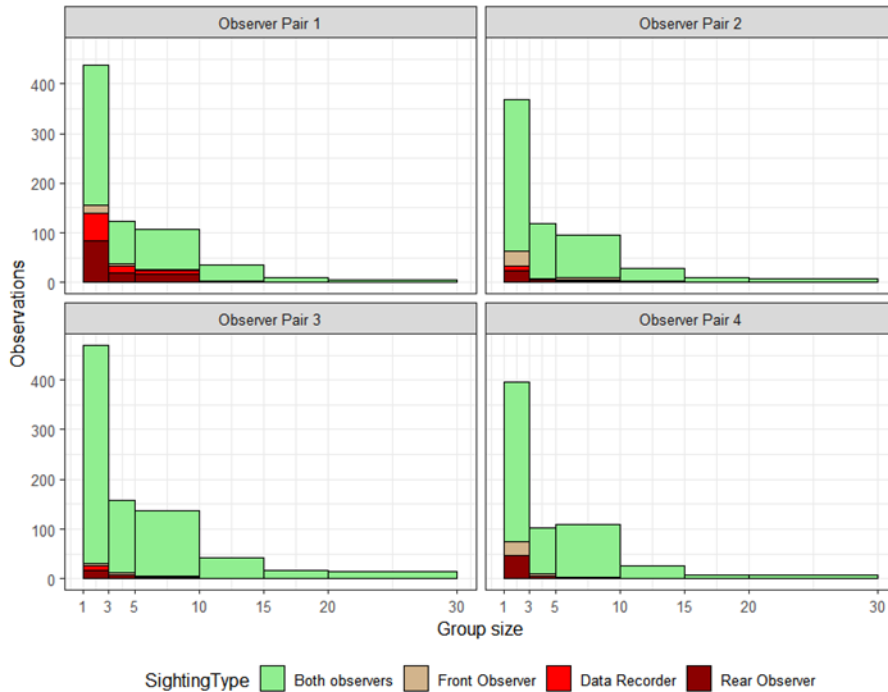
cover was consistent for both the reconnaissance and abundance phases of the survey with over 80% of observations recording 0% snow cover for the reconnaissance, and over 95% of observations recording within 5% to 25% snow cover for the abundance.

**Table 8.** Summary of double observer pairings with sample sizes and naïve detection probabilities for each pair. Observations are summarized by observation type (BO-both observers, DR-data recorder, FO-front observer, RO-rear observer). Naïve detection probabilities are based upon proportions not seen by the front observer. Single (p) and double observer (p2x) probabilities are shown. They are calculated excluding data recorder observations (no DR) and including data recorder observations (DR).

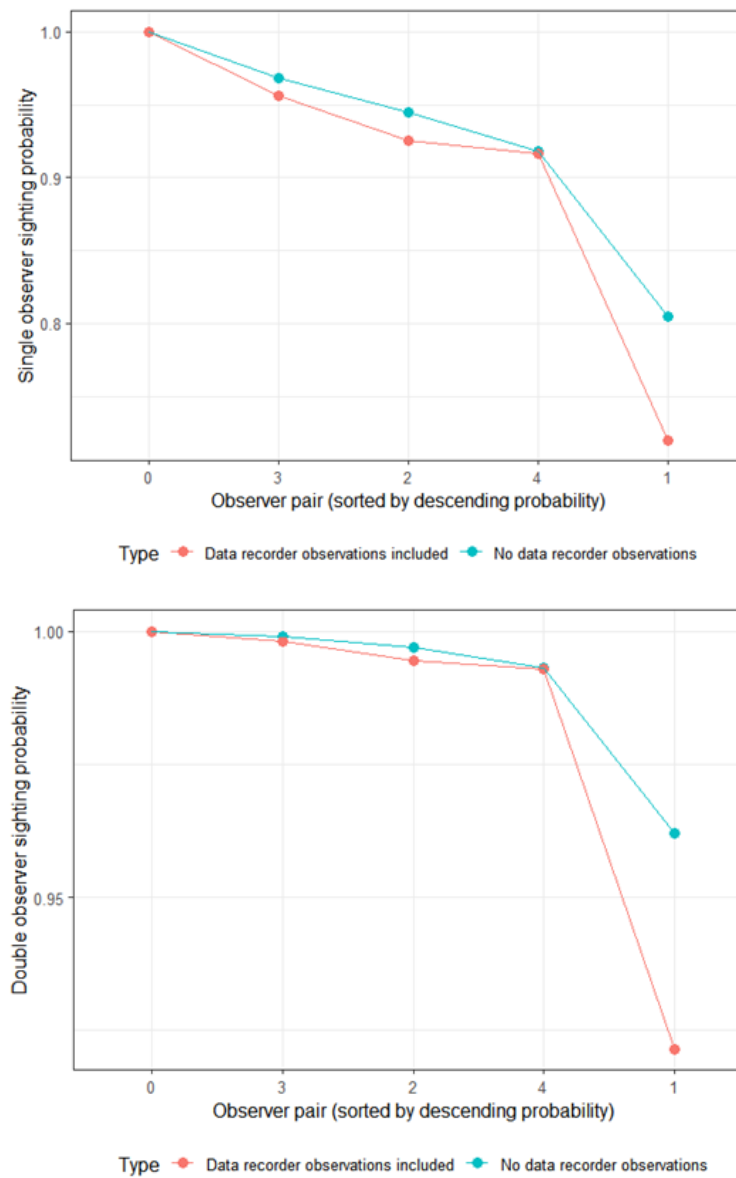
Pair	Observations (type)				Totals total	Naïve detection probabilities			
	BO	FO	RO	DR		P1x (no DR)	p2x (no DR)	P1x (DR)	P2x (DR)
1	495	21	125	76	719	0.80	0.96	0.72	0.92
2	557	38	35	13	647	0.94	1.00	0.93	0.99
3	802	12	27	10	857	0.97	1.00	0.96	1.00
4	569	33	54	1	665	0.92	0.99	0.92	0.99



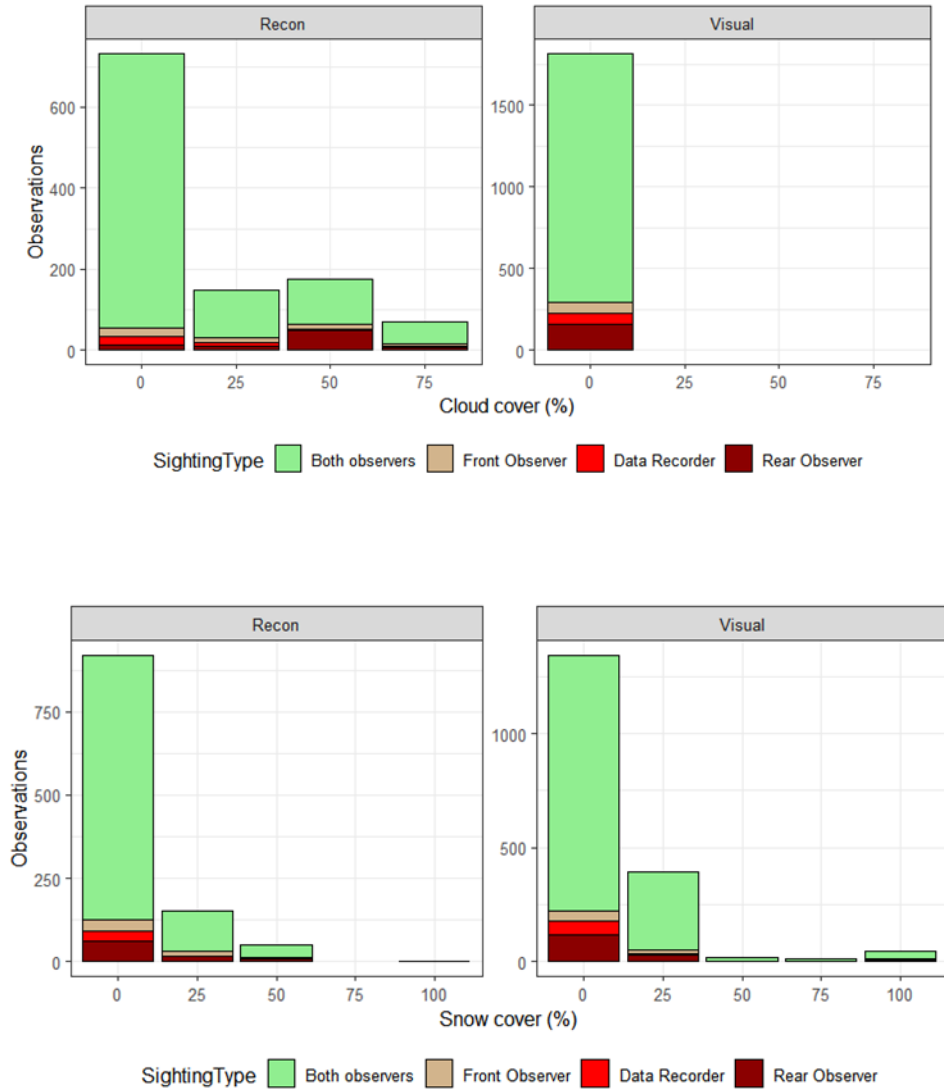
**Figure 18.** Distribution of group sizes observed during the visual and reconnaissance surveys (green) with observation type delineated as sub-bars (brown and reds). Group size observations of greater than 80 caribou (only observed during the reconnaissance survey) were not used in the double observer analysis. Observations greater than 30 caribou are summarized in the 20-30 bin.



**Figure 19.** Graphical summary of observer pair detections by group size for the June 2022 Qamanirjuaq caribou calving-ground abundance survey.



**Figure 20.** Graphical representation of the effect of inclusion of data recorder observations for the June 2022 Qamanirjuaq caribou calving-ground abundance survey.



**Figure 21.** Summary of cloud and snow cover for observations during the recon and visual components of the survey.

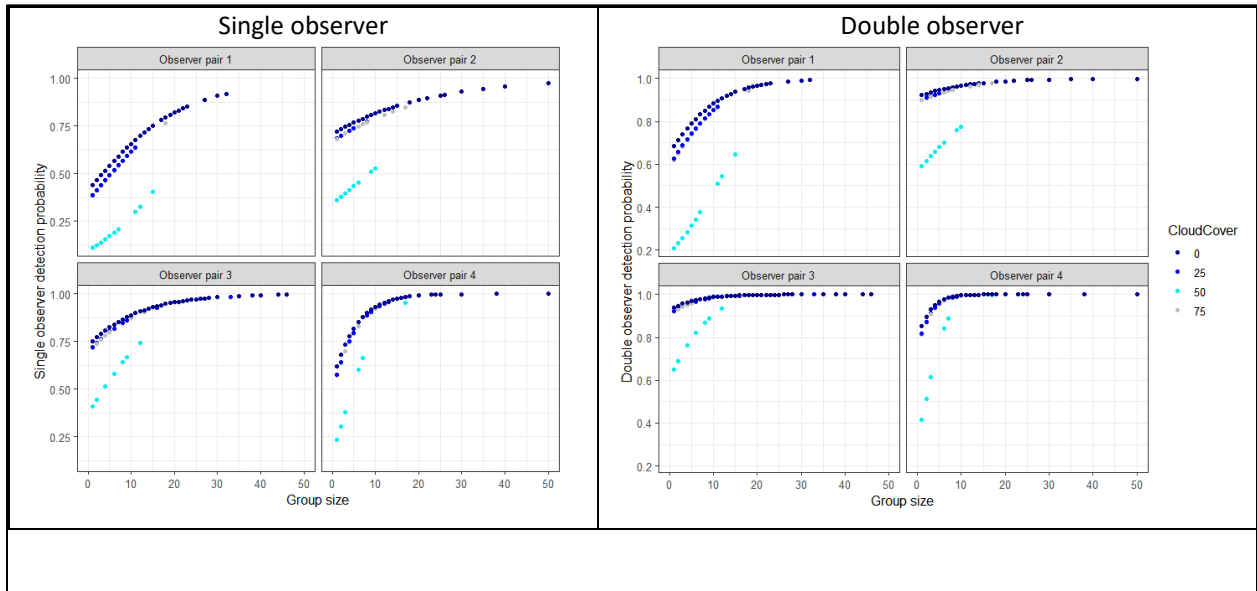
#### **4.4.2 Model selection**

The general model building procedure followed a hierarchical process (**Table 9**). Initially, model building focused on determining the relative strength of each covariate with unique observer, group size, and cloud cover, showing substantially higher support than a constant model. Observer and group size were considered as additive and interactive terms, with interaction models showing higher support (model 6). Cloud cover was then considered as an additive continuous or categorical term. From this the most supported model (model 1) contained an interaction of observer (pair) and group size with an additive effect of cloud cover.

Table 9. Double observer model selection results. Main model terms are listed as columns with covariate names as defined in Table 1. Sample size adjusted Akaike Information Criterion (AICc), the difference in AICc between the most supported model for each model ( $\Delta AIC_c$ ), AICc weight ( $w_i$ ), number of model parameters (K) and deviance is given.

No	Model	AIC <sub>c</sub>	$\Delta AIC_c$	$w_i$	K	Deviance
1	observer*size+cloudf	1790.53	0.00	1.00	11	-883.6
2	observer*size+cloudc	1807.89	17.35	0.00	9	-894.5
3	observer*size	1837.39	46.86	0.00	8	-910.4
4	observer*size+phase	1837.97	47.44	0.00	9	-909.6
5	observer*size+strata	1838.65	48.12	0.00	12	-906.6
6	observer+size	1840.96	50.43	0.00	5	-915.3
7	observer+size+phase	1841.36	50.83	0.00	6	-914.5
8	observer*log(size)	1842.62	52.09	0.00	8	-913.0
9	observer+cloudc+snowc	1868.98	78.45	0.00	6	-928.3
10	observer+cloudc	1869.73	79.20	0.00	5	-929.7
11	observer+snowc	1896.55	106.02	0.00	5	-943.1
12	observer	1897.38	106.85	0.00	4	-944.6
13	observer+phase	1899.20	108.66	0.00	5	-944.5
14	cloudf	2016.00	225.47	0.00	4	-1003.9
15	size	2031.77	241.24	0.00	2	-1013.9
16	log(size)	2036.57	246.04	0.00	2	-1016.3
17	cloudc	2053.82	263.29	0.00	2	-1024.9
18	strata	2092.80	302.27	0.00	5	-1041.3
19	snowF	2093.59	303.06	0.00	5	-1041.7
20	constant	2096.99	306.45	0.00	1	-1047.5
21	phase	2097.32	306.79	0.00	2	-1046.6
22	snowc	2098.44	307.91	0.00	2	-1047.2

The influence of observer pair, group size, and cloud cover on sighting probabilities (**Figure 24**) suggested that the largest degree of variation was due to group size and different observer pairs, however, the overall range in probabilities was not large. Furthermore, double observer probabilities (the combined probability of at least one observer in a pair sighting a caribou group) was close to 1 regardless of observer pairing or cloud cover (**Figure 22**). Lower detection probabilities did occur when cloud cover was 50% or greater, however, this only occurred during the recon survey and therefore had no effect on the visual survey estimates.



**Figure 22.** The Qamanirjuaq June 2022 calving-ground visual abundance survey single (left) and Double (right) observer sighting probabilities as a function observer and cloud cover.

Double observer estimates were derived in program MRDS from Model 1 (**Table 10**) and compared to non-corrected count-based estimates. In general, the estimates were very close (1.3% difference) with the total estimate for all strata being 473 caribou higher than the non-corrected estimate. As discussed later, the minimal difference in estimates was due to the larger group sizes encountered during survey (with high sightabilities (**Figure 22**)), and good survey conditions. Precision of double observer estimates was slightly higher due to the advanced methods used to estimate variance in the *mrds* package. Overall precision of estimates was quite high demonstrating that survey allocation and strata layout was optimal for obtaining precise estimates based on reasonable' km's of flying on transect.

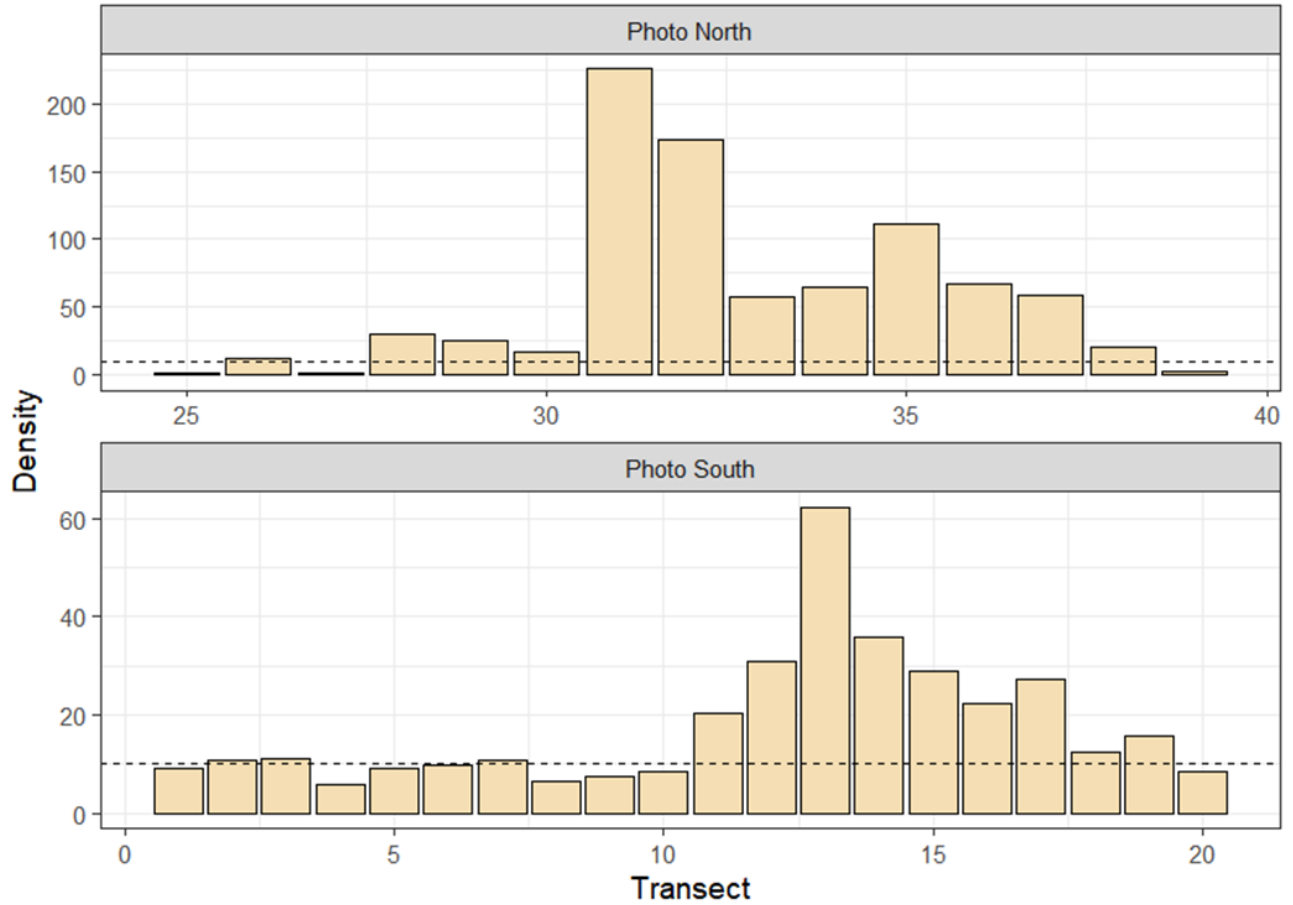
Table 10. Double observer estimates of all caribou in each stratum and uncorrected count-based estimates for comparison purposes.

Strata	Caribou counted	Double observer (MRDS)				Count-based estimate			
		N	SE	95% CI		CV	N	SE	CV
Vis1	5,323	23,083	1640.9	19,886	26,795	7.1%	22,708	1633.6	7.2%
Vis2	435	2,880	597.9	1,823	4,552	20.8%	2,872	506.0	17.6%
Vis3	425	2,996	351.2	2,310	3,886	11.7%	2,926	458.2	15.7%
Vis4	1,066	6,313	401.1	5,405	7,374	6.4%	6,295	868.7	13.8%
Total	7,249	35,273	1826.7	31,717	39,228	5.2%	34,801	1972.2	5.7%

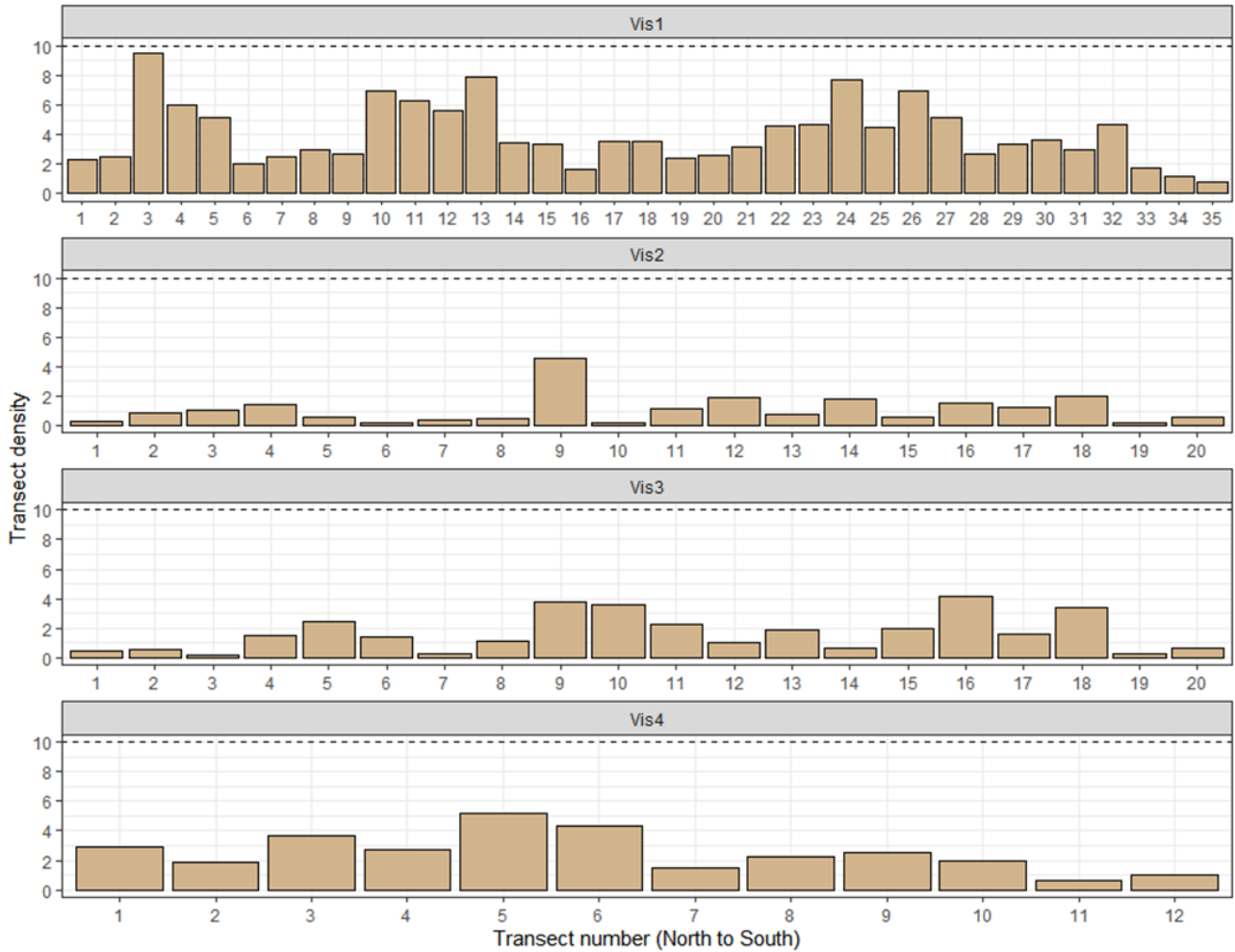
#### 4.4.3 High density photo and visual survey estimates

High density photographic strata were flown at GSD 8 which resulted in an average strip width of 1.35 km (sd=0.025, min=1.28, max=1.39, n=39). Strip width and transect area was measured using geo-referenced photos for each survey line. Transect densities were estimated as the number of caribou counted on a given transect divided by the transect area (**Figure 23**). Densities were above 10 caribou per km<sup>2</sup> in the High-density Photo-North Photo on all transects except two (2) on the west-central end of the stratum, and one (1) on far east end of the stratum. Very-high densities occurred on the central lines of this stratum with very-low densities on peripheral lines especially to the west. This variation reduced overall estimate precision.

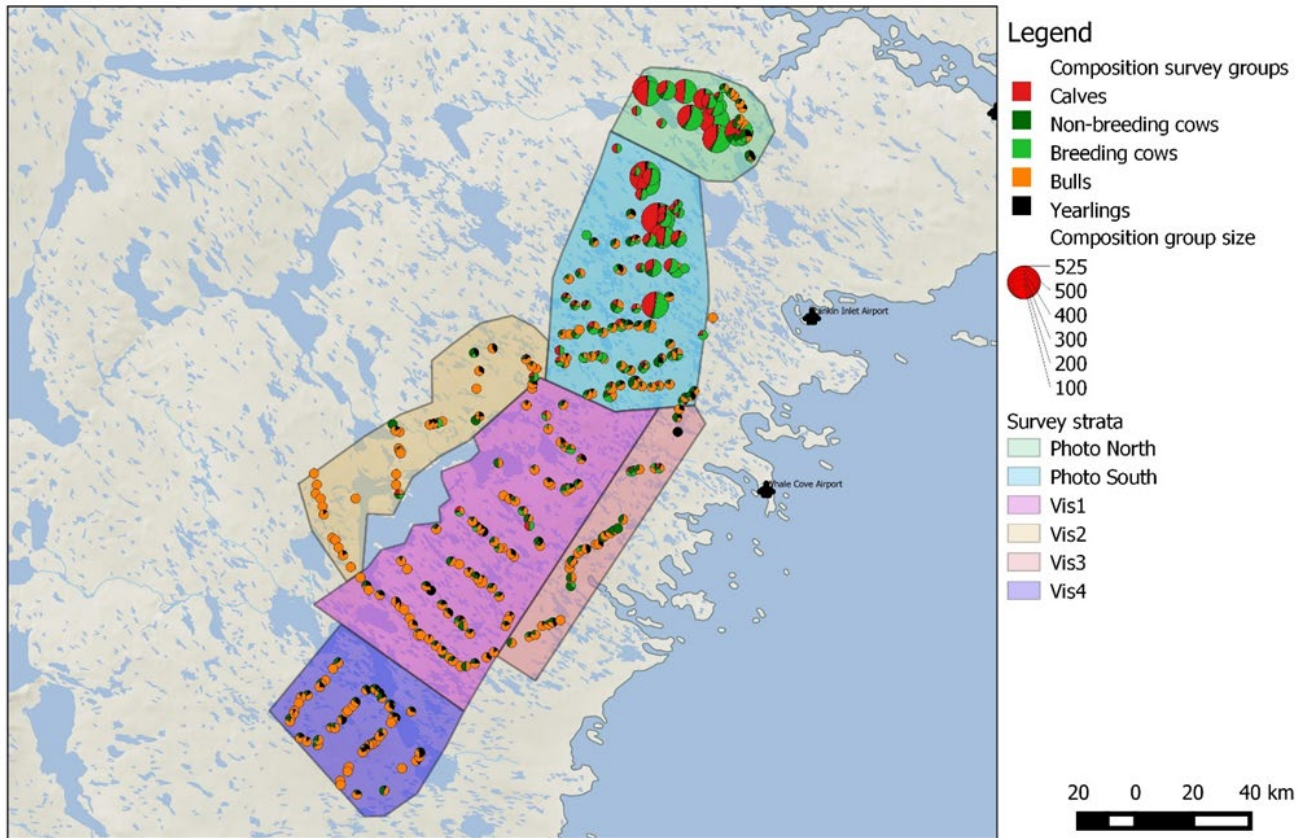
Within the Photo-south stratum most densities were at the 10 caribou per km<sup>2</sup> level with densities up to 50 caribou per km<sup>2</sup> in the central section of the stratum. For the remaining visual abundance survey strata density of caribou along transects was below 10 caribou per km<sup>2</sup> (**Figure 24**).



**Figure 23.** Estimates of caribou density (caribou per km<sup>2</sup>) on high density photo stratum by transect. Note the different y-axis scales. Density of 10 caribou per km<sup>2</sup> which denotes the level when photo plane sampling is used is given as a horizontal dashed line. Transects went from west to east for the Photo-North stratum and from south to north for the Photo-South stratum.



**Figure 24.** Transect densities within visual strata for the 2022 Qamanirjuaq calving-ground survey. The horizontal dashed line represents a density of 10 caribou per km<sup>2</sup> which denotes the level when photo plane sampling is used.



**Figure 25.** Summary of caribou classified for each of the core strata as listed in **Table 8** for the June 2022 Qamanirjuaq herd calving-ground abundance survey.

**4.4.4 Composition surveys to determine proportions of females**

Composition surveys were conducted on each of the photographic and visual survey strata (**Table 11**). A spatial representation of the composition data reveals that the majority of breeder groups including breeding and non-breeding females, occurred in the two photo strata with proportionally higher non-breeder/female groups occurring in the visual stratum as well as in the southern half of the photo south stratum (**Figure 25**). The composition data for all strata was analyzed further using a bootstrap procedure to estimate standard errors. One thousand bootstrap replications were conducted which resulted in robust standard error estimates and percentile-based confidence limits (**Table 12**). The proportion of breeding females on the calving ground (breeding females / (breeding females+non-breeding females+bulls+yearlings)) as well as other cohorts, were estimated. The proportion of adult cows was highest on the photo-north and photo-south strata with lower (<28%) in visual strata. The proportion bulls were relatively high (>50%) in visual strata.

Table 11. Summary of composition data by stratum collected for the June 2022 Qamanirjuaq caribou abundance survey.

Strata	n	Breeders	Non-breeders				Total caribou Breeder & non-breeders
		Cows <sup>A</sup>	Cows <sup>B</sup>	Bulls	Yearlings	Total	
Photo North	27	3204	270	220	149	639	3843
Photo South	87	3025	706	902	248	1856	4881
Vis1	78	80	187	810	197	1194	1274
Vis2	35	8	16	171	18	205	213
Vis3	33	13	45	120	37	202	215
Vis4	52	4	85	428	101	614	618

<sup>A</sup>As indicated by presence of a calf, antlers, or an udder.

<sup>B</sup>As indicated by absence of calf, an udder or antlers (UCO in database).

Table 12. Estimates of proportions of various cohorts from composition surveys flown during the June 2022 Qamanirjuaq caribou herd calving-ground abundance survey.

Strata	Estimate	SE	95% CI		CV
<u>Proportion breeding cows (breeding cows/(breeding cows+non breeding cows+bulls+yearlings))</u>					
Photo North	0.904	0.024	0.847	0.940	2.6%
Photo South	0.764	0.038	0.678	0.824	5.0%
Vis1	0.210	0.019	0.172	0.249	9.2%
Vis2	0.113	0.032	0.054	0.181	28.5%
Vis3	0.270	0.040	0.193	0.350	14.7%
Vis4	0.144	0.020	0.106	0.185	14.1%
<u>Proportion adult cows (cows/(cows+bulls+yearlings))</u>					
Photo North	0.834	0.040	0.741	0.895	4.8%
Photo South	0.620	0.055	0.488	0.704	8.9%
Vis1	0.063	0.014	0.039	0.093	22.4%
Vis2	0.038	0.016	0.011	0.071	42.2%
Vis3	0.060	0.022	0.021	0.111	37.0%
Vis4	0.006	0.003	0.001	0.013	48.1%
<u>Proportion of bulls (bulls)/(cows+bulls+yearlings))</u>					
Photo North	0.057	0.015	0.034	0.092	26.2%
Photo South	0.185	0.035	0.132	0.264	18.9%
Vis1	0.636	0.023	0.590	0.684	3.7%
Vis2	0.803	0.039	0.721	0.876	4.9%
Vis3	0.558	0.046	0.473	0.649	8.2%
Vis4	0.693	0.031	0.635	0.758	4.5%

## 4.5 Estimates

### 4.5.1 Estimates of total caribou on the calving ground

Estimates of the total number of caribou on the annual core calving ground and peripheral calving strata using both the visual and photo-survey data, are displayed in **Table 13**. Estimates in most strata had coefficients of variation (CV) levels of less than 20% with the exception of the photo-north stratum which had a CV of 21.4% which was due to high variation in densities observed within the strata (**Figure 23**). Vis2 also had

a CV of greater than 20%. However, the estimate of abundance was low and therefore it did not contribute significantly to the overall estimate. The resulting precision of the overall estimate of 213,079 caribou on the annual core calving ground was relatively precise with a CV of 11.5%.

Table 1. Estimates of caribou (1+year old) on the annual core calving ground from the core photo (Photo-North & Photo-South), core visual (Vis-1 & 4), and peripheral visual strata (Vis-2 & 3).

Strata	N	SE	95% CI		CV	df
Photo North	98,614	21135.8	62,594	155,360	21.4%	14.0
Photo South	79,193	12212.6	57,456	109,155	15.4%	19.0
Vis1	23,083	1640.9	19,886	26,795	7.1%	18.1
Vis2	2,880	597.9	1,822	4,552	20.8%	10.0
Vis3	2,996	351.2	2,309	3,887	11.7%	10.0
Vis4	6,313	401.1	5,405	7,374	6.4%	6.0
<b>Total</b>	<b>213,079</b>	<b>24478.6</b>	<b>166,781</b>	<b>272,229</b>	<b>11.5%</b>	<b>14.4</b>

#### **4.5.2 Estimates of breeding females and other cohorts on the core breeding ground.**

Estimates of the proportion of breeding females (**Table 12**) were then multiplied by the number of caribou on each stratum (**Table 13**) to derive a breeding female estimate of 133,125 (95%-CI=96,561-183,534) (**Table 14**). The estimate of adult cows (breeders and non-breeders) was 156,540 (**Table 15**) (95%-CI=116,635-210,099) suggesting that roughly 23,000 cows on the core calving ground were non-breeding (as determined by lack of calf, antler, or udder). The photo stratum, which was classified as having 90% and 76% adult females (Photo-North and Photo-South respectively), contributed the most to the overall estimate of breeding females and non-breeding females. Relatively few adult females (breeding or non-breeding) were found within the visual abundance strata.

Table 2. Estimates of breeding females from composition data and survey strata estimates (CG= Calving ground).

Strata	Caribou on C.G.		Proportion breeders		Breeding female estimate				CV
	N	CV	Estimate	CV	N	SE	95% CI		
Photo North	98,614	21.4%	0.834	4.8%	82,244	18063.8	51,633	131,004	22.0%
Photo South	79,193	15.4%	0.620	8.9%	49,100	8738.0	33,929	71,054	17.8%
Vis1	23,083	7.1%	0.063	22.4%	1,454	341.1	894	2,364	23.5%
Vis2	2,880	20.8%	0.038	41.7%	109	51.0	40	294	46.8%
Vis3	2,996	11.7%	0.060	37.3%	180	70.3	78	417	39.0%
Vis4	6,313	6.4%	0.006	51.9%	38	19.8	11	126	52.1%
<b>Total</b>	<b>213,079</b>	<b>11.5%</b>			<b>133,125</b>	<b>20069.4</b>	<b>96,561</b>	<b>183,534</b>	<b>15.1%</b>

Table 3. Estimates of adult females from composition data and survey strata estimates.

Strata	Caribou on C.G.		Proportion adult females		Adult female estimate				CV
	N	CV	Estimate	CV	N	SE	95% CI		
Photo North	98,614	21.4%	0.904	2.6%	89,147	19251.9	56,395	140,921	21.6%
Photo South	79,193	15.4%	0.764	5.0%	60,503	9803.2	43,197	84,743	16.2%
Vis1	23,083	7.1%	0.210	9.1%	4,847	561.1	3,804	6,176	11.6%
Vis2	2,880	20.8%	0.113	28.4%	325	114.6	152	697	35.3%
Vis3	2,996	11.7%	0.270	14.7%	809	152.0	534	1,225	18.8%
Vis4	6,313	6.4%	0.144	14.1%	909	141.0	623	1,326	15.5%
<b>Total</b>	<b>213,079</b>	<b>11.5%</b>			<b>156,540</b>	<b>21612.7</b>	<b>116,635</b>	<b>210,099</b>	<b>13.8%</b>

### 4.5.3 Extrapolated estimate of total herd size

A composition survey of the Qamanirjuaq fall rutting range was conducted October 2016 to obtain an estimate of the proportion of females in the Qamanirjuaq caribou herd. With no recent fall compositions available, we used the 2016 results to determine the proportion of females within the Qamanirjuaq herd to generate the whole herd estimate. During the fall 2016 composition survey, two main breeding aggregations of caribou were classified with 6,419 and 9,894 bulls and cows classified respectively. The

resulting estimates of bull-cow ratios, and overall proportion of cows (cows/(bulls+cows)) are given in **Table 16** (Campbell et al. 2018).

Table 4. Fall 2016 composition survey results.

Ratio	Estimate	SE	Conf. Limit		CV
Bull/cow ratio	0.616	0.026	0.566	0.664	4.1%
Proportion cows	0.619	0.010	0.601	0.639	1.6%
Calf-cow ratio	0.391	0.008	0.376	0.407	2.0%

In 2014, an alternative estimate of herd size was derived by assuming that all adult cow caribou were on the core calving ground (Campbell et al. 2012; Boulanger et al. 2015). This avoided the need of a pregnancy rate since it was assumed that all non-pregnant cows (1.5 years old and older) were on the annual core area, a method that is now successfully integrated into the Qamanirjuaq survey analysis and adopted by other mainland migratory caribou herds across Nunavut and the NWT. Using this method, the estimate of the herd is simply the estimate of females divided by the proportion of females in the herd (**Table 17**). This estimate still pertains to adult caribou and not yearlings (calves of the previous year). The resulting whole herd estimate for the June 2022 Qamanirjuaq calving ground abundance survey is 252,892 (95%-CI=188,050-340,092) 1.5+ year old caribou.

Table 5. Extrapolated population estimates for the Qamanirjuaq herd using estimates of females on the calving ground (CG) and proportion females estimated in fall composition surveys.

Survey data	Estimate	SE	CV	95% Conf. Limit	
Number of caribou on core and peripheral cg	213,079	24478.6	11.5%	166,781	272,229
Number of females (breeding+non-breeding) in core calving ground	156,540	21612.7	13.8%	116,635	210,099
Proportion females in the entire herd	0.619	0.010	1.6%	0.601	0.639
Total estimate of adult (1.5+ yr old caribou) in the herd	252,892	35153.7	13.9%	188,050	340,092

#### 4.5.4 Estimates of trend

Various metrics can be used to estimate trends in ungulate abundance (**Figure 26**). Of these the most robust metric for some herds, including the Qamanirjuaq herd, is adult females. Breeding females will be influenced by yearly variation in pregnancy rates making extrapolation from this metric less reliable in most cases. The number of caribou on the calving ground will be influenced by how extensive the survey was in targeting bulls and yearlings which often may not occur in the vicinity of the annual core calving area. For example, in June 2008, the primary target of survey efforts on the Qamanirjuaq calving ground was adult females and therefore it is likely that bulls and yearlings were counted less than other years, resulting in a lower estimate. Herd size is based on the adult female estimate and trends in herd size will be proportional to adult females since the same assumed bull-cow sex ratio has been used for all herd size estimates. For this reason, we focus on trend estimates of adult females across all surveys.

The estimate of adult females is composed of breeding and non-breeding females. **Figure 27** shows how the proportion of breeding females varied yearly with a relatively low proportion of breeding females in 2014 and 2008. For consistency between surveys, we compared sequential estimates of adult females using a one-tailed t-test to assess if a significant decline had occurred (**Table 18**). Degrees of freedom were estimated for combined estimates for each year using variances and degrees of freedom from each of the sampled stratum (Thompson, 1992). The difference in estimates was significant for the 2008 to 2014 and the 2008 to 2022 comparison (at  $\alpha=0.1$ ) but not significant for other comparisons. The ratio of successive estimates can also be used to estimate gross and annual change (**Table 19**) with yearly change varying from 0.95 to 1.03 between successive surveys. If the ratio of 2008 to 2022 is used to estimate annual change ( $\lambda$ ), the resulting estimate is 0.98 (95%-CI=0.96-1.00).

Overall trend was also estimated using weighted log-linear regression of the adult female estimates from 2008 to 2022, which reveals a non-significant decreasing trend with a yearly  $\lambda$  estimate of 0.98 (CI=0.96-1.00) (**Table 20**). This further suggests a slightly longer-term declining trend of 2% per year which is similar to the ratio of the 2008 to 2022 estimate. However, this estimate was not statistically significant. A plot of

regression estimates demonstrates the potential of a decreasing trend when the confidence limits of individual estimates are considered (**Figure 28**).

Table 6. Comparison of adult female estimates from successive surveys using t-tests. Also included is a test comparing 2008 and 2022 estimates. P-values are from a one-tailed t-test ( $H_0 N_2 \geq N_1$ ,  $H_a N_2 < N_1$ ).

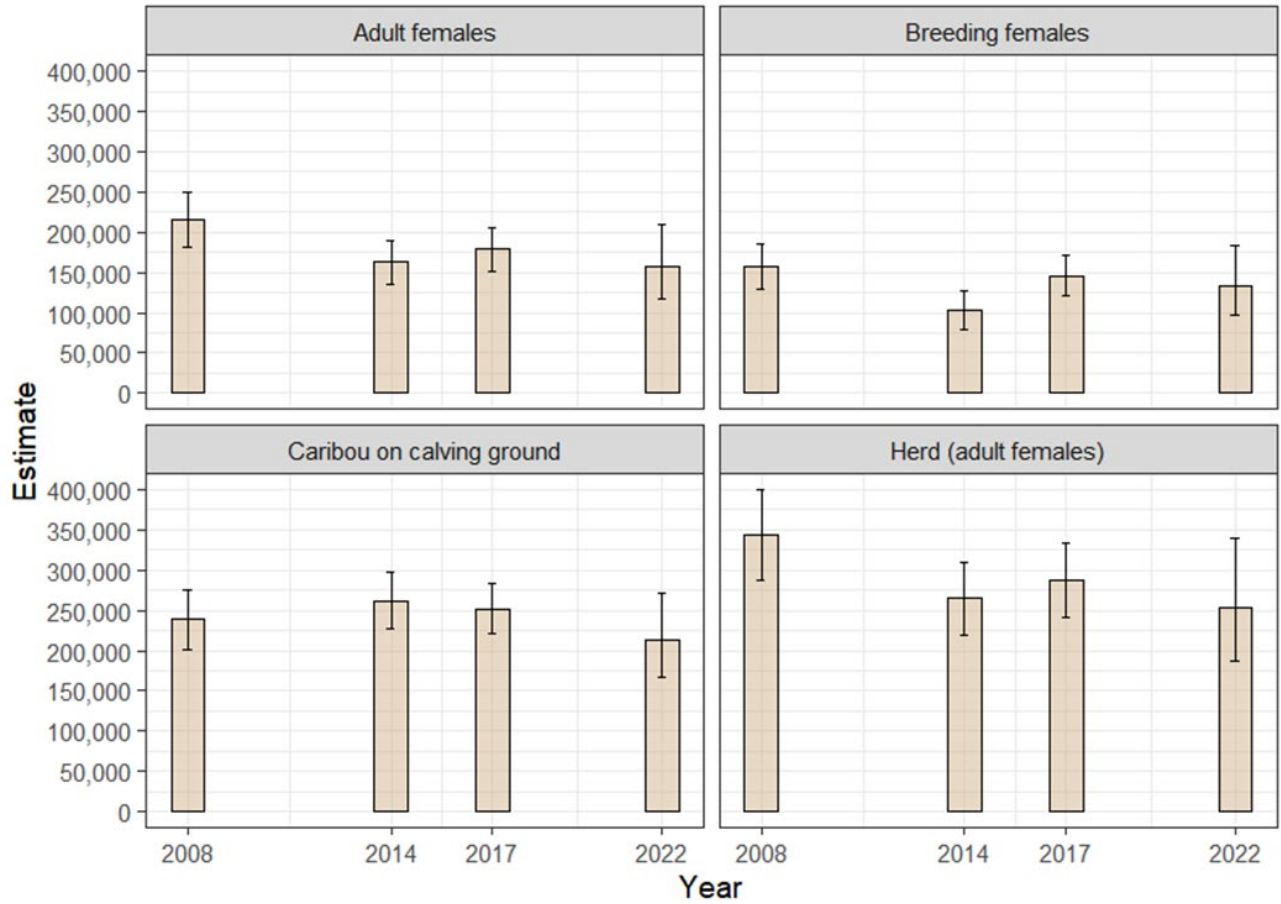
Years compared	N <sub>(year 1)</sub>	SE N <sub>(year 1)</sub>	Df <sub>(year1)</sub>	N <sub>(year 2)</sub>	SE N <sub>(year 2)</sub>	Df <sub>(year2)</sub>	t-test	Df t	p-value
2008-14	215,049	17373.9	35	163,066	13296.4	28	-2.38	61.6	0.010
2014-17	163,066	13296.4	28	178,423	13599.8	27	0.81	54.9	0.789
2017-22	178,423	13599.8	27	156,540	21612.7	18	-0.86	31.8	0.199
2008-22	215,049	17373.9	35	156,540	21612.7	18	-2.11	40.2	0.021

Table 7. Estimates of adult females for 2008, 2014, 2017, and 2022. The gross change in estimates (based on the ratio of successive N estimates) and yearly rate of change is also given.

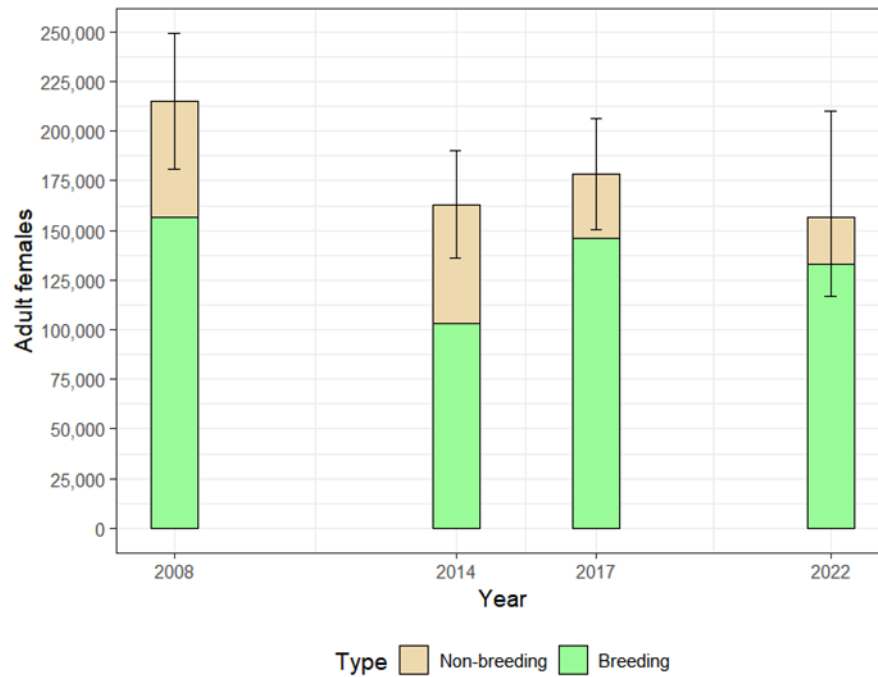
Year	Estimate N	SE	Gross change			Yearly change ( $\lambda$ )		
			Estimate	Conf. Limit		Estimate	Conf. Limit	
2008	215,049	17,373.9						
2014	163,066	13,296.4	0.76	0.61	0.95	0.95	0.92	0.99
2017	178,423	13,599.8	1.09	0.88	1.36	1.03	0.96	1.11
2022	156,540	21,612.7	0.88	0.64	1.19	0.97	0.91	1.03

Table 20. Regression estimates of trend (2008-2022). The per capita rate of increase ( $r$ ) is estimated as the slope term with the annual finite rate of increase ( $\lambda$ ) estimated as the exponent of  $r$ .

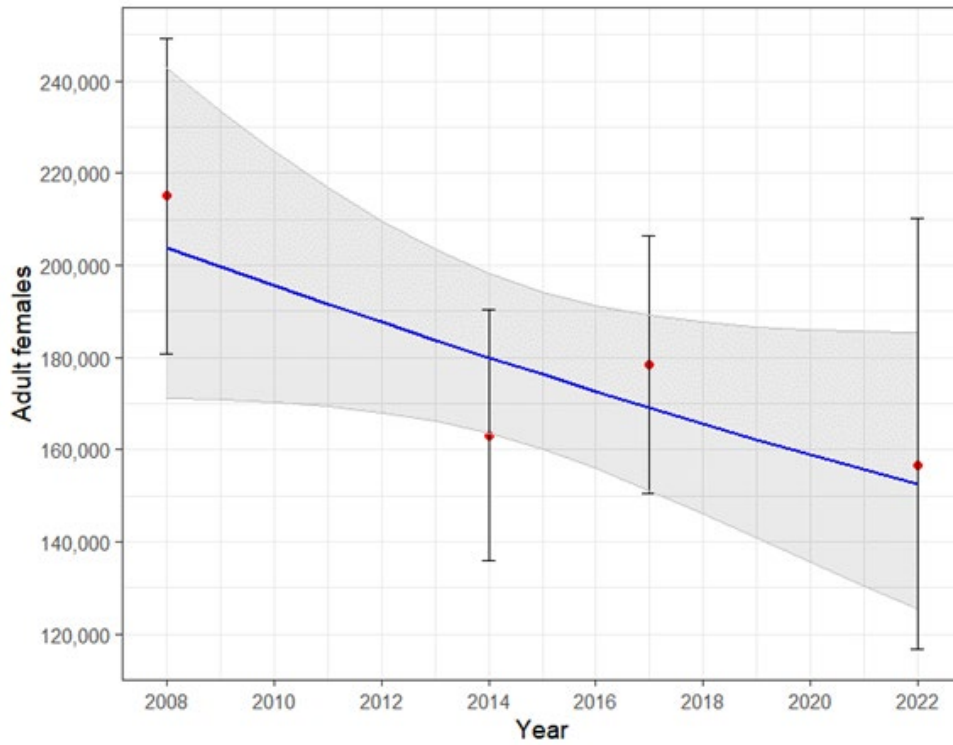
Parameter	Estimate	SE	95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	12.246	0.099	12.049	12.436	124.062	0.000
Year ( $r$ )	-0.021	0.012	-0.043	0.002	-1.804	0.213
$\lambda$	0.979		0.958	1.002		



**Figure 26.** Estimates of Qamanirjuaq herd status using various metrics from 2008 to 2022. Estimates from previous years taken from previous survey reports (Campbell et al. 2010, Campbell et al. 2016, Boulanger et al. 2018).



**Figure 27.** Estimates of Qamanirjuaq adult females, breeding females, and extrapolated herd size based on adult females (**Table 18** for the 2008, 2014, 2017, and 2022 surveys).



**Figure 28.** Predicted trends in Qamanirjuaq herd abundance from log-linear regression. Confidence limits on regression predictions are given as hashed blue lines. Individual estimates are shown as red points with displayed 95% confidence limits.

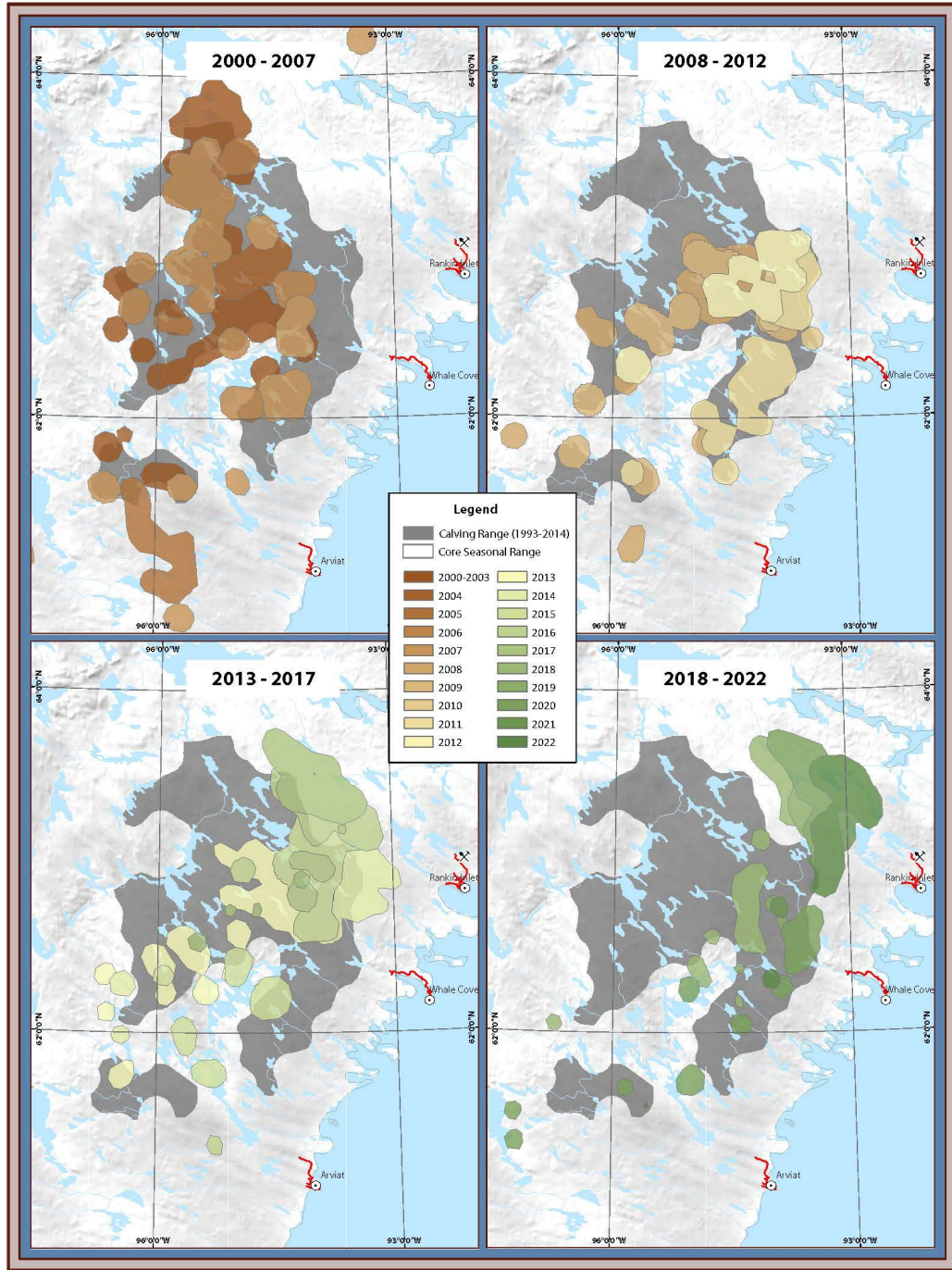
## 4.6 Changes in Annual Calving Extents

Qamanirjuaq mainland migratory barren-ground caribou typically do not calve in the same locations year after year but rather utilize geographically distinct annual calving grounds within a larger and more geographically predictable concentrated core calving ground (**Figure 29**). Amongst Inuit Qaujimagatuqangit (IQ) and scientific study there is general agreement that the mainland migratory caribou herds, including the Qamanirjuaq herd, cycle every 40 to 60 years (from population low to population low) (Bongelli 2020; Bongelli et al, 2022). Unfortunately, we only have useful telemetry data for the last 30 years, leaving an estimated 20-year gap in our complete understanding of the full extent of the core concentrated seasonal calving range through one complete population cycle (amongst other seasonal ranges). In the case of the Qamanirjuaq herd, both long-term monitoring studies and IQ predict that the spatial extents of annual calving grounds when examined over the long-term will remain within a geographically larger core calving ground, an area representative of the long-term calving needs of the herd (**Figure 29**).

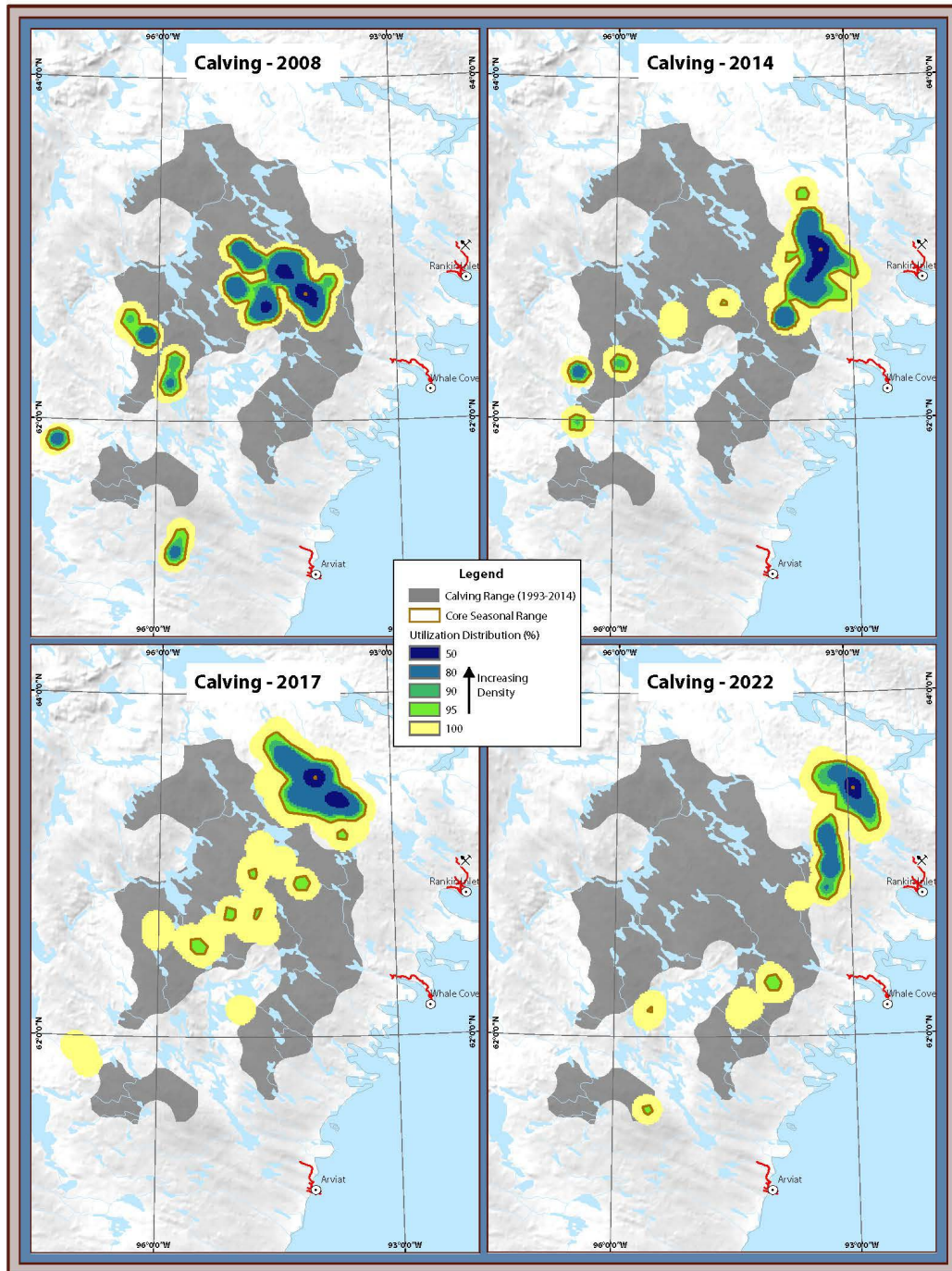
More recently, delineated annual calving grounds have extended beyond the 2013 delineated core calving area. This finding is not entirely unexpected when considering the 20-year gap in our spatial knowledge of Qamanirjuaq herd calving through a full 40-to-60-year population cycle. To understand the herds long-term calving needs in terms of minimum spatial extents, we will need to examine a time series of seasonal range use from population low to population low. To assume we currently hold sufficient information to assess the herds spatial needs for calving, migratory, post-calving, summer, rutting and winter seasonal range, would be misleading and risk the long-term viability of the herd should an underestimate of the long-term core calving requirements of the Qamanirjuaq herd be made.

An examination of telemetry delineated annual calving-grounds for the 2008, 2014, 2017, and 2022 June calving abundance surveys suggest that the annual calving grounds (represented by the 95% utilization distribution) were substantively different, with a general geographic trend to the north and east of 2013 delineated core calving

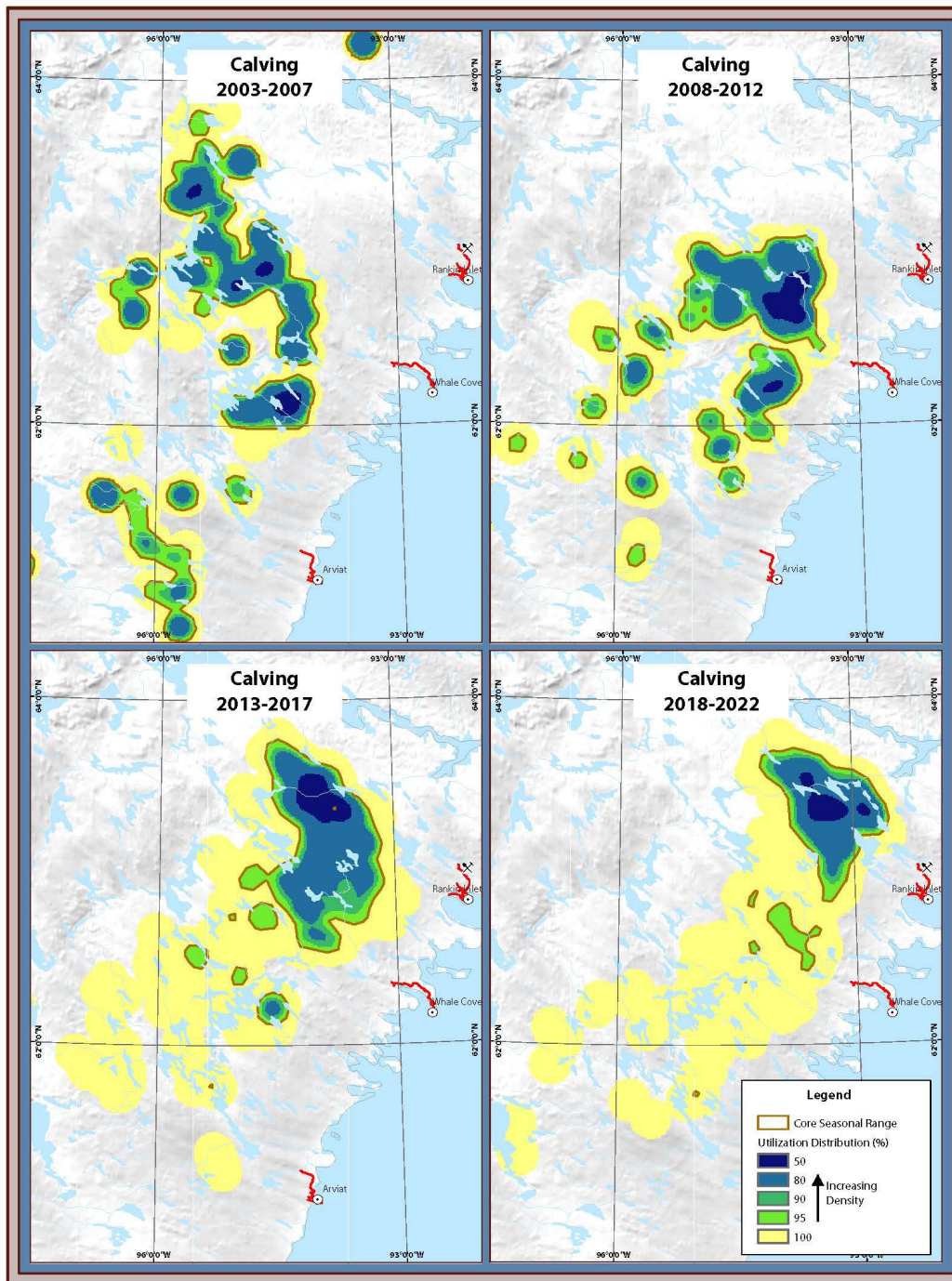
extents when compared to an updated core calving seasonal range polygon current to 2023 using the same analytical methods (**Figure 30**). This same general trend is also seen within a 20-year assessment further broken down into 5-year segments. The results of the 5-year segmented approach suggests that the 4 survey years were representative of more normal environmental patterns and not an artifact of extreme environmental conditions known to have occurred on occasion, within long-term telemetry data (**Figure 31**). We suspect annual core calving range will see further changes as we expand the telemetry database. As more telemetry data is collected, we strongly suspect that annual core calving extents will expand to accommodate annual variations repeated throughout the population cycle. The resulting updated polygons will better predict long-term annual requirements for the herd.



**Figure 29.** A representation of annual calving grounds from June 9<sup>th</sup> through June 22<sup>nd</sup> for the years 2000 through 2022. Polygons developed using a kernel density estimation (KDE) of caribou cow telemetry data.



**Figure 30.** A spatial assessment of Qamanirjuaq Herd annual calving extents for each of the 2008, 2014, 2017, and 2022 (this report) calving-ground abundance surveys. A kernel density estimation (KDE) approach was used to generate utilization distributions.



**Figure 31.** A spatial assessment of Qamanirjuaq Herd annual calving extents over a 20-year period broken down by 5-year increments. A kernel density estimation (KDE) approach was used to generate utilization distributions.

## 5.0 DISCUSSION

The overall survey results suggest that the herd is relatively stable when compared to the 2014 and 2017 estimates. However, direct comparison with the 2008 estimate along with the 2014 and 2017 estimates, suggests a slow decline. A one-tailed t-test comparison of 2008 and 2022 estimates reveals a significant decline. However, the overall trend from a regression analysis was not statistically significant.

Survey precision was lower in 2022 (CV=14% for adult females) than previous years but still within the acceptable range (CV<20%). The main reason for this lower precision of the photo-north stratum was due to a high level of aggregation (**Figure 23**) which caused high variation in densities amongst individual transects. One approach to address this issue would be to increase the number of lines and subsequent coverage in the stratum. The coverage in the photo-north stratum was reasonably high (42%) when compared with previous surveys. For example, the highest coverage in the 2017 survey was 35% in two of the photo-stratum. The approach of increasing coverage and aggressively sampling likely areas of aggregation with visual strata buffers could be considered as an approach to confront aggregation in future surveys.

Coverage in other caribou surveys, such as the Bathurst in 2012 has been as high as 72% which was due to a highly aggregated group of caribou in a small (914.2 km<sup>2</sup>) survey area (Boulanger et al. 2014b). The resulting CV for the estimate in this stratum was 8%. A randomization approach was used to assess if there was an optimal coverage level where the CV did not change with increasing coverage with no asymptote found. A coverage level of 65% was still required to obtain a CV of less than 10%.

Recently, new approaches have been developed that consider multiple sources of information to improve our estimates and understanding of trends. The demographic status of a herd can be better understood using an Integrated Population model (Schaub and Kery, 2022) that uses data from composition surveys, collar survival rates, and

calving ground surveys to provide an overall estimate of trend as well as refined estimates of demographic parameters. This approach has been used successfully to provide refined estimates of trend for the Bluenose East and Bathurst herds (Adamczewski et al. 2022, Boulanger et al. 2022). This approach will be pursued for the Qamanirjuaq herd in the future.

Our collective experience from the Bathurst Herd shows that major declines in mainland migratory barren-ground caribou subpopulations must be detected as early as possible to inform decisions to maintain the subsistence needs of Inuit and other indigenous peoples. Knowing the trend and status of the population will provide co-management partners with more options such as critical habitat protection, non-quota limitations (NQLs), commercial harvesting restrictions, in order to maintain herds or promote recovery following any major declines. All monitored indices of the herd, when examined in series, indicate that the Qamanirjuaq herd is in a continued slow decline. Therefore, lack of appropriate actions may exacerbate or prolong or halt herd recovery and place undue hardship on Inuit that harvest this herd both commercially and for subsistence. These hardships will also impact harvesters from Northern Manitoba, Northern Manitoba, and the NWT.

It is well known within the scientific literature, and amongst Northern Indigenous peoples that Barren-ground caribou undergo regular and long-term (between 50 and 70 years) cycles of abundance (Bongelli et al. 2020; Gunn, 2003; Zalatan et al. 2006; St. John, 2022). Additionally, there appears to be synchrony between the barren-ground herds including the Bluenose, Bathurst, Beverly, Leaf River, and George River mainland migratory herds that could be in response to large-scale environmental factors such as climate change and associated localized weather events and patterns, density dependant reproductive disease and parasites, and predator and human harvest effects. This also suggests that these mainland migratory caribou herd declines and associated mechanisms would impact all herds eventually. These impacts could be exacerbated by other anthropogenic effects on caribou mortality such as a growing internet market for caribou meat within Nunavut Territory, or industrial disturbance and associated avoidance behaviour and habitat loss within sensitive seasonal range such as the core calving grounds, post-calving areas and migratory routes (Panzacchi et al. 2012, Plante

et al. 2020, Boulanger et al. 2021, Boulanger et al. 2023, Severson et al. 2023). Loss of seasonal range access and availability would likely result in quantitative changes to long-term abundance through the loss of productive annual range and herd fragmentation. The impacts of anthropogenic activities such as industrial development or extractive practices on caribou and their range are uncertain, however, the scientific literature warns of the very real risk of negatively impacting caribou and their range over the long-term. With the industrial extraction of natural resources on the increase in northern North America, and more specifically within barren-ground caribou critical seasonal range, it is becoming more and more important that land use regulators and wildlife managers and biologists develop a better understanding of important seasonal range while closely monitoring herd status in order to more effectively manage anthropogenic impacts on range size and use, migratory behaviour, and herd productivity. Not doing so would work against Article 5, Part 1, Section 5, of the Nunavut Agreement as it could reduce harvesting opportunities, negatively impacting Inuit's right to harvest wildlife to meet their subsistence needs as described in the Nunavut agreement (**Figure 32**).

5.1.5 The principles of conservation are:

- (a) The maintenance of the natural balance of ecological systems within the Nunavut Settlement Area;
- (b) The protection of wildlife habitat;
- (c) The maintenance of vital, healthy, wildlife populations capable of sustaining harvesting needs as defined in this Article; and
- (d) The restoration and revitalization of depleted populations of wildlife and wildlife habitat.

Figure 32. Article 5.1.4 of the Nunavut Agreement “*The Principles of Conservation*”, an excerpt from the Nunavut Agreement Page 27 (Agreement Between the

Inuit of the Nunavut Settlement Area and Her Majesty the Queen in right of Canada, 2009).

as well as negatively impacting the harvesting rights and cultural practices of Indigenous cultures within Manitoba, Saskatchewan, and the Northwest Territories.

## **6.0 MANAGEMENT CONSIDERATIONS**

Concerns regarding the Qamanirjuaq herd have changed little since the June 2017 Qamanirjuaq caribou calving ground abundance survey. Hunters and Trappers Organizations (HTO's) and the Kivalliq Wildlife Board (KWB) continue to communicate their concerns over the status of the Qamanirjuaq herd. Some of the most common concerns brought forward during annual consultative meetings include: 1) inter-territorial caribou meat sales, primarily between the Kivalliq and Baffin Regions, are believed to be excessive and negatively impacting the local harvest of caribou for community based food needs; 2) there is extreme concern over development in calving grounds, Key Access Corridors (mutually inclusive calving, post-calving, and spring migratory seasonal range), water crossings, and post-calving grounds, as well as concern over disturbance to migrating caribou along linear industrial infrastructure. Both peer-reviewed science and IQ agree that industrial development in calving and post-calving grounds have not been shown to be mitigated in other contexts and areas resulting in changes in caribou abundance, distribution, behaviour, and health over the long term. These impacts, should they occur, would negatively impact caribou and Inuit harvesting; 3) Many hunters from across the region have communicated their sense of a general decline in abundance, and increase in disease prevalence. These concerns suggest that conditions are changing on the Qamanirjuaq range, and that our ability to monitor these changes should be heightened so that all co-managers can effectively advocate effective management action to safeguard Nunavut's largest caribou population.

Though the regression-based trend of Qamanirjuaq herd abundance estimates between the June 2008 and June 2022 indicates a non-significant declining trend of 2% annually (Figure 28 and Table 20), the current survey results show a significant decline in mean herd abundance between June 2008 and June 2022 (Table 18). The lack of statistical significance in regression-based trend estimates (that include 2008, 2014, 2017, and

2022 estimates) may be due to stability in the period of 2014-2017, however, it should be noted that precision of estimates (large confidence intervals) is low along with lower sample sizes of survey points. Spring composition studies when examined together suggest productivity levels consistent with a slow decline. The fact that mainland migratory barren-ground caribou are well known within both scientific (Bongelli et al 2020) and local knowledge to follow long-term (40 to 60 year) population fluctuations suggests that the Qamanirjuaq herd is at high risk of further decline over the next 5 to 10 years as food resources become over utilized and as a result, harder to find.

Because of the uncertainty between the 2014, 2017, and 2022 abundance estimates, this report is not recommending any management action at this time. This report does however acknowledge the slow decline indicated by comparison of June 2008 and 2022 estimates and for this reason highlights the importance of continued monitoring of herd trend. Of equal importance is the protection of critical range to ensure healthy seasonal range remains accessible to Qamanirjuaq caribou when recovering from cyclical and/or significant declines in abundance, typical of mainland migratory barren-ground caribou herds such as the Qamanirjuaq herd. Such protections will act to secure Inuit harvesting rights by respecting the principles of conservation guaranteed to Inuit within the Nunavut Agreement which in turn will maximize harvesting opportunities and the associated health and monetary benefits that result from healthy abundant caribou populations. These actions align with Regional Wildlife Organization (RWO), HTO, and community priorities to protect caribou annual core calving areas, key access corridors, post-calving range, water crossings, and other important seasonal range across the Qamanirjuaq herd's annual range.

Initial survey results and progress have been shared with co-management partners, including representatives from the KWB, Kivalliq HTO's, Beverly Qamanirjuaq Caribou Management Board (BQCMB), Nunavut Wildlife Management Board (NWMB), and the jurisdictions of Saskatchewan, Manitoba, NWT and Canada (ECCC). Consultations with community Hunters and Trappers Organizations regarding survey results occurred in early 2024, however, co-management partners including HTO's, the Kivalliq Wildlife Board (KWB), the Nunavut Wildlife Management Board (NWMB), and the Nunavut Department of Environment (ENV), will continue to discuss survey results and

recommendations (as represented in this report) and other issues at upcoming annual meetings. The GN ENV will continue to include, investigate, and report on, any findings derived from new scientific analysis, and IQ that may provide additional insight into the mechanisms influencing Qamanirjuaq caribou herd abundance and trend.

## 7.0 ACKNOWLEDGMENTS

We would like to thank the following people for their contribution to the June 2022 Qamanirjuaq Herd calving-ground photographic survey. We would like to thank Leo Ikakhik, David Makkigak, Dennis Larocque, Jackie Batstone, John Etegyok, John Voisey, Oliver Shipton, and Russell Toolooktook for their tireless, keen observation skills, and for their valuable input which help lead to the successful completion of this survey. We would also like to thank Vicky Trim and Joanie Kennah from the Manitoba Department of Natural Resources and Northern Development for their assistance in survey logistics and composition studies. Environment and Climate Change Canada (ECCC), the Nunavut Wildlife Management Board (NWMB), the Government of Nunavut, and the Government of Manitoba, all contributed substantial financial support as well as human resources towards all aspects of this study. We would also like to thank the Government of Saskatchewan for supporting the participation of an experienced community-based observer through the survey's duration. We would like to thank NTI for their continued staffing support of community supported survey efforts including the this Qamanirjuaq survey. We would like to thank Bob Schnurr and Ted Dunkier from Air Tindi for their coordination of fixed winged support, and to the Twin Otter Pilots Xavier Dencausse, Abigail Guthrie, Kevin Carr, and Jeremy DeGeer, for their exceptional flying skills and for keeping our crews safe during the survey effort. We would also like to thank Vic Cobb with Custom Helicopters for his continued exceptional flying abilities during the composition phase of the Qamanirjuaq survey effort. Brayden StPierre with GeodesyGroup Inc. did an exceptional job of accurately and efficiently photographing the high-density photo strata, and Derek Fisher with GreenLink Forestry Inc. did an equally exceptional job of interpreting the photos and providing accurate caribou counts. The Kivalliq HTOs supported us from the beginning to end of this survey effort for which our entire survey team was and remains truly grateful. Finally, we would

like to thank Drikus Gissing, Director of Wildlife Research for his continued behind the scenes support, without which, these major survey efforts could not be achieved.

## 8.0 LITERATURE CITED

- Adamczewski, J., J. Boulanger, B. Croft, T. Davison, H. Sayine-Crawford, and B. Tracz. 2012. A comparison of calving and post-calving photo-surveys for the Bluenose-East herd of barren-ground caribou in the Northwest Territories, Canada in 2010. Environment and Natural Resources, Government of Northwest Territories.
- Adamczewski, J., J. Boulanger, J. Williams, D. Cluff, K. Clark, S. Goodman, K.-S. Chan, R. Abernathy, and J. Nishi. 2022. Estimates of Breeding Females & Adult Herd Size and Analyses of Demographics for The Bathurst Herd of Barren-Ground Caribou: 2021 Calving Ground Photographic Survey Environment and Natural Resources.
- Agreement Between the Inuit of the Nunavut Settlement Area and Her Majesty the Queen in right of Canada. 2009. Indian and Northern Affairs Canada. Catalogue No. R32-134/1993 E. ISBN 0-662-20725-4. 283 pp.
- Bergerud, A.T., S.N. Luttich, and L. Camps. 2008. The Return of The Caribou to Ungava. Queens University Press. Montreal, Quebec, Canada. 656 pp.
- Bongelli E., M. Dowsley, H.D. Cluff, M. Campbell and M. Taylor. 2022. North American barren-ground caribou cycles are driven by logistic trophic dynamics. *Authorea*, 21 pp.
- Bongelli E., M. Dowsley, V.M. Velasco-Herrera, and M. Taylor. 2020. Do North American Migratory Barren-Ground Caribou Subpopulations Cycle? *Arctic*. Vol. 73, No. 3. Pp. 326-346.
- Boulanger, J., J. Adamczewski, J. Williams, D. Cluff, K. Clark, S. Goodman, K.-S. Chan, and R. Abernathy. 2022. Estimates of Breeding Females & Adult Herd Size and Analyses of Demographics for the Bluenose-East Herd of Barren-Ground Caribou: 2021 Calving Ground Photographic Survey Environment and Natural Resources.

- Boulanger, J., M. Campbell, and D.S. Lee. 2018. Estimating Abundance and Trend of the Qamanirjuaq Mainland Migratory Barren-ground Caribou Sub-population – June 2017. GN ENV Technical Summary: No: 01-2018. 100 pp.
- Boulanger, J., M. Campbell, D. Lee, M. Dumond, and J. Nishi. 2014a. A double observer method to model variation in sightability of caribou in calving ground surveys. Unpublished manuscript.
- Boulanger, J., B. Croft, and J. Adamczewski. 2014b. An estimate of breeding females and analyses of demographics for the Bluenose East herd of barren ground caribou: 2013 calving ground photographic survey. Department of Environment and Natural Resources, Government of Northwest Territories, File Report No. 143.
- Boulanger, J., B. Croft, and J. Adamczewski. 2014e. An estimate of breeding females and analysis of demographics from the 2012 Bathurst barren ground caribou calving ground survey. Department of Environment and Natural Resources, Government of Northwest Territories File Report No. 142.
- Boulanger, J., A. Gunn, J. Adamczewski, and B. Croft. 2011. A data-driven demographic model to explore the decline of the Bathurst caribou herd. *Journal of Wildlife Management* 75:883-896.
- Boulanger, J., R. Kite, M. Campbell, J. Shaw, D. Lee, and S. Atkinson. 2023. Estimating the effects of roads on migration: a barren-ground caribou case study. *Canadian Journal of Zoology* DOI: 10.1139/cjz-2023-0121
- Boulanger, J., K. G. Poole, A. Gunn, J. Adamczewski, and J. Wierzchowski. 2021. Estimation of trends in zone of influence of mine sites on barren-ground caribou populations in the Northwest Territories, Canada, using new methods. *Wildlife Biology* 2021:10.2981/wlb.00719.
- Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance Sampling. Estimating Abundance of Biological Populations. Chapman & Hall, London.

- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: A practical information theoretic approach. Springer, New York, New York, USA.
- Buckland, S. T., J. Laake, and D. L. Borchers. 2010. Double-observer line transect methods : levels of independence *Biometrics* 66:169-177.
- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: A practical information theoretic approach. Springer, New York, New York, USA.
- BQCMB. 2005. Beverly and Qamanirjuaq caribou management plan: 2005-2012. Beverly and Qamanirjuaq Caribou Management Board. 17 p.
- BQCMB. 1999. Protecting Beverly and Qamanirjuaq caribou and caribou range. Beverly and Qamanirjuaq Caribou Management Board. 40 p.
- Brown D. and P. Rothery. 1993. Models in biology: mathematics, statistics and computing. John Wiley and Sons. New York. 687 p.
- Calef, GW., and R. Hawkins. 1981. Kaminuriak Caribou Herd Calving Ground Survey, 1976. Wildlife Service. Government of the NWT. ESCOM Report No. **AI-41**. 15 pp.
- Campbell, M.W., A. Kelly, B. Croft, J.G. Shaw, C.A. Blyth. 2014. Barren-ground Caribou in Nunavut and Northwest Territories – Map Atlas. Government of Nunavut, Department of Environment. Government of Northwest Territories, Department of Environment and Natural Resources. Map series.
- Campbell, M.C., J.G. Shaw and C.A. Blyth. 2012-A. Kivalliq Ecological Land Classification Map Atlas: A Wildlife Perspective. Caslys Consulting Limited. Government of Nunavut, Department of Environment. Technical report Series **#1-2012**. 274 pp.
- Campbell, M., J. Nishi and J. Boulanger. 2010. A Calving Ground Photo Survey of the Qamanirjuaq Migratory Barren-Ground Caribou (*Rangifer tarandus groenlandicus*) Population – June 2008. Nunavut Wildlife Research Section. Nunavut Government. Arviat, NU. Technical Report Series No. **1-10**. 121 pp.

- Campbell, M., J. Boulanger, and D.S. Lee. 2015-A. Estimating Abundance of the Qamanirjuaq Mainland Migratory Barren-ground Caribou Sub-population – June 2014. Government of Nunavut, Department of Environment, Technical Report Series: No: 01-2016. 90 pp.
- Campbell, M., J. Boulanger, D. Lee, M. Dumond, and J. McPhearson. 2012-B. Calving Ground Abundance Estimates of the Beverly and Ahiak Subpopulations of Barren-Ground Caribou (*Rangifer tarandus groenlandicus*) – June 2011, Technical Summary. Department of Environment, Government of Nunavut.
- Campbell, M., J. Goorts, D.S. Lee, J. Boulanger, and T. Pretzlaw. 2015-B. Aerial Abundance Estimates, Seasonal Range Use, and Demographic affiliations of the Barren-Ground Caribou (*Rangifer tarandus groenlandicus*) on Baffin Island – March 2014. Department of Environment, Nunavut Wildlife Research Division, .
- Cochran, W.G. 1977. Sampling techniques, 3rd ed. John Wiley and Sons, Inc. New York. 428 p.
- Dauphine, T. C. Jr. 1976. Biology of the Kaminuriak population of barren-ground caribou. Part 4: Growth, reproduction and energy reserves. Canadian Wildlife Service Report Service No. 38. 69 p.
- Environment Canada. 2001. Narrative Descriptions of Terrestrial Ecozones and Ecoregions of Canada. <http://www.ec.gc.ca/soer-ree/English/Framework/Nardesc/efaultt.cfm>. Accessed 13 August 2001. Last Updated 08-13-2001.
- Fewster, R. M., S. T. Buckland, K. P. Burnham, D. L. Borchers, P. E. Jupp, J. Laake, and L. Thomas. 2009. Estimating the Encounter Rate Variance in Distance Sampling. *Biometrics* 65:225-236.
- Gasaway, W. C., S. D. Dubois, D. J. Reed, and S. J. Harbo. 1986. Estimating moose population parameters from aerial surveys. *Biological Papers of the University of Alaska* No 22:1-108.
- Gates, C.C. 1983. Composition of the Kaminuriak Caribou Population in the Fall of 1979 and 1981. N.W.T. Wildlife Service File Report. 25pp.

- Gates, C. C. 1985. The Fall and Rise of the Qamanirjuaq Caribou. – In: Meredith, T.C. and Martell, A.M. (eds). Second North American Caribou Workshop. McGill Subarctic Research Paper No. **40**. McGill University, Montreal. 215-228.
- GNWT. 2006. Bathurst caribou herd 2006 survey results and next steps. Department of Environment and Natural Resources Briefing Note.
- Gunn A. 2003. Voles, Lemmings and Caribou – Population Cycles Revisited? *Rangifer*, 23. 105-111 pp.
- Gunn, A., J. Nishi, J. Boulanger and J. Williams. 2005. An estimate of breeding females in the Bathurst herd of barren-ground caribou, June 2003. Department of Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No. 164. 75 p.
- Gunn, A. and M. Sutherland. 1997. Surveys of the Beverly caribou calving grounds, 1957-1994. Northwest Territories Department of Resources, Wildlife and Economic Development. File Report No. 120. 119 p.
- Heard, D.C. 1981. An Estimate of the Size and Structure of the Kaminuriak Caribou Herd in 1977. Wildlife Service, Government of the Northwest Territories. Report No. AI-**40**:40 pp.
- Heard, D. C. 1985. Caribou census methods used in the Northwest Territories. McGill Subarctic Research Papers 40:229-238.
- Heard. D. C. 1987a. Allocation of effort in stratified survey design. Department of Renewable Resources Manuscript Report No. 19. 9 pp.
- Heard D. C. 1987b. A simple formula for calculating the variance of products. Department of Renewable Resources Manuscript Report. 5 p.
- Heard, D. and G.W. Calef. 1986. Population Dynamics of the Qamanirjuaq Caribou Herd, 1968 – 1985. *Rangifer*, Special Issue No. **1**:159-166.
- Heard, D.C., Jackson, F. J. and T.M. Williams. 1990. Beverly Calving Ground Survey 2-14 June 1987. NWT Department of Renewable Resources File Report No. **22**:118 pp.

- Huggins, R. M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. *Biometrics* 47:725-732.
- Innes, S., M. P. Heidi-Jorgensen, J. L. Laake, K. L. Laidre, H. J. Cleator, P. Richard, and R. E. A. Stewart. 2002. Surveys of belugas and narwhals in the Canadian High Arctic NAMMMCO Scientific Publications No. 3.
- InterGroup Consultants Ltd. 2013. Economic Valuation and Socio-Cultural Perspectives of the Estimated Harvest of the Beverly and Qamanirjuaq Caribou Herds. InterGroup Consultants Ltd., 500-280 Smith Street, Winnipeg, MB. Report for: Beverly and Qamanirjuaq Caribou Management Board. 58 pp.
- Johnson, D. and R. Mulders. Systematic reconnaissance survey of the Beverly herd of barren ground caribou, June 2002. Department of Environment and Natural Resources Manuscript Report. in prep. v.
- Jolly, G. M. 1969. Sampling method for aerial census of wildlife populations. *East African Agricultural and Forestry Journal*. 34: 46-49.
- Krebs, C. J. 1998. *Ecological Methodology* (Second edition). Benjamin Cummins, Menlo Park, California.
- Laake, J., D. L. Borchers, L. Thomas, D. Miller, and J. Bishop. 2012. Mark-recapture distance sampling (MRDS) 2.1.0. R statistical package program.
- Laake, J., M. J. Dawson, and J. Hone. 2008a. Visibility bias in aerial survey: mark-recapture, line-transect or both? *Wildlife Research* 35:299-309.
- Laake, J., R. J. Guenzel, J. L. Bengtson, P. Boveng, M. Cameron, and M. B. Hanson. 2008b. Coping with variation in aerial survey protocol for line-transect sampling. *Wildlife Research* 35:289-298.
- Manly, B. F. J. 1997. *Randomization and Monte Carlo methods in biology*. Chapman and Hall. New York. 281 p.
- Marshall, L. 2021. Distance Sampling Survey Design: dssd R package.

- Nagy, J. and M.W. Campbell. 2012. Herd Structure, Movements, Calving Grounds, Activity Periods, Home Range Similarity, and Behaviours of Migratory and Tundra-Wintering Barren-Ground Caribou on Mainland Nunavut and Eastern Mainland Northwest Territories, Canada. Nunavut Department of Environment. Wildlife Research Section. Technical Report Series. No. 01-12. 152 pp.
- Nagy, J.A.S. 2011. Use of Space by Caribou in Northern Canada. Department of Biological Sciences. University of Alberta. Edmonton Alberta. PhD Thesis. 164 pp.
- Nagy, J.A., D.L. Johnson, N.C. Larter, M.W. Campbell, A.E. Derocher, A. Kelly, M. Dumond, D. Allaire, and B. Croft. 2011. Subpopulation Structure of Caribou (*Rangifer tarandus L.*) in Arctic and Subarctic Canada. *Ecological Applications*. **21(6)**: 2334-2348.
- Nagy, J. and D. Johnson. 2006a. Estimates of the number of barren-ground caribou in the Cape Bathurst and Bluenose West herds and reindeer/caribou on the upper Tuktoyaktuk Peninsula derived using post-calving photography, July 2006. Department of Environment and Natural Resources Manuscript Report. in prep. v.
- Nagy, J. A. and D. Johnson. 2006b. Estimates of the number of barren-ground caribou in the Cape Bathurst and Bluenose-West herds using post-calving photography, July 2005. Department of Environment and Natural Resources Manuscript Report in prep. v.
- Panzacchi, M., B. V. Moorter, P. Jordhoy, and O. Strand. 2012. Learning from the past to predict the future: using archaeological findings and GPS data to quantify reindeer sensitivity to anthropogenic disturbance in Norway. *Landscape Ecol* 28:847-859.
- Parker G.R. 1972. Biology of the Kaminuriak Population of Barren-Ground Caribou Part 1. Canadian Wildlife Service Report Series Number **20**:88pp.
- Pebesma, E. 2018. Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal* 10:439-446.

- Plante, S., C. Dussault, J. H. Richard, M. Garel, and S. D. Côté. 2020. Untangling Effects of Human Disturbance and Natural Factors on Mortality Risk of Migratory Caribou. *Frontiers in Ecology and Evolution* 8.
- Priest, H. and J.U. Usher. 2004. The Nunavut Wildlife Harvest Study. Nunavut Wildlife Management Final Report. Iqaluit Nunavut Canada. 822 pp.
- QGIS Foundation. 2020. QGIS Geographic Information System. QGIS Association. <http://www.qgis.org>.
- R Development Core Team. 2009. R Foundation for Statistical Computing, Vienna, Austria.
- Russell, H.J. 1990. A Photocensus of the Kaminuriak Herd in July 1987. Dept. of Renewable Resources Government of the N.W.T. File Report No. 97:24pp.
- Schaub, M., and M. Kery. 2022. *Integrated Population Models*. Academic Press, London, UK.
- Seber, G. A. F. 1982. *The Estimation of Animal Abundance*. 2nd edition. Charles Griffin and Company, London. 654 pp.
- Severson, J. P., T. C. Vosburgh, and H. E. Johnson. 2023. Effects of vehicle traffic on space use and road crossings of caribou in the Arctic. *Ecological Applications* 33:e2923.
- Silverman, B. W. 1986. *Density Estimation for Statistics and Data Analysis*. Monographs on Statistics and Applied Probability. New York: Springer.
- St. John J.R. 2022. Understanding Caribou Population Cycles. Undergraduate Thesis, University of Montana. Professional Papers, and Capstone Artifacts.355. 35 pp.
- Thompson, S. K. 1992. *Sampling*. John Wiley and Sons, New York.
- Thomas, D. 1998. Needed: Less Counting of Caribou and More Ecology. The Seventh North American Caribou Conference, Thunder Bay, Ontario, Canada. *Rangifer*, Special Issue No. 10:15-23.

- Thomas, D. C. and S. J. Barry. 1990. Age specific fecundity of the Beverly herd of barren ground caribou. *Rangifer Special Issue No. 3*: 257-263.
- White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study Supplement* 46:120-138.
- Wickham, H. 2009. *ggplot2: Elegant graphics for data analysis*. Springer, New York.
- Wiken, E. 1986. *Terrestrial Ecozones of Canada. Ecological Land Classification Series, No. 19*. Environment Canada. Ottawa, Ont. ISBN 0-662-14761-8.
- Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. *Analysis and management of animal populations*. Academic Press, San Diego.
- Williams, M. 1995. Beverly calving ground surveys, June 5-16, 1993 and June 2-13, 1994. Department of Renewable Resources File Report No. 114. 36 p.
- Williams, M. 1994. Manual for conducting photographic calving ground surveys in the NWT. Department of Renewable Resources. 15 p.
- Zalatan, R., A. Gunn, and G. H. R. Henry. 2006. Long-term abundance patterns of barren-ground caribou using trampling scars on roots of *Picea mariana* in Northwest Territories, Canada. *Arctic, Antarctic, and Alpine Research* 38:624-630.
- Zar, J. H. 1996. *Biostatistical analysis*. Third edition. Prentice-Hall, London.