Estimating Abundance and Trend of the Qamanirjuaq Mainland Migratory Barren-Ground Caribou Subpopulation - June 2017.

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ABSTRACT

We set out to obtain a current abundance estimate and trend of the number of females in the Qamanirjuaq herd of barren ground caribou then extrapolate that estimate using fall composition studies to a whole herd estimate. In June 2008 the Government of Nunavut estimated 344,078 (95% CI=56,870; CV=8.1) adults and yearlings. A second survey flown in June 2014 estimated 264,718 (95% CI=44,084; CV=8.3) adults and yearlings. The reduction in abundance between June 2008 and June 2014 tested positive for significance (DF=71.3; T=-2.23; P=0.029) suggesting a 23% decline over the 6 years between estimates. The most recent abundance estimate, flown in June 2017, estimated 288,244 (95% CI= 46,123; CV=7.8) adults and yearlings. Total number of caribou estimated on the calving ground, however, was 262,272 (SE=16,746) in June 2014 and 252,060 (SE=15,493) in June 2017. Weighted log-linear regression of the adult female estimates from 2008, 2014, and 2017 estimates suggest a non-significant decreasing trend with a yearly λ estimate of 0.98 (CI=0.94-1.01) suggesting a longer term declining trend of 2% (CI=-6% to +1%) per year. A simulation approach was used to further explore potential trends. Random estimates were generated based on the confidence intervals for the 2008, 2014, and 2017 surveys. Regression lines were then fit to the randomly generated estimates for 1000 iterations. The resulting distribution of trend estimates demonstrates that the majority of trend estimates suggested a negative trend (λ<1). The mean λ estimate in this case is 0.975 (percentile 95% CI=0.95-1.00) which is similar to that obtained from regression analysis.

Past calving ground photo surveys have relied on the assessment of breeding females to estimate and track abundance in mainland migratory barren-ground caribou subpopulations such as the Qamanirjuaq subpopulation. An examination of the reliability of breeding female status has indicated a between year variability within the Qamanirjuaq subpopulation that could reduce estimate reliability and thus accuracy and precision. The use of the annual core calving area by female

caribou has been found to be a much more reliable metric, as past surveys of the Qamanirjuaq subpopulation have indicated strong affiliation of females, regardless of their breeding condition, to the core calving area.

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

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1.0 INTRODUCTION

Caribou are circumpolar in their distribution and occur in northern parts of Eurasia and North America. In Canada, caribou are represented by four subspecies; Peary (*R. t. pearyi*), Woodland (*R. t. caribou*), Grant's (*R. t. granti*), and Barren ground (*R. t. groenlandicus*). Of the four, barren-ground caribou are the most abundant and can be further divided into two ecotypes, the taiga wintering mainland migratory, and the tundra wintering types (Nagy et al. 2011). The Qamanirjuaq herd of barren-ground caribou is a taiga wintering mainland migratory ecotype.

The Qamanirjuaq Caribou Herd is the largest herd in the western arctic occupying a massive (300,000km^2) yet poorly understood annual range. Kivalliq Inuit utilize over 8,000 Qamanirjuaq caribou per year followed by Manitoba Dene utilizing just over 2,000 caribou per year. Both Saskatchewan and NWT aboriginal harvesters utilize an estimated 500 to 1,000 animals though this harvest varies from year to year depending on the subpopulations seasonal distribution and local availability (InterGroup, 2008). In total an estimated 10,000 to 11,000 Qamanirjuaq caribou are harvested annually with an estimated annual meat replacement value of over fifteen (15) million dollars. Any decline in productivity or increase in mortality herd wide would have a devastating impact on thousands of subsistence harvesters and their families across the range.

The logistics involved in determining how these caribou use their range are both difficult and cost restrictive. The modification of a satellite telemetry program launched in 1993 into a GPS/satellite program has aided in the building of a comprehensive location and activity database. Additionally this data has been informing on the herds seasonal range extents and use. This database has been providing biologists, Hunter Trapper Organizations, Regional Wildlife Organization and inter-jurisdictional and jurisdictional management boards with the only source of information connecting the Qamanirjuaq caribou to their range.

Historically, a dramatic decline in Qamanirjuaq numbers, first identified in the early 1950's, sparked a flood of scientific studies all attempting to understand the underlying mechanisms responsible for the decline (Heard, 1985; Parker, 1972). Research efforts were at their peak between the late 1970's and late 1980's. A population survey in 1982 showed that the trend was dramatically, and despite research based predictions, reversed (Gates, 1989). This unexplained increase was not surprising to local hunters as the local knowledge of the time disagreed strongly with scientific findings. Early surveys first monitored an increasing trend beginning in the late 1970s with an estimate of 44,000 adult and yearling caribou (Heard, 1981; Gates, 1983). By 1988 the herd was estimated to have increased to 221,000 (SE = 72,000), and by 1994, 495,665 (SE = 105,426), the highest recorded abundance for the herd. Though we are unclear on when the trend in abundance began to turn negative, by June 2008 the Qamanirjuaq subpopulation was estimated to have declined to 348,661 (SE = 44,861) adults and yearlings (Russell, 1990; Williams, 1995; Campbell et al., 2010).

In recent years estimates of herd size are based on a combination of visual counts and aerial photography of the calving ground where cows aggregate for a 10 to 15 day period (peak calving) before dispersing. To obtain the whole herd estimate the numbers of cows are counted and herd abundance extrapolated using fall composition counts. Up until 1994 the herd has appeared to have been growing. Herd trend from 1994 to 2014 was significantly declining while current monitoring indices such as spring recruitment have also suggested a steady decline in mean calf production between spring 1999 and 2017. Local hunter observations clearly describe observations of fewer caribou and a high incidence of disease between 2008 and 2017. Additionally hunters have described their observations of larger animals mixed with smaller animals of the same age suggesting a mixing of herds could have occoured over the 2017 survey period. This community based information has raised considerable concern for the future of the herd across the Kivalliq region. These concerns were heightened with a documented drop in relative densities of calving Qamanirjuaq caribou between reconnaissance surveys flown in June 2008, 2010, 2012, 2014, and 2017.

Results from photographic calving ground surveys of the Bathurst herd from June 2003 through June 2016 indicated that the Bathurst herd has been declining at about 5% a year (Gunn et al. 2005, GNWT 2017). At present the Bathurst Herd has declined below the basic needs of subsistence harvesters leading to a harvest moratorium in an attempt to recover herd numbers. Post-calving photographic surveys of the Cape Bathurst and Bluenose East and West herds in July 2005 and 2006 (Nagy and Johnson 2006a, 2006b) showed significant and continued declines in these three herds. There appears to be synchronicity between the barren ground herds that could be in response to large-scale events such as weather patterns, density dependant reproductive disease, and parasites, preditors, suggesting that these mainland caribou declines could be related and thus likely to follow the same pattern for eastern herds. With mining and exploration on the increase within calving and post calving habitat of the Qamanirjuaq herd, as well as an excellerating market for caribou meat within Nunavut Territory, it is important managers determine the status of the herd in order to provide timely mitigation of potential human impacts that could mitigate and/or prevent these impacts that would otherwise have a negative influence on reproductive productivity and overall herd abundance and trend.

Our collective experience from the Bathurst Herd example warns that major declines in mainland migratory barren-ground caribou subpopulations are likely occouring within eastern populations and must be caught early to reduce the hardship of a long-term restrictive harvest on subsistence harvesters. Knowing the trend and status of the population will allow managers to start, if required, less restrictive actions, such as habitat protection, non-quota limitations (NQLs), and/or commercial harvesting restrictions, earlier in the cycle to foster quicker recovery. All current population indices indicate that the Qamanirjuaq herd is declining, lack of appropriate management actions may exacerbate or prolong herd recovery and place future undue hardship on communities that harvest this herd both commercially and for subsistence.

The present work was designed to determine the abundance and distribution of caribou within the Qamanirjuaq mainland migratory barren-ground caribou subpopulation, and in comparison with past abundance estimates, determine the subpopulations status and trend. We designed the survey to meet the following 5 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 the number of females on the calving ground 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) Conduct a fall composition study for the purposes of extrapolating to a whole herd estimate: 5) Delineate the spatial extent of the annual calving ground and compare this to historical calving ground use.

This summary report is an excerpt of the analysis of the photographic and aerial survey data used to estimate herd size of the Qamanirjuaq herd in June 2017. These results will be included in the larger report being prepared by the Government of Nunavut. The general conclusion from the ongoing analysis suggests that since the June 2008 calving ground photographic survey, the Qamanirjuaq herd has decreased at an approximate rate of 2% per year. Comparison of 2017 with estimates from the 2014 survey suggests an apparent stabilization of herd size, however, imprecision of estimates and survey factors prevent a definitive conclusion from this comparison.

2.0 STUDY AREA

Using annual location data collected from satellite and GPS collars between 1993 and 2008 we estimated the Qamanirjuaq caribou herd range to cover 310,000 km^2, (Figure 1). The study area 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 entire study area 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 (NT), and includes seven communities; Brochet Man., Tadoule Lake Man., Black Lake Sask., Wollaston Lake Sask., Arviat NT, Whale Cove NT, Rankin Inlet NT, Baker Lake NT, and Chesterfield Inlet, NT. Most of the annual range including the calving, post-calving range, as well as the spring and fall migration corridors, lie entirely within Nunavut, while the early- mid- and late-winter ranges spread across 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, 2001, Figure 2).

Qamanirjuaq caribou rarely range into the northern arctic ecozone and are commonly seen within the southern arcticeEcozone during spring and summer. Within the southern arctic ecozone, the Dubwant Lake plain/upland ecoregion forms the northwestern extents of the herds range and is primarily used by post calving caribou during the months of July and August (Campbell et al., 2012: Environment Canada, 2001) (Figure 3). This ecoregion is characterized by annual temperatures of approximately -10.5 ^{0}C with a summer mean of 6^{0}C and a winter mean of -26.5^{0}C. Mean annual precipitation varies from 225-300mm. The Dubwant Lake plain/upland ecoregion is classified as having a low shrub arctic eco climate. It is characterized as having a nearly continuous cover of tundra vegetation, consisting of *Betula nana* (dwarf birch), *Salix* spp (Willow), *Ledum decumbens* (Labradoor tea), and *Vaccinium* spp. Tall shrubs including *Betula* spp (Birch), *Salix* spp and *Alnus crispa* (Alder) occur on warm sites while wet sites are dominated by *Salix* spp, *Carex* spp (Sedges) and moss. Sandy flats sparsely covered by vegetation characterize most of the surface of this region. Permafrost is continuous with low to medium ice content in the eastern extents of the region.

The Maguse River upland ecoregion is the dominant ecoregion making up much of the northern extents of the herds range through May, June, July and August. Annual concentrated calving grounds of the herd are entirely within this ecoregion including much of the post-calving range and spring migration corridor (Campbell et al., 2012). The ecoregion is characterized by mean annual temperatures ranging from -8^{0}C in the south to -11^{0}C in the north. A mean summer temperature of 6^{0}C and a winter mean of -24^{0}C occur across the region. Mean annual precipitation varies from 250-400mm. The coastal climate is moderated by the open waters of the Hudson Bay during late summer and early fall. The ecoregion is classified as having a low arctic eco-climate. It is characterized as having a cover of shrub tundra vegetation. *Betula glandulosa*, *Salix* spp and *Alnus crispa* occur on warm dry sites while poorly drained sites are dominated by *Salix* spp, *Sphagnum* spp (Sphagnum moss) and *Carex* spp. The region is associated with areas of continuous permafrost with medium ice content. Hummocky bedrock outcrops covered with discontinuous, acidic, sandy, granitic tills are dominant. Prominent fluvialglacial ridges (eskers) and beach ridges occur. Wetlands make up 25% to 50% of the land area and are characterized by low and high centered polygon fens.

There are three ecoregions within the Taiga Shield ecozone; the Kazan River upland, the Selwyn Lake upland and Tazin Lake upland. The Kazan River upland ecoregion roughly covers the middle third of the Qamanirjuaq caribou herd annual range. The eastern and southeastern portions of this ecoregion are used by the Qamanirjuaq herd primarily for post-calving (August), and fall migration and rut (September and October)

(Campbell et al., 2012). The western extents are used during most years as rutting habitat and during some years as early winter range. The Kazan River upland is characterized by a mean annual temperature of approximately -8^{0}C with a mean summer temperature of 8^{0}C and a mean winter temperature of -24.5^{0}C. Mean annual precipitation ranges between approximately 200mm in the north to over 400mm in the south. This ecoregion is classified as having a high subarctic eco-climate. It is part of a broad tract of taiga (treeless tundra and boreal forest transition) extending from Labrador to Alaska. Dominant plants include stands of *Picea mariana* (black spruce), *Picea glauca* (white spruce), *Larix laricina* (tamarak) with a lower canopy of *Betula glandulosa*, *Salix* spp, ericaceous shrubs and a ground cover of *Carex* spp, *Eriophorum* spp, fruticose lichens and moss. Drier sites are usually dominated by *Picea glauca*, ericaceous shrubs with a ground cover of moss and lichen, while poorly drained sites largely support *Carex* spp, *Eriophorum* spp, and *Sphagnum* moss. In more open areas a low shrub tundra of *Betula glandulosa* and *Salix* spp is more common. Ridged to hummocky bedrock outcrops covered with discontinuous sandy, granitic till are characteristic. Predominant eskers and small to medium sized lakes are common. Permafrost is mostly continuous with low to medium ice content grading to mostly discontinuous in the southern extents.

The Selwyn Lake upland ecoregion dominates the southern extent of the ecozone and is used by caribou primarily during the late fall, winter and early spring (November through April) (Campbell et al., 2012). This ecoregion forms the southern extents of the Qamanirjuaq annual range. Mean annual temperatures are approximately -5^{0}C with a mean summer temperature of 11^{0}C and a mean winter temperature of -21.5^{0}C. The ecoregion is classified as having a low subarctic eco-climate. As in the Kazan River upland the Selwyn Lake upland is part of the same broad tract of taiga (treeless tundra and boreal forest transition) extending from Labrador to Alaska. Stands of *Picea maraina* and *Picea glauca* are common and support ground covers of largely fruticose lichens and moss. Bog-fen communities are common and dominated by a *Picea glauca* canopy and ericaceous shrub and moss ground cover. Wetlands cover approximately 25% to 50% of the southeastern extents of the ecoregion largely consisting of moss, *Sphagnum* moss, *Salix* spp and graminoide communities including *Carex* spp.. Ridged to hummocky massive rocks form broad sloping uplands and lowlands and are covered with discontinuous acidic sandy tills. Prominent sinuous esker ridges and lakes are common throughout the region. Permafrost is extensive though discontinuous with low to medium ice content and sporadic ice wedges grading to sporadic and discontinuous with low ice content into the regions southern extents. Qamanirjuaq caribou rarely extend their range into the Tzin Lake upland ecoregion and then only during late winter Campbell et al., 2012; Environment Canada, 2001).

Within the Boreal Shield ecozone, Qamanirjuaq caribou have seldom used the Athabasca plain and Churchill River upland ecoregions since 1993. The two ecoregions represent the southern and southwestern extremes of Qamanirjuaq winter range. The Coastal Hudson Bay lowland ecoregion within the Hudson Plains ecozone is most commonly used during late winter and at times during late fall. This ecoregion represents the southeastern extent of the Qamanirjuaq herd annual range receiving little use in some years and no use over most years (Campbell et al., 2012).

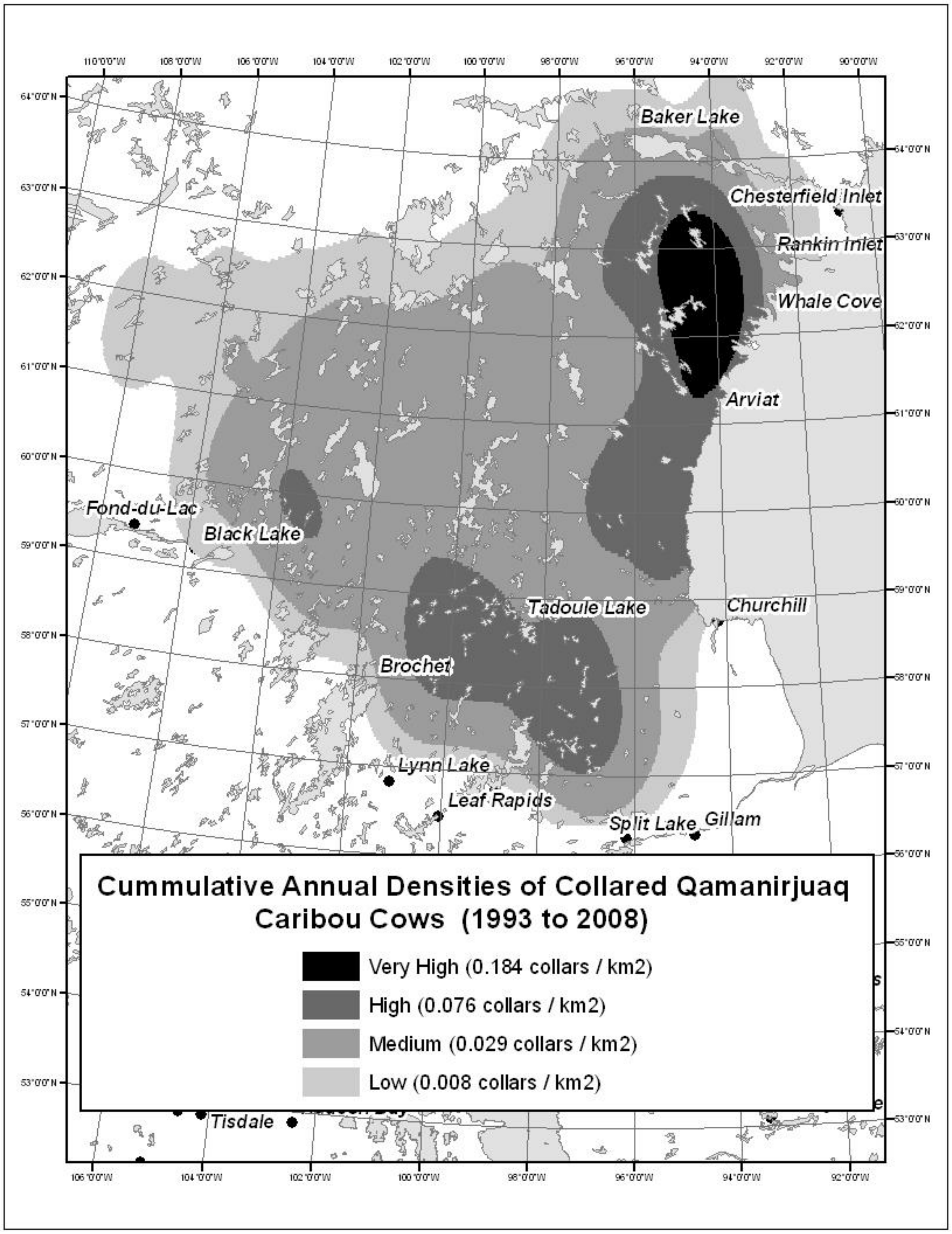

Figure 1 The range extents and annual densities of the Qamanirjuaq barren-ground caribou herd. Range extents were calculated using a kernel analysis of satellite and GPS collar data collected between November 1993 and April 2008.

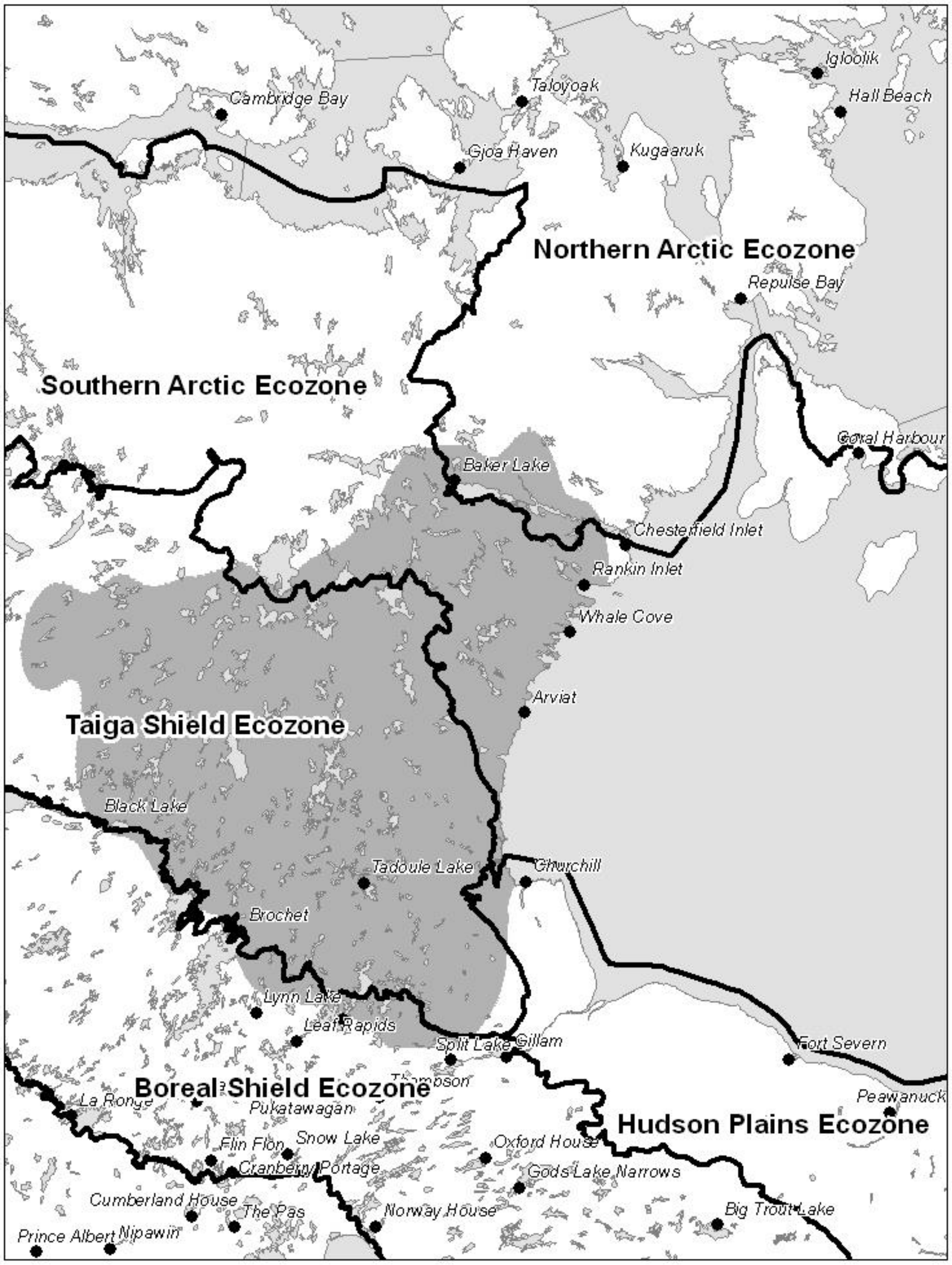

Figure 2 Ecozones of the Qamanirjuaq caribou herd annual range (1993 to 2008) (Environment Canada, 2009).

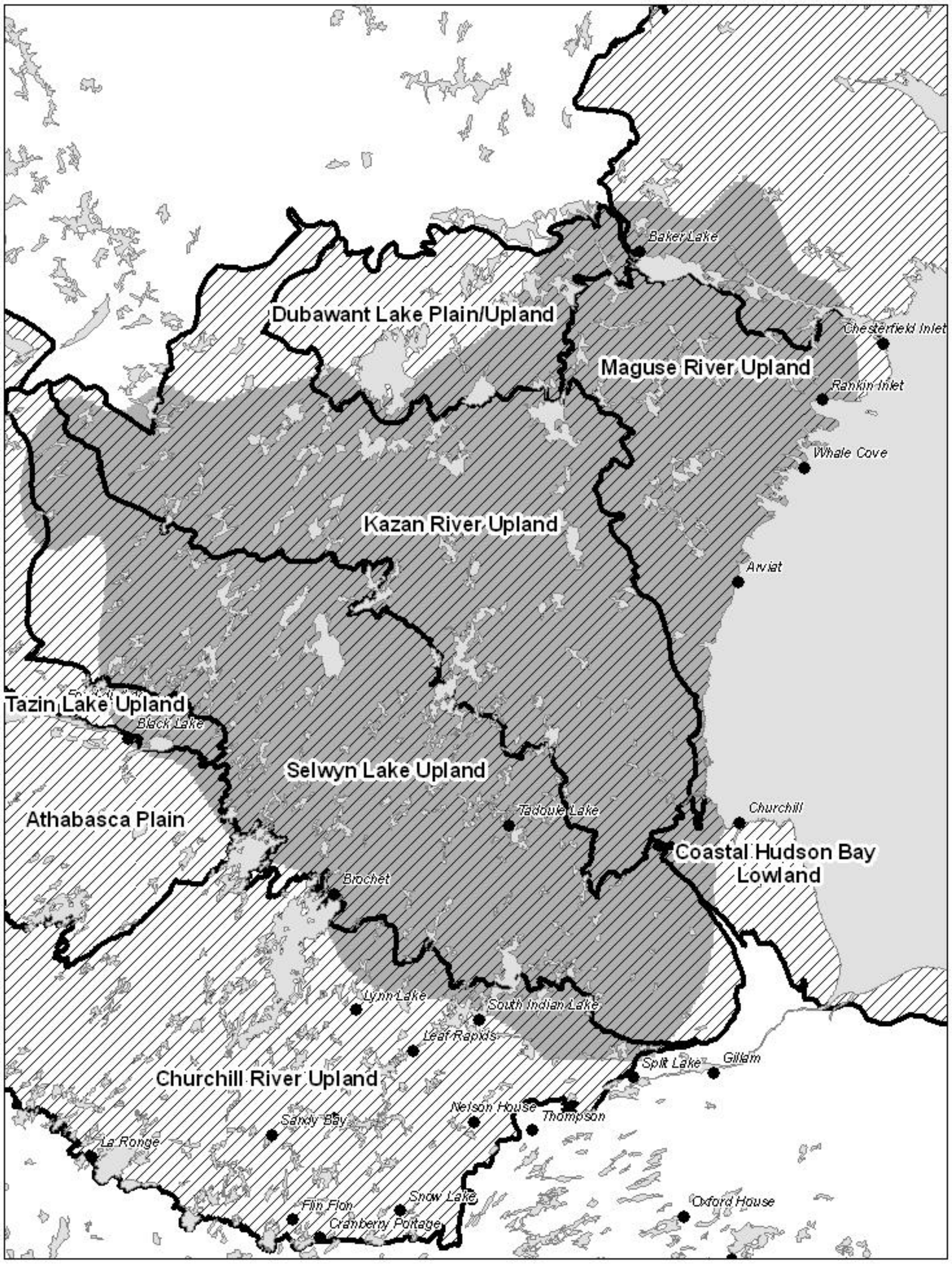

Figure 3 Ecoregions of the Qamanirjuaq caribou Herd annual range extents.

3.0 Methods

The 2017 Qamanirjuaq barren-ground caribou double observer pair visual and photographic calving ground surveys were 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 survey, 2) Double observer pair visual survey, 3) Photographic survey, 4) Density stratum based composition surveys and 5) fall composition surveys. The double observer pair systematic reconnaissance surveys were designed to determine the timing and distribution of calving as well as to stratify subsequent survey effort based on observed relative densities of females and breeding females. The photographic survey was designed to access caribou abundance within densities too high for effective visual assessment. The double observer pair visual surveys and the composition surveys were used to estimate the number of females and breeding females on the annual concentrated calving grounds while the fall composition survey was used to extrapolate the female estimates to subpopulation estimates by estimating the male to female ratio.

3.1 Visual Surveys

Two high wing, single engine, turbine, Cessna Grand Caravans were used for both the reconnaissance and visual surveys across the entire study area. Strip widths were established using streamers attached to the wing struts (Figure 4). Strip width (w) was calculated using the formula of Norton-Griffiths (1978):

$$w = W * h/H$$

Where:

$\boldsymbol{W}$ = *the required strip width;*

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

H *= the required flying height*

Strip width calculations were confirmed by flying perpendicularly over runway distance markers. The strip width was 400 m out each side of the aircraft, for a total transect width of 800 m. All aircraft were equipped with radar altimeters to ensure an altitude of 400 feet above ground level (AGL) was maintained accurately. Off-transect observations were optional during the abundance phase of the survey so that observers could focus on indicated strips marked out on each of the left and right wing struts. During the reconnaissance survey, caribou were classified as much as possible as adult with or without antlers, adult with or without calf, and yearling or bull.

For this survey, a double observer pair method using two observers on each side of the aircraft was utilized. The double observer pair method implemented during all phases of the June 2017 survey was very similar to the strip transect method used in previous calving ground surveys. For strip transect surveys, caribou that are observed within the strip width (as defined by the wheel of the plane and the indicator on the wing strut) are recorded. The double observer pair method uses the same strip transect method, but also collects additional information to estimate caribou sightability through the addition of two dedicated observers.

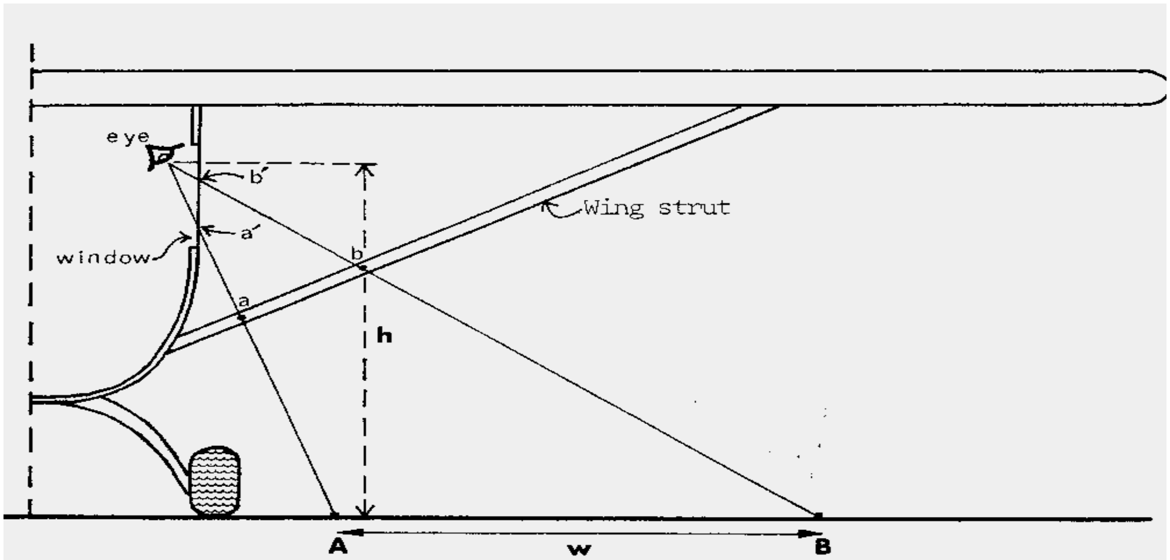

Figure 4 Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978). W is marked out on the tarmac, and the two lines of sight a' – a – A and b' – b – B established. The streamers are attached to the struts at a and b, whereas a' and b' are the window marks.

3.1.1 Double Observer Pair Visual Method

The double-observer pair method was designed to replace the need of a photo plane for surveys encountering more moderate densities of wildlife. This method involves two pairs of observers on each of the left and right hand sides of the aircraft. One “primary” observer who sits in the front seat of the plane and a “secondary observer” who sits behind the primary observer on the same side of the plane (Figure). The method adhered 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).

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 the right seat beside the pilot and the other on the rearmost seat on the left side of the aircraft, 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. at lunch or within a stratum) as part of the survey methods 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.

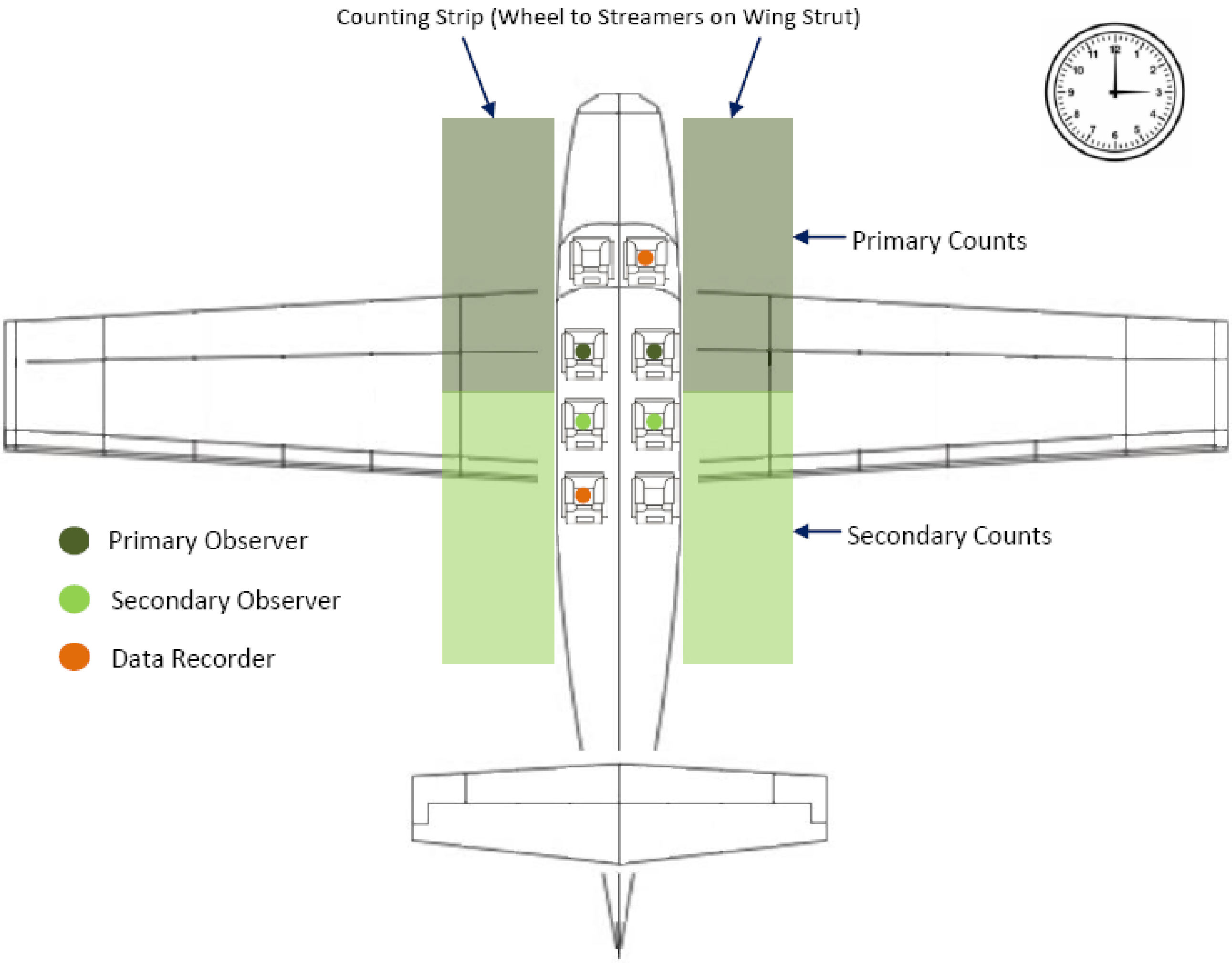

Figure 5 Observer position for the double observer pair method employed on this survey. The rear (secondary) observer calls caribou not seen by the front (primary) observer after the caribou have passed the main field of vision of the front observer. The small hand on a clock is used to reference relative 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.).

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 (an estimated 250 meters) to other individuals then the caribou were considered a group.

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 (Russell et al. 2005). The systematic reconnaissance survey of the annual calving ground was flown between June 7th and 12th, 2017.

The reconnaissance survey was based on a systematic array of transects running north-south (Figure 6) and spaced at 10 kilometer intervals. Each transect was 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 extent. 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, the northern extent of the distribution was modified from that of the southern, eastern and western. Consecutive transect segments were flown north until no females and/or breeding females (Hard antlered cows or cow/calf pairs) were observed within the ten kilometer segment. Two additional ten kilometer transect segments would be flown north of the last observed breeding female/female and two parallel ten kilometer transect segments to the east and west of the transect segment within the last observed breeding female/female. 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.

Following the systematic reconnaissance but prior to the initiation of the visual and photographic surveys, all 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 ArcToolbox. The tools allowed us to calculate the relative density of observed caribou locations along the sample transects 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^2 (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^2); 4) The relative density (#obs/km^2) 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 distribution into High, Medium and low density strata.

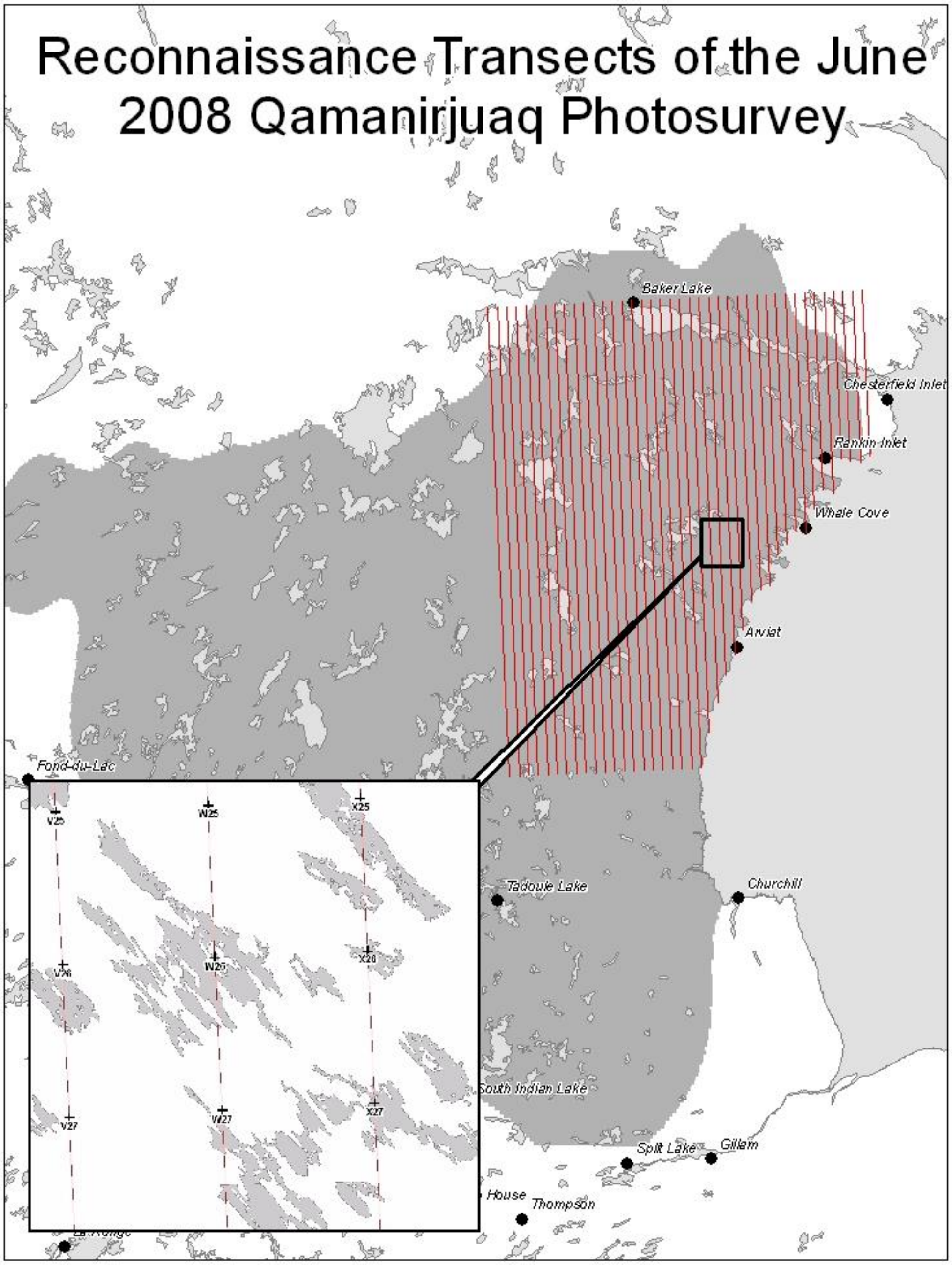

Figure 6 Potential reconnaissance transects and transect stations designed to cover the known extent of calving for the Qamanirjuaq barren-ground caribou herd in June 2008. These same transects were used in all consecutive surveys. Not all lines were flown during the 2017 survey.

3.1.3 Visual Abundance Surveys

The visual survey was conducted within 5 medium density, 3 low density and 2 very low density stratum located entirely within the female/breeding female distribution identified using reconnaissance survey results (Figure 7). ESRI GIS software was used to visually display reconnaissance survey results including both numbers of animals and breeding status. Stratum boundaries would be visually aligned with the relative density graphic to capture transect segments of similar density. All low-density strata were surveyed following the completion of the systematic reconnaissance of female/breeding female distributions. We continued the reconnaissance along known spring migratory corridors to ensure distributions of females/breeding females were not missed.

The visual survey followed the same methods discussed in the systematic reconnaissance survey with the exception of transect allocation and alignment. Transects within each of four low-density stratum 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 strata (Figure 7). Within the medium density stratum transects were placed 2.6 to 5.0 kilometers apart providing approximately 30% to 20% coverage, while within low strata transects were placed between 5.5 and 6.5 km spacing for a range of coverage of 18% to 16%. Yery low density strata transect spacing was set at 10 km spaceing with an estimated coverage of 9%.

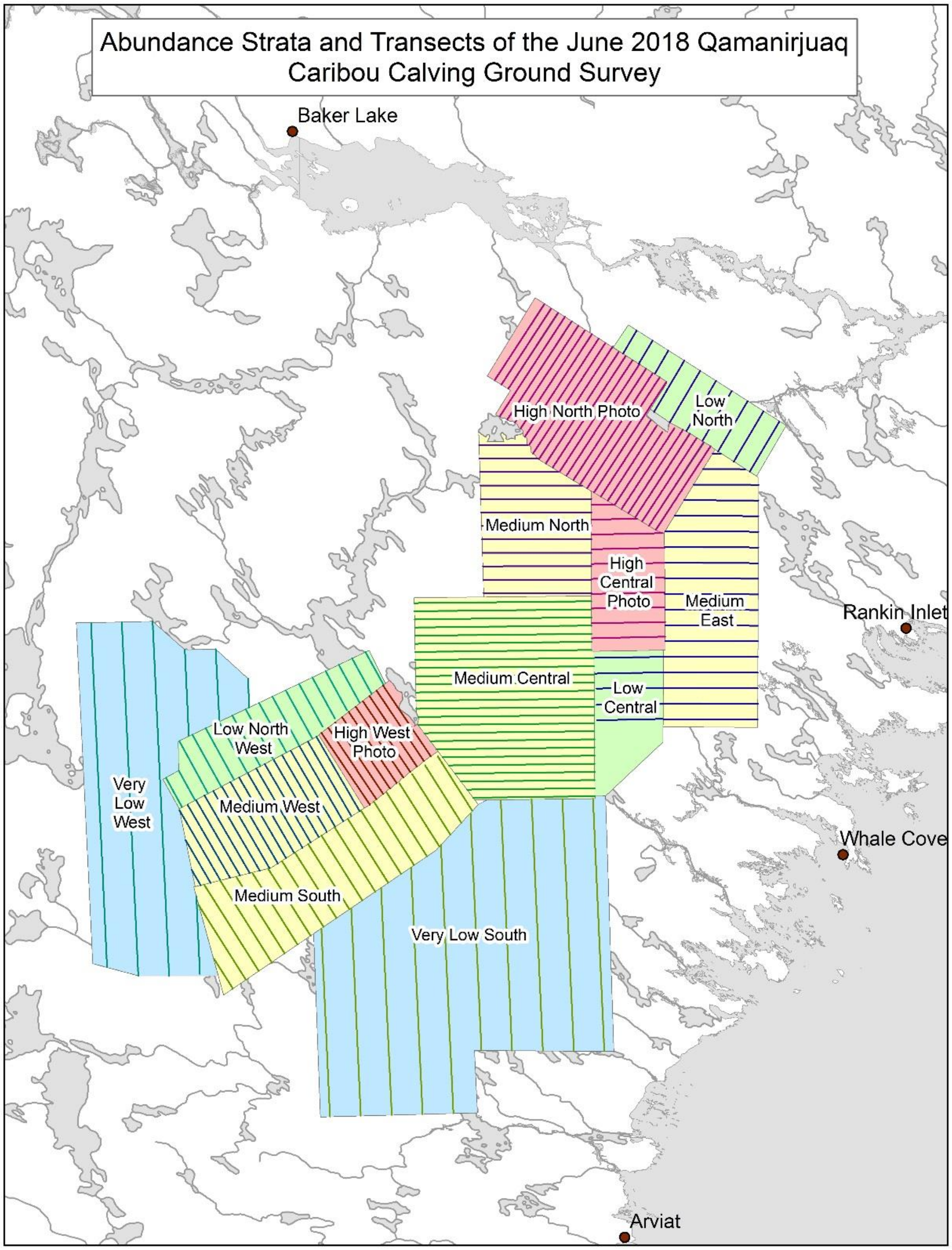

Figure 7 Visual and photographic strata of the June 2017 Qamanirjuaq calving ground abundance survey.

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

3.2 Photographic Surveys

Aerial photography provides more accurate estimates of caribou because observer errors and bias leading to increased variation in observations is considerably reduced. This is due to the ability of the interpreter to count caribou under controlled conditions. Geodesy Services was contracted to fly the photographic component of the survey. The plane used was 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 aircraft was positioned from Calgary to Rankin Inlet just prior to the completion of the reconnaissance. Approximately 5,700 photos were taken representing an estimated 1,510 linear kilometers of flying.

The photographic component of the calving ground survey was designed to photograph relative density strata of breeding females in excess of ten caribou per kilometer squared as close to the completion of the systematic reconnaissance survey as possible. The systematic reconnaissance survey over breeding female distributions was completed June 7th, 2017 though we continued the reconnaissance along known spring migratory corridors to ensure distributions of breeding females were not missed.

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 2017 survey effort high density transect spacing was set at 2.6 within the northern and western high density strata and 4.6 within the central high density photo strata yielding a photo coverage of 35% and 30% respectively.

3.3 Composition Surveys

3.3.1 Calving

Composition studies were conducted concurrently with visual surveys following study area stratification. Caribou were classified as yearlings (>/= 1.0 but < 1.1 years of age termed 1+ years of age in this document), bulls, cows with calves (< one month old), cows with udders, udderless cows with antlers, and udderless cows without antlers. We also recorded whether antlered cows had either 1 or 2 antlers. Breeding cows were tallied as cows with calves, cows with udders, and udderless cows with antlers. Non-breeding females were tallied as udderless cows with no antlers, while the remaining animals were classified as yearlings and 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, 1000 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 and non-breeding females, calves, yearlings and bulls (Manly, 1997).

Composition survey effort was allocated consistently within each stratum with the exception of the northern Photographic strata where extra limital calving took place well north and west of previously recorded calving distrributions. . Previously positioned fuel caches were not sufficient to cover the northern extents of the 217 calving distribution. Selection of flight paths were based on fuel cache locations and caribou aggregations, but attempted to use the reconnaissance transect station locations 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 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 the aircraft would proceed to the next nearest transect station to the north and/or south, priority sampling the next nearest caribou group including individuals. At times, observed groups of caribou and fuel requirements “pulled” the composition survey from the pre-planned flight path. 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 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. Variances were obtained for the combined estimate using the delta method (Seber, 1982; Williams et al., 2002) assuming no correlation between the two estimates.

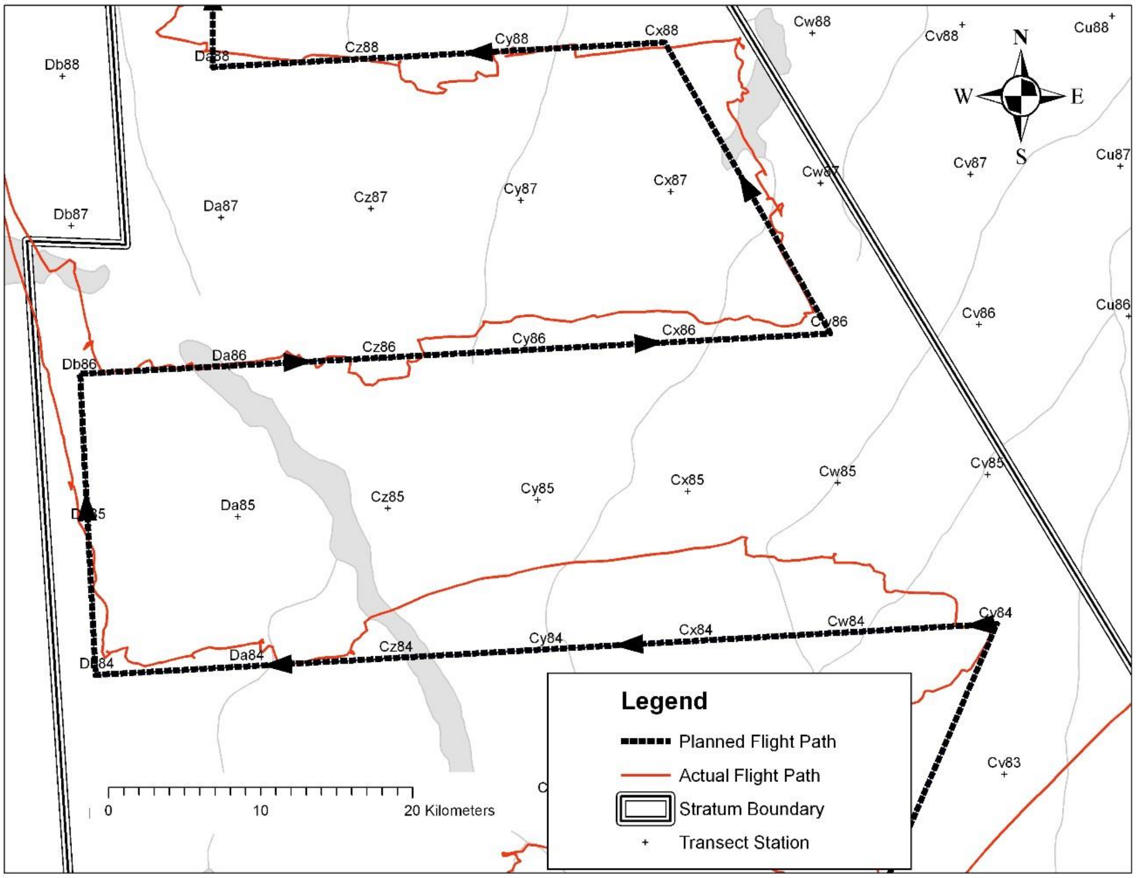

Figure 8 Strata composition flight lines vs. planned routes. Deviations due to observed caribou groups away from flight path. The next nearest group would be classified up to a maximum of 10 km (half way between adjacent transects) perpendicular to the planned flight path.

3.3.2 Fall/Rut

The purpose of the Qamanirjuaq fall-rut composition survey was 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. Though a combined estimate of breeding and non-breeding females are the best indicator of population trend, for management purposes, an estimate of total population size is desirable.

The Qamanirjuaq caribou fall composition survey was flown between October 15th and 18th out of Arviat Nunavut utilizing remote fuel caches to access aggregations further from the community. The survey itself used the locations of 20 Telonics GPS III and IV collars to locate aggregations of caribou and establish search patterns. Caribou groups encountered between and in the immediate vicinity of the collars 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, with exceptions made when adjacent areas included boulder fields, large lakes, the Hudson Bay coast, or fuel limitations. Fresh tracks in snow were used in all areas to locate new groups. The search of a collar area would terminate once no fresh tracks were observed or when a possibility of double sampling occurred. In instances where several hours passed between classification runs, previous GPS tracks were followed to relocate the groups and search a different direction from the group. GPS tracks were also used to insure the same groups were not re-sampled, which at times required the skipping of groups where mixing could have occurred. 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.

To estimate the total population size, the number of non-breeding and breeding females estimated in June 2017, was divided by the product of the proportion of females in the population as determined during the 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 and more accurate/precise estimator as the proportion of females pregnant, used to extrapolate a whole herd estimate from breeding females alone, and is based on dated information and for the Qamanirjuaq population, not immediately known. In the past, we used pregnancy rate proportions generated for Bathurst caribou surveys calculated from earlier studies to estimate whole herd abundance from breeding female estimates during calving (Gunn et al. 2005; Seber, 1982). This method has the disadvantage of introducing substantial error to whole herd estimates due to the known annual variability in pregnancy rates evident within the Qamanirjuaq caribou subpopulation.

3.4 Analysis

3.4.1 Double Observer Pair Visual Survey

The Huggins mark-recapture model (Huggins 1991) was 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 observer of which some are also seen by the second 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 second 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 second 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).

Models were built and compared in program MARK (White and Burnham 1999). We note that the model that we used was not a strict removal model in that it was not assumed that once a caribou group was observed by the first observer that it would always be observed by the 2nd observer. It was assumed that the second observer would not count a missed caribou as an independent group though. Using simulation modeling in MARK, we found that estimating the resighting probability (*c*) rather than fixing it (as 1) provided a more robust estimate of initial sightability of groups (p) (John Boulanger, unpublished data).

MARK produced estimates of sighting probability (*p*) and when possible resighting probability (*c*) for the secondary observer. The combined probability that a group of caribou was seen by at least one of the observers (*p**) therefore *1-(1-p)(1-p).* Figure 2 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.

Corrected counts for each group encountered were then estimated as group size divided by *p** for each group. The total corrected count for a series of observations could then be estimated as:

$$\hat{Y} = \sum_{i=1}^{j} \frac{y_i}{p_i^*}$$

where there were j groups encountered and y_i is the count or average count (if 2 observers both counted the caribou) and p^*_i was the sighting probability (from both observers that was potentially influenced by the size of the group) of the ith group. Therefore, for each stratum it was possible to add up all the corrected counts to obtain a corrected count of caribou observed on transect for the given stratum. Using the ratio of transect area sampled (a) to total stratum area (A) it was then possible to obtain an estimate of total population size for the stratum (Buckland et al. 2010).

$$\hat{N} = \frac{A}{a} \sum_{i=1}^{j} \frac{y_i}{p_i^*}$$

Note that this formula is equivalent to the estimator of (Jolly 1969) used for uncorrected visual estimates if p* is assumed to 1 (sightability is 1).

$$\hat{N} = \frac{A}{a} \sum_{i=1}^{j} \frac{y_i}{1}$$

Estimates of herd size 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. For this component, program DISTANCE (Buckland et al. 1993, Thomas et al. 2009) was initially used to input data into program MRDS. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002). Estimates from MRDS were cross checked with strip transect estimates (that assume sightability=1) using the formulas of Jolly (1969).

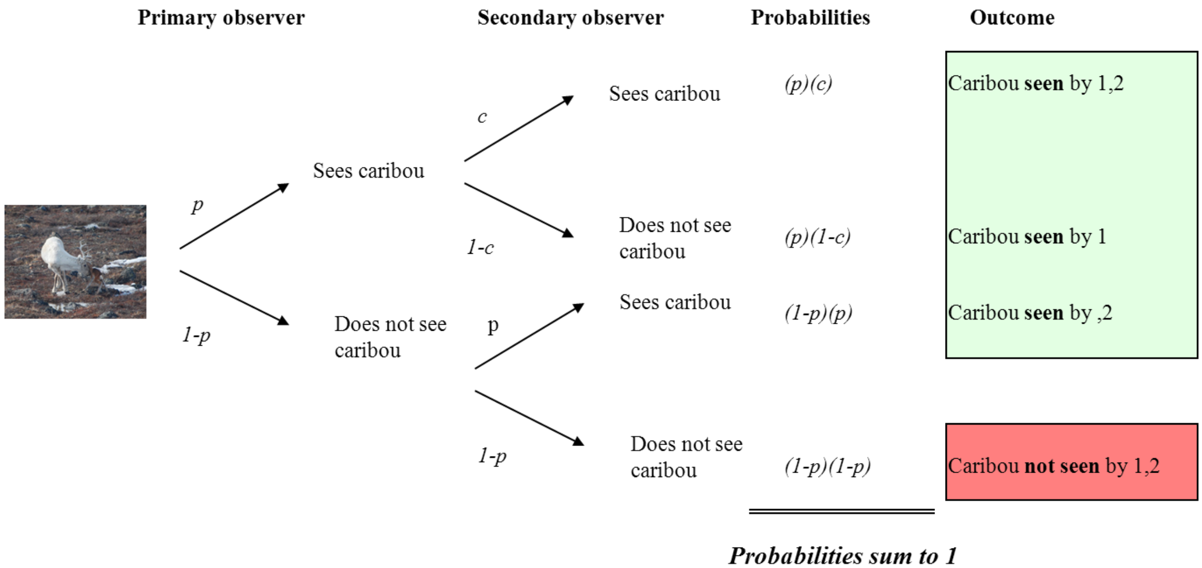

Figure 4: Conceptual diagram of how the probability of both observers not sighting a caribou group is estimated, and how the probability that at least one of the observers sees the caribou group (p^*) is estimated. The green boxes correspond to outcomes where caribou are seen and the red box corresponds 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 resighting probability of the 2nd 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.

3.4.2 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 MARK Huggins analysis (Table 1). Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. In addition, differences in sightability between the two observers was tested by adding a binary covariate that was a 1 when one observer was primary. This order covariate was modeled uniquely for each observer pair. If sighting probabilities were equal between the two observers it would be expected that order of observers would not matter and therefore the confidence limits for this covariate would overlap 0. This covariate was modeled using an incremental process in which all observer pairs were tested followed by a reduced model in which only the beta parameters whose confidence limits did not overlap 0 were retained.

Previous analyses (Campbell et al. 2012, Boulanger et al. 2014) suggested that the size of the group of caribou had strong influence on sighting probabilities and therefore we considered linear and log-linear relationships between group size and sightability (Table 1). Cloud and snow cover were recorded as they changed by data recorders as ordinal rankings. We suspected that sightability was most likely lowest in mixed snow cover conditions and therefore we considered both categorical and non-linear models to describe variation in sightability caused by snow cover. Cloud cover could also influence sightability by causing glare, flat light, or variable lighting. We used the same basic strategy to model cloud cover variation as snow cover variation.

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 (ΔAIC_c) was also used to evaluate the fit of models when their AIC_c

scores were close. In general, any model with a ΔAIC_c score of less than 2 was worthy of consideration.

Table 1: Covariates used to model variation in sightability for double observer analysis.

covariate	acronym	description
observer pair	obspair	each unique observer pair
observer order	obsorder	order of pair
group size	size	size of caribou group observed
Survey phase	recon	Survey phase of recon or abundance estimation
snow cover	snow	snow cover (0,25,75,100)
cloud cover	cloud	cloud cover(0,25,75,100)
Cloud cover	cloudc	Cloud cover (continuous)

3.5 Photo survey methods

A photo survey plane was used to survey higher density stratum where it would not be possible to count caribou accurately from the visual survey planes. The photo survey plane was flown at a specified altitude with a corresponding GSD resolution of aerial photos. Caribou detected on photos were counted by a team of photo interpreters and supervised by Derek Fisher, president of Green Link Forestry Inc., Edmonton, AB using specialized software that allowed three dimensional viewing of photographic images. The number of caribou counted was tallied by stratum and transect. The exact survey strip width of photos was also determined using the geo-referenced digital photos by Green Link Forestry.

The photo survey plane was forced to change survey altitude during the photo survey due to variable cloud ceilings. As a result, the strip width and survey area varied by transect in the photo stratum which could bias estimates due to non-random coverage of the stratum. To mitigate this issue, a method was used that estimated population size by equally weighting densities of caribou on each transect line regardless of strip width. More precisely, population size within a stratum is usually estimated as the product of the total area of the stratum (*A*) and the mean density ($\overline{D}$) of caribou observed within the strata ($\widehat{N} = \overline{D}A$) where density is estimated as the sum of all caribou counted on transect divided by the total area of transect sampling ($\overline{D}$=caribou counted/total transect area). An equivalent estimate of mean density can be derived by first estimating transect-specific densities of caribou ($\widehat{D}_i = caribou_i/area_i$) were *caribou$_i$* is the number of caribou counted in each transect and *area$_i$* is the transect area (as estimated by transect length X strip width). Each transect density is then weighted by the relative length of each transect line (w_i) to estimate mean density ($\overline{D}$) for the stratum. More exactly, $\overline{D} = \sum_i^n \widehat{D}_\iota w_i / \sum_i^n w_i$ where the weight (w_i) is the ratio of the length of transect line (l_i) i to the mean length of all transect lines ($w_i = l_i/\overline{l_\iota}.$) and *n* is the total number of transects sampled. Using this weighting term accommodates for different lengths of transect lines within the stratum therefore ensuring that each transect line contributed to the estimate in proportion to its length. Abundance of caribou in the stratum is then estimated using the standard formula ($\widehat{N} = \overline{D}A$). Estimates of variance were calculated using standard formulas that allow transects of different size and area (Jolly 1969). Confidence limits for estimates were based upon a t-statistic with degrees of freedom calculated using the number of lines surveyed in all strata and survey variances (Gasaway et al. 1986).

3.6 Estimates of breeding females, adult females and adults on the calving ground.

Composition surveys were conducted concurrently with visual surveys. During surveys caribou were classified as yearlings, bulls, cows with calves, cows with udders, udderless cows with antlers, and udderless cows without antlers. Breeding cows were tallied as cows with calves, cows with udders, and udderless cows with antlers. Non-breeders were tallied as udderless cows with no antlers, yearlings and bulls. Using this information, the proportion breeding females, adult females and adults was estimated for each stratum surveyed on the calving ground. Bootstrap methods were used to obtain variance estimates. In this case, 1000 resampling of the data were used and the mean and standard deviation from resampling were used as point estimates of proportion breeders and the associated standard error (Manly 1997).

Estimates of proportion breeders were then multiplied by the double observer estimate of all caribou for each stratum to obtain an estimate of the number of breeding females. Variances for combined visual strata were obtained using program MRDS therefore accounting for covariances introduced by the double observer sightability models. Variances for photo and visual strata, or composition survey and strata estimates were obtained for the combined estimates using the delta method (Seber 1982, Williams et al. 2002) assuming no correlation between the two estimates. Degrees of freedom for combined estimates were estimated using the formulas of Buckland et al (1993).

3.7 Analysis of fall composition data

Composition surveys were conducted in the fall of 2016 to determine bull-cow ratios and proportion adult cows needed for extrapolated population estimates. The bull-cow ratio was simply the count of bulls divided by the count of cows whereas the proportion of adult cows was the number of cows divided by the number of adult cows and adult bulls. As with the calving ground composition survey data, a bootstrap procedure was used for point estimates, standard error, and percentile-based confidence limits. For this 1000 bootstrap resampling were conducted on the original data set (Manly 1997).

3.8 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 the two surveys.

Regression methods were used to estimate yearly rate of change of adult females based on estimates from the 2008,2014, and 20176 surveys. Weighted regression analysis was 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. Monte Carlo methods (Manly 1997) were used to further explore trend estimates.

4 RESULTS

4.0 Layout of survey strata

Survey strata were designed based on reconnaissance survey flights as well as the monitoring of the movements 74 collared females. The threshold for the peak of calving was based upon observation of cows with calves and when movement rates declined to less than 5 km per day for collared cows. There were 2 groups of caribou that approached the calving ground. The first moved up the coast and arrived in the core calving area in early June. The second group moved eastward from Manitoba and only arrived in the core calving area in the first week of June. Monitoring of collared cow movements suggested that the peak of calving started at June 7 for the core area which contained the majority of the caribou in the herd (Figure 3).

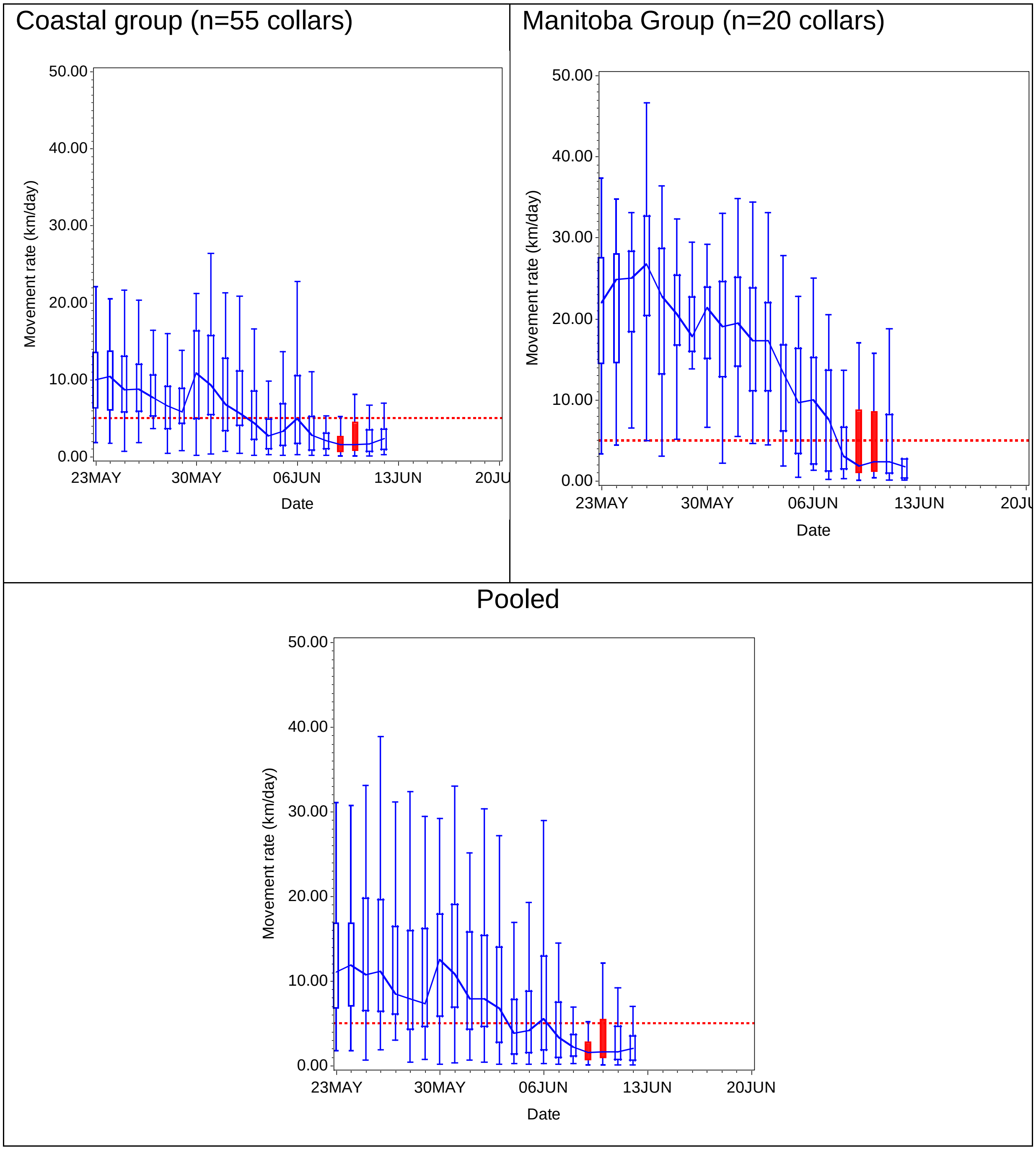

Figure 5: Movements of collared cows during the calving ground surveys as denoted by boxplots. The red boxes indicate when the main photo and visual survey occurred.

A plot of the locations of caribou on June 8th with movement rate delineated suggests most caribou were in the core area some stragglers to the East (Figure 4). Survey strata contained, as discussed next, contained all the collared caribou with the majority occurring in the photo stratum.

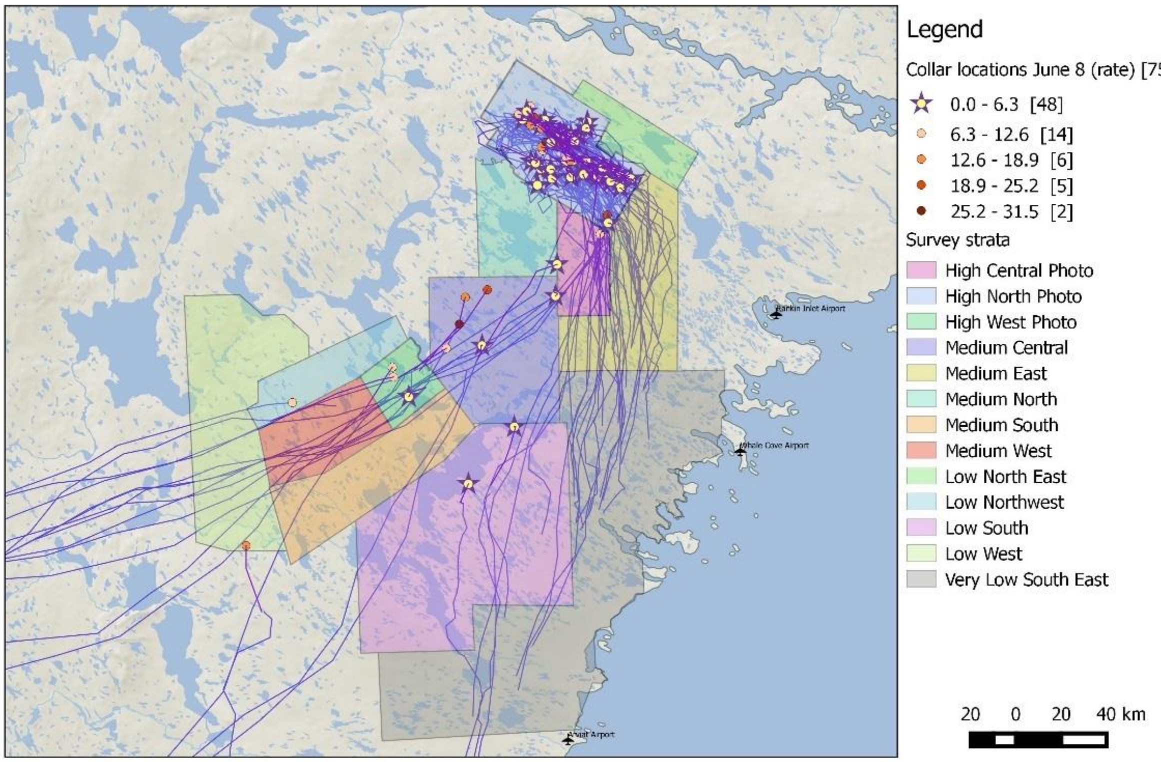

Figure 6: Movement of radio collared female caribou including movement rates on June 8 when survey strata were developed.

Survey stratum were layed out based on reconnaissance survey results (Figure 5). Prelminary estimates of density were derived for each stratum which were then used to allocate the number of transects flown per strata. Three photo strata were used based on high segment densities of caribou. Allocation for photo stratum were based upon the maximum number of photos that could be taken by the photo plane. The remaining areas were surveyed visually with allocation based upon the total number of kilometers that the 2 survey planes could fly in one to 1.5 days of flying assuming 2 trips per day with ferrying to survey strata considered in the calculations. This amounted to 3300 kilometers of flying on transect (including ferrying in-between transects). Assessment of collar locations during the reconnaissance survey and the visual/photo survey suggested minimal movement of caribou between the reconnaissance and visual/photo surveys (Figure 6).

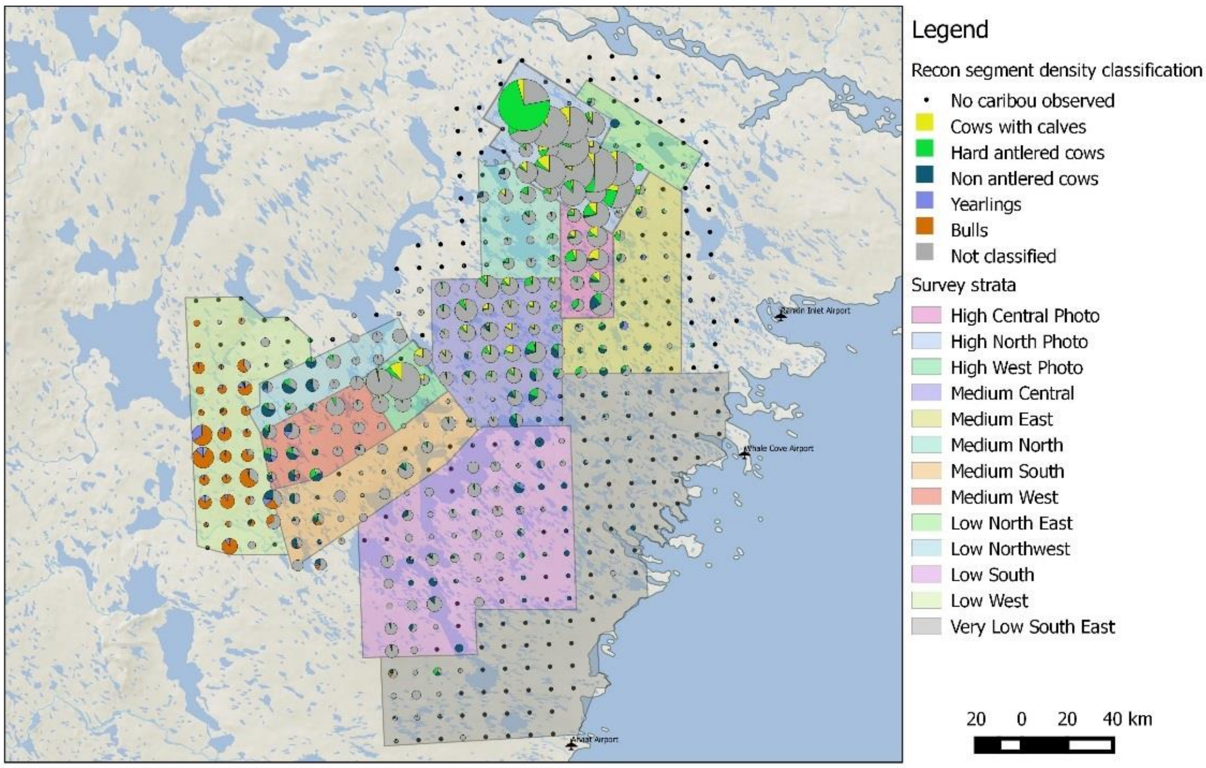

Figure 7: Reconnaissance segment densities and layout of survey strata. Composition of survey strata is given as a pie chart for each segment.

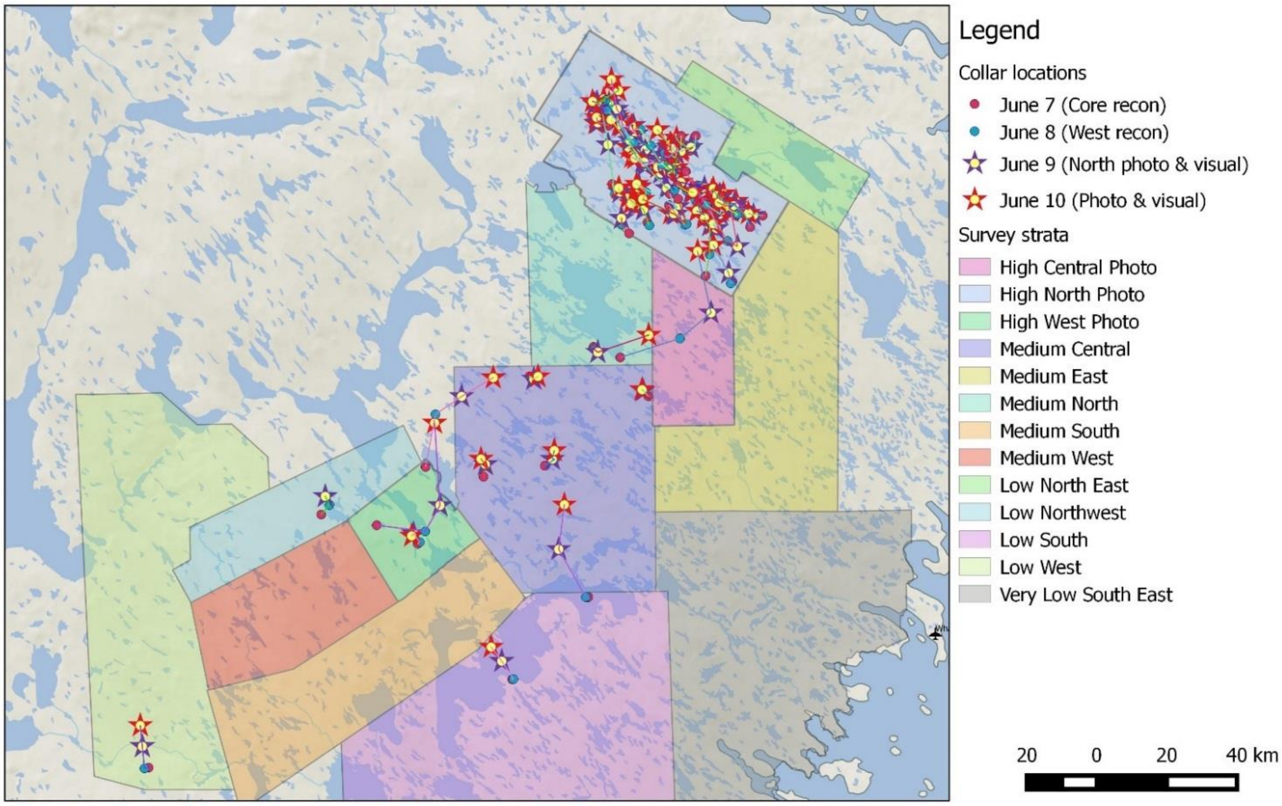

Figure 8: Movements of collar locations between reconnaissance and visual/photo surveys

Table 2 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 times 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 stratum was much higher than the visual stratum with the highest densities in the high north photo stratum.

A preliminary estimate of abundance can be gained by dividing the caribou counted by coverage (Table 2). This estimate is preliminary for the photo strata given the variable strip widths of transects due to differences in altitude of the photo plane. The weighted method, as described in the methods, was used to further refine estimates to ensure equal weighting of transects regardless of strip width. A plot of visual and photo survey results (Figure 7) suggests that the high north photo stratum delineated the core group of caribou adequately with a tailing off of observations to the northwest of the stratum. Larger group sizes were observed in the medium central stratum as well as some of the western stratum. However, these were mainly bulls as demonstrated by the reconnaissance survey results (Figure 5) and helicopter-based composition surveys discussed later in the report.

Table 2: Summary of sampling and count-based results by strata.

Strata	Strata area (km^2)	Transects	Area surveyed	coverage	Caribou counted	Density on transect	Preliminary N
Photo core strata							
High_Central_Photo	1029	10	213.5	20.7%	2293	10.74	11,052
High_North_Photo	2707	28	944.0	34.9%	51126	54.16	146,608
High_West_Photo	783	10	271.9	34.7%	3323	12.22	9,571
Visual core strata							
Low_North_East	925	10	126.1	13.6%	75	0.59	550
Low_North_West	1266	17	217.5	17.2%	1419	6.52	8,260
Medium_Central	3451	25	1061.2	30.8%	6289	5.93	20,451
Medium_East	2924	18	467.7	16.0%	726	1.55	4,539
Medium_North	1564	12	297.2	19.0%	1655	5.57	8,708
Medium_South	2479	20	395.1	15.9%	767	1.94	4,812
Medium_West	1566	19	406.3	25.9%	2016	4.96	7,770
Peripheral visual strata							
Low_South	7328	10	610.0	8.3%	916	1.50	13,675
Low_West	4103	7	337.5	8.2%	1125	3.33	11,004
Very_Low_South	9834	16	796.4	8.1%	258	0.32	3,186

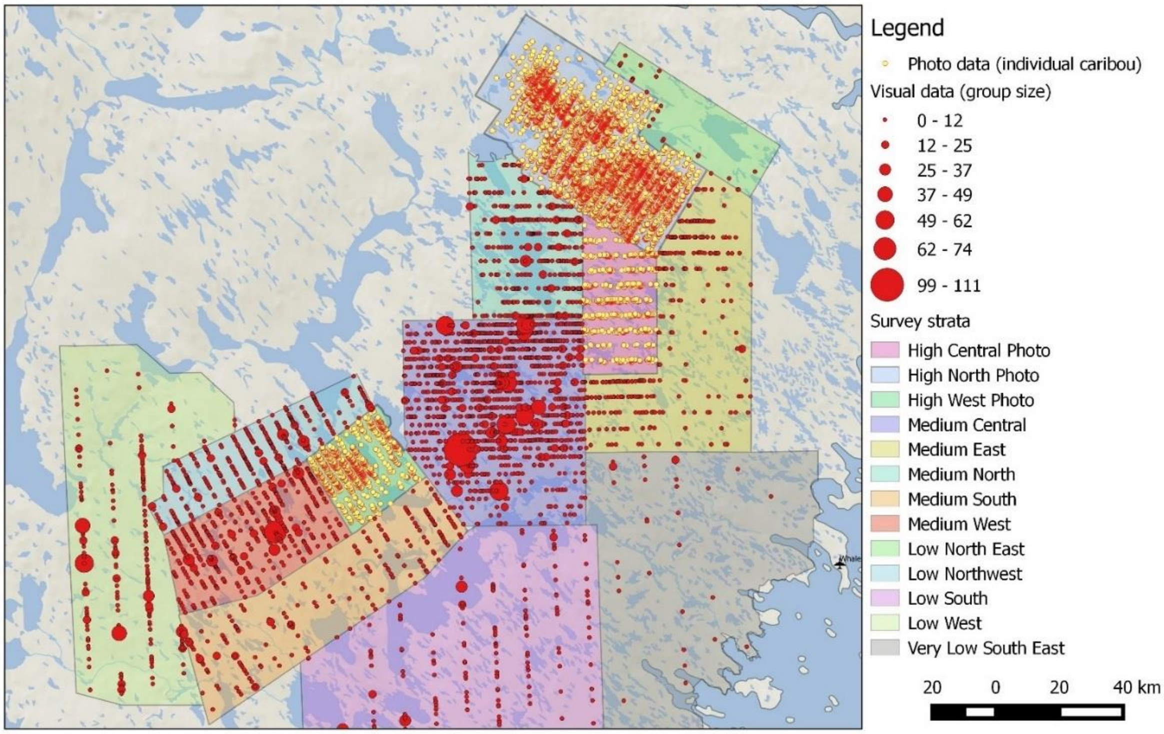

Figure 9: Summary of photo and visual survey with group sizes indicated for visual surveys and densities of individual caribou shown for photo data.

4.1 Visual survey double observer 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 8).

During the reconnaissance surveys the core of the calving ground was surveyed which led to observations of larger group sizes (Figure 8). 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. For the abundance phase, most group sizes were less than 25 caribou.

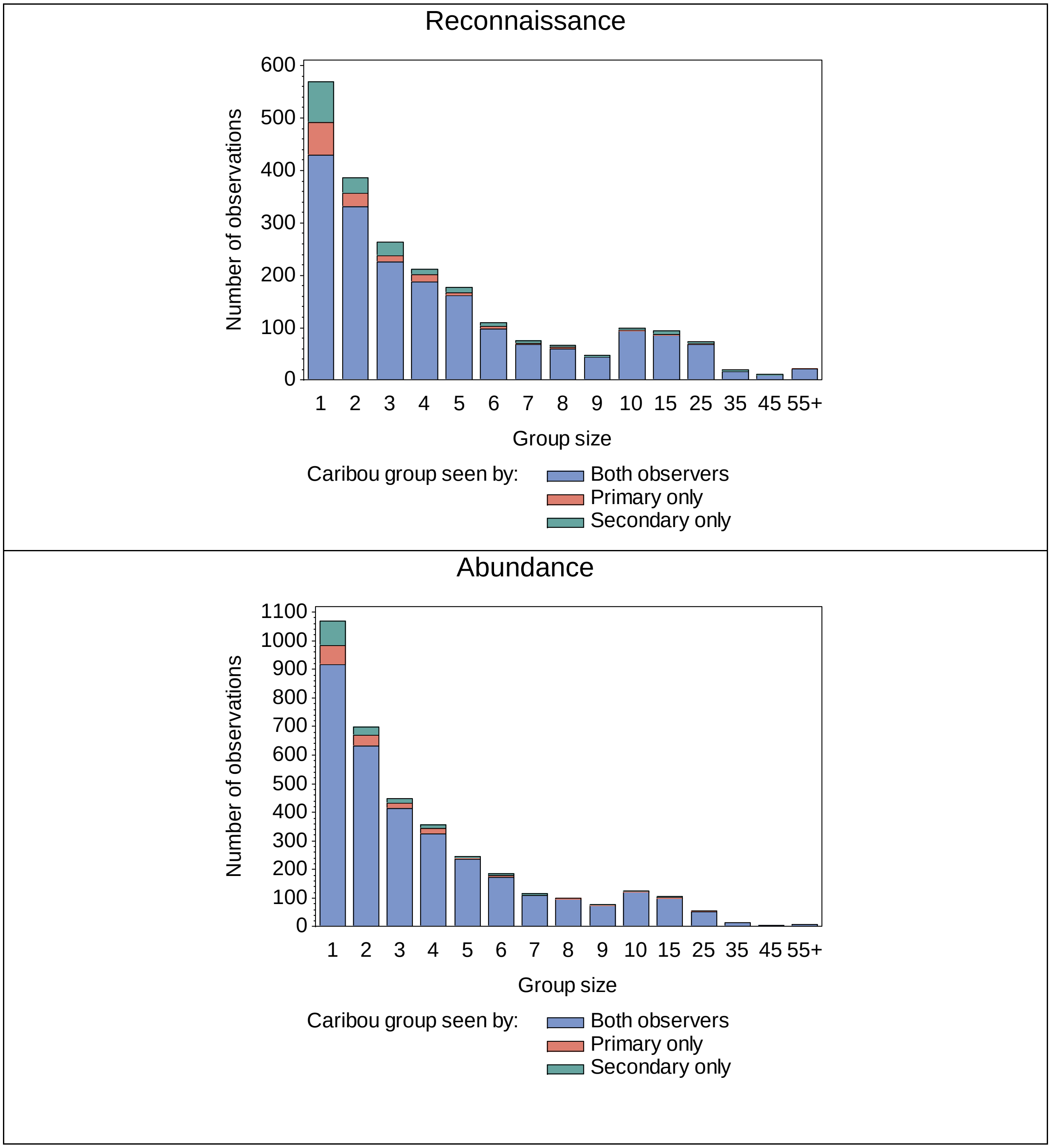

Figure 10: The frequencies of caribou observations as subdivided by observation type and midpoint of group size. The last category contains observation of 55 or more caribou. Counts of greater than 10 were binned with the midpoint of each bin displayed. The highest bin represents all counts within and above the bin interval.

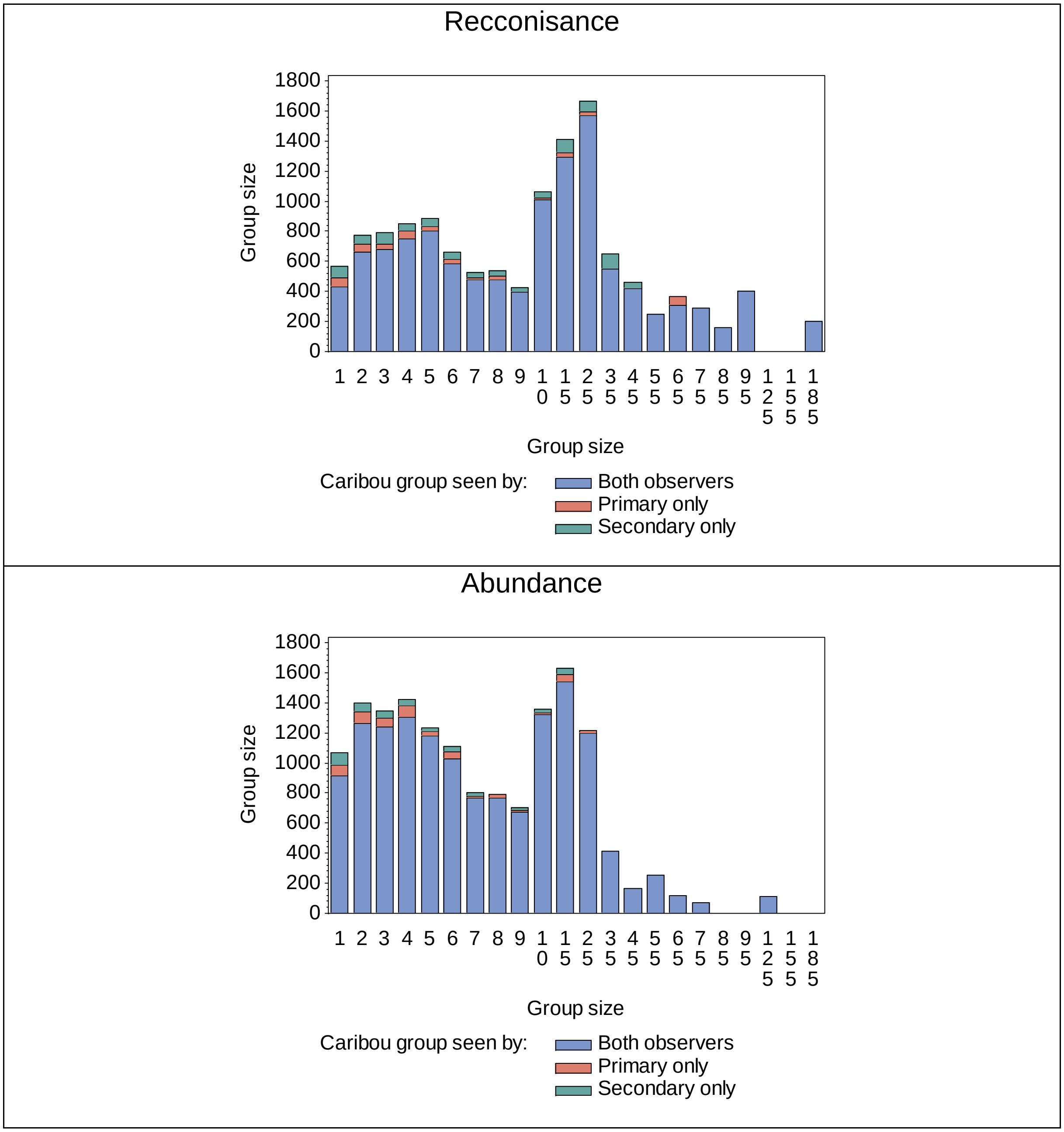

Figure 11: The net number of caribou observed (frequency of observations (from Figure 3) X group size) as a function of group size as subdivided by observation type. Counts from 1 to 10 caribou are represented by a single bar. Counts of greater than 10 were binned with the midpoint of each bin displayed. The highest bin represents all counts within and above the bin interval.

The net number of caribou counted (i.e. frequency of a given group size X group size) is shown in Figure 9. Of most interest is the abundance phase since these observations were used to estimate overall herd size. It can be seen that group sizes of 10 -25 caribou contributed the most to counts, however, counts of smaller group sizes (less than 10) when considered together contributed as much or more than counts of larger group sizes.

Overall, there were 16 unique pairs of observers during the visual portion of the survey. Of these pairs, 7 of them switched position from primary to secondary during the survey (Table 3). In general, sighting probabilities were high as indicted by low proportions (<.1) of observations that were only seen only the second observer. In addition, the proportion of caribou seen by observers was relatively similar when they switched from primary and secondary. However, the overall number of observations that occurred when the 2nd observer was primary was half of the number when observer 1 was primary suggesting that switching of observers did not occur equally during the survey.

Two pairings (pairs 11 and 15) only occurred during the reconnaissance phase of the survey and contained higher proportions of observations where the primary observer missed a larger proportion (48%) of caribou (pair 15) or both observers sighted all the caribou (pair 11). These results were anomalous, however, it was not possible to verify these estimates since the observers never switched positions. These observations were not used in the analysis since they only pertained to the reconnaissance phase.

Observer pairing were pooled based upon primary observers with pairs that switched being kept and other pairs being pooled based upon main observers in each group. This resulted in 8 observer pairs. The pooled data from observer pairs (Table 4) suggested slight differences in proportions of caribou sighted as indicated by proportion of caribou only observed by the secondary observer. In general survey conditions were ideal with 0% snow cover in 98% of observation during the visual phase but variable cloud cover during both phases of the survey (Figure 10).

Table 3: Summary of double observer observation based on observer pairings. Frequencies of observations for observer orderings are shown. Pairings where observed did not switch resulted in 0 frequencies and are shaded in grey. The naïve proportion of caribou groups not seen is given for each pairing. Observer pairing were pooled based on occurrence of primary observers.

Observers				Observer order 1				Observer order 2				
Pair	pooled	Ob1	Ob2	2nd only	1st only	Both	P(2nd)	2nd only	1st only	Both	P(2nd)	total
1	1	Barney	EvanAa	10	2	158	0.06	5	14	176	0.03	365
2	2	Barney	JoeSav	2	4	49	0.04	28	7	302	0.09	392
3	2	Barney	LeoIka	0	0	0		8	3	67	0.12	78
4	3	Jackie	JoeSav	0	0	0		13	5	117	0.11	135
5	3	Jackie	LeoIka	33	18	409	0.08	29	18	475	0.06	982
6	4	JoeSav	EvanAa	0	0	0		4	27	99	0.04	130
7	4	JoeSav	RogerP	11	3	227	0.05	17	5	637	0.03	900
8	5	LeoIka	RogerP	6	9	121	0.05	0	0	2	0.00	138
9	6	Lisa	Matthew	6	8	69	0.09	7	11	137	0.05	238
10	7	Matthew	ConorM	0	0	0		14	75	326	0.04	415
12	7	Matthew	Qovik	0	0	0		16	0	550	0.03	566
13	7	Matthew	Raymond	0	0	0		5	18	198	0.03	221
14	8	Robert	SteveF	0	0	0		11	41	169	0.07	221
16	8	RogerP	Robert	0	0	0		10	16	223	0.04	249
Excluded from analysis (reconnaissance phase only)												
11		Matthew	Ivan	0	0	0		0	0	420	**0**	420
15		RogerP	Lisa	0	0	0		118	18	247	**0.48**	383

Table 4: Pooled observation frequencies with ordering of pooled together. Estimates of proportion of groups missed by the primary observer are given (p(2nd only)

Pooled pairs	Frequencies of caribou observed by 2nd only	1st only	both	total	Proportion observed by 2nd only
1	15	16	334	365	0.045
2	28	11	309	348	0.091
3	69	36	890	995	0.078
4	32	34	963	1029	0.033
5	4	6	86	96	0.047
6	13	19	205	237	0.063
7	31	71	1007	1109	0.031
8	16	37	316	369	0.051

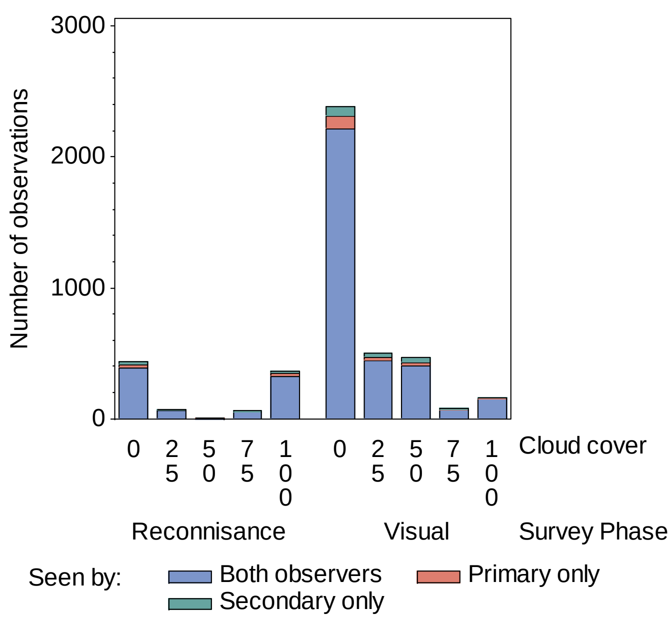

Figure 12: Summary of cloud cover for observations during the abundance.

4.1.1 Model selection

The general model building procedure followed a hierarchical process. Initially, model building focused on the best curve to describe the relationship between group size and sightability. A model with log-transformed group size (Table 5, model 14) was more supported than a model without log-transformation of groups size (model 16). Models that considered observer- specific variation were attempted next. A model with observer-pair specific probabilities was more supported (Model 2). Next models with cloud cover influencing sighting probabilities with (Model 1) and without observers (Model 5) were considered. Cloud cover was modelled as a categorical covariate which was more supported than a continuous version (Model 12: which assumes a linear relationship between cloud cover and sightability). As suspected snow cover was not supported as a predictor (Model 5 vs Model 6). The effect of the reconnisance phase was considered as an additive term (Model 3) and as an interaction with group size (Model 4) with minimal support. Overall a model with log-transformed group size, observers, and cloud cover was most supported (Model 1). A plot of mean single observer sighting probabilies (at mean levels of all covariates) suggested that single caribou had a sighting probability of 0.93 with probabilities being close to 1 once group size was greater than 10 (Figure 11).

The influence of covariates on sighting probabilities (Figure 12) suggested that the largest degree of variation was due to 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 12).

Table 5: Double observer closed Huggins model selection results. Main model terms are listed as columns with covariate names as defined in Table 3. Sample size adjusted Akaike Information Criterion (AICc), the difference in AICc between the most supported model for each model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and deviance is given.

No	Model	AIC_c	ΔAIC_c	w_i	K	Deviance
1	log(size)+cloud+observers	3388.1	0.00	0.40	14	3360.1
2	log(size)+observers	3389.3	1.17	0.22	11	3367.3
3	log(size)+cloud+observers+recon	3389.7	1.61	0.18	15	3359.7
4	log(size)+recon*log(size)+cloud+observers+recon	3390.1	1.96	0.15	15	3360.0
5	log(size)+cloud	3394.0	5.90	0.02	8	3378.0
6	log(size)+cloud+snow	3394.7	6.58	0.01	9	3376.7
7	log(size)+recon*log(size)+cloud	3395.3	7.16	0.01	9	3377.3
8	size+observers	3398.1	10.02	0.00	11	3376.1
9	size+cloud	3402.6	14.52	0.00	8	3386.6
10	size+recon*size+cloud	3404.0	15.88	0.00	9	3386.0
11	size+cloud+snow+snow2	3405.3	17.20	0.00	10	3385.3
12	log(size)+cloud(continuous)	3406.4	18.24	0.00	5	3396.4
13	log(size)+snow(continuous)	3410.4	22.23	0.00	5	3400.4
14	log(size)	3412.1	23.95	0.00	4	3404.1
15	log(size)+snow<25+snow>75	3413.6	25.43	0.00	5	3403.5
16	size	3421.0	32.91	0.00	4	3413.0
17	size+recon	3422.7	34.56	0.00	5	3412.7
18	constant	3467.6	79.46	0.00	3	3461.6

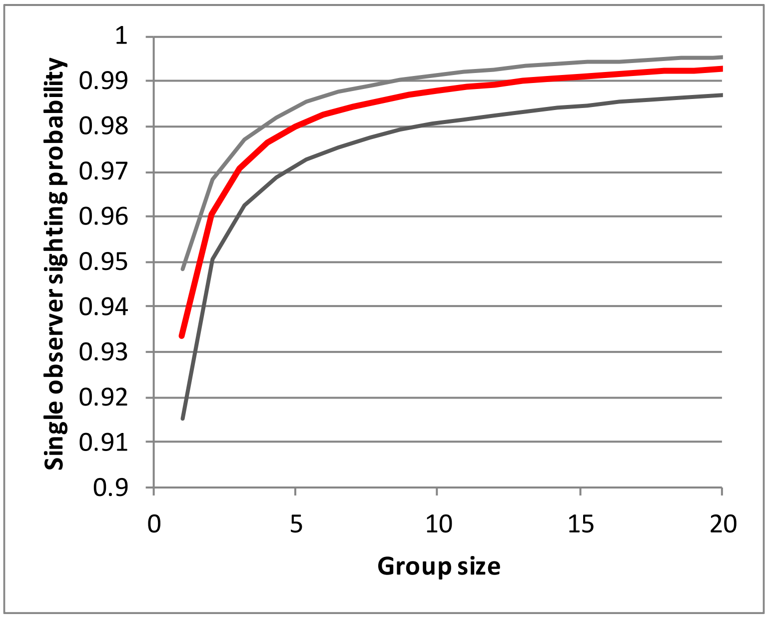

Figure 13: Single observer sighting probabilities for observer pairs based on size of caribou group observed based on model 1 (Table 3) at 0% cloud cover. Confidence limits are shown on predictions

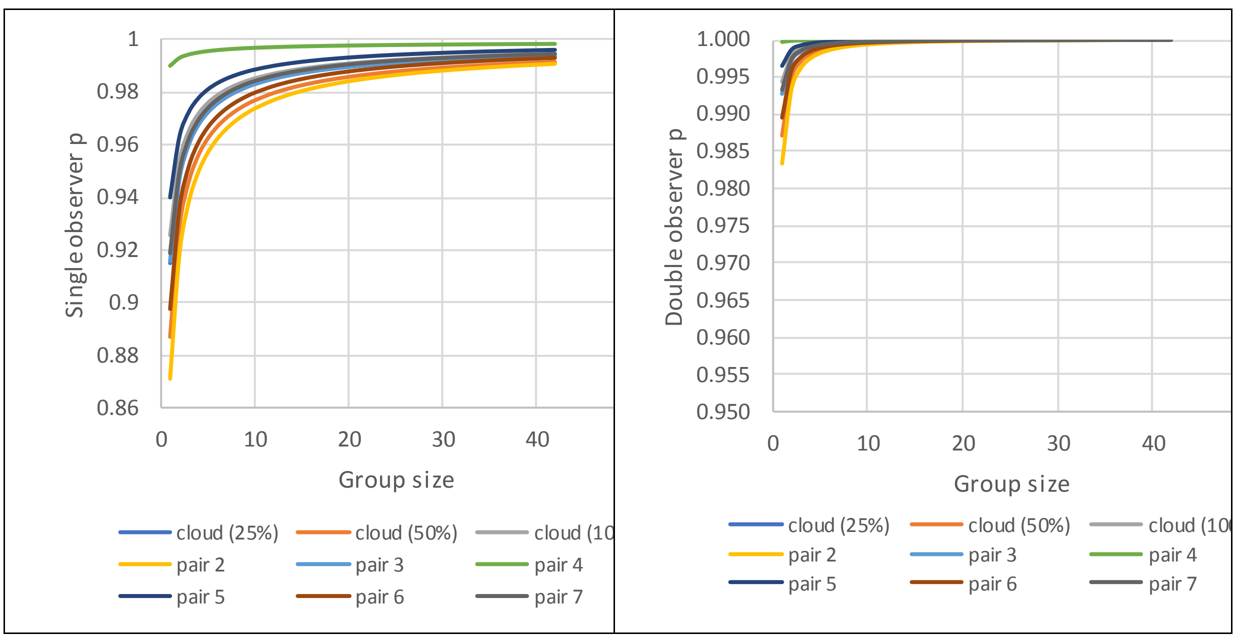

Figure 14: Single (left) and double (right) observer sighting probabilities as a function of model covariates. Observer pair covariates are based upon 0% cloud cover.

4.1.2 High density photo survey estimates

The photo plane changed altitude during surveys to maximize the coverage of photos given local cloud cover conditions. This approach reduced the number of photos taken but also created a variable strip widths (Table 6).

Table 6: Photo transect strip widths during survey

Strata	transects	Strip Width			
		Mean	SD	Min	Max
High_Central_Photo	10	0.99	0.23	0.72	1.18
High_North_Photo	28	0.92	0.07	0.83	1.02
High_West_Photo	10	0.99	0.06	0.87	1.04

Transect densities were estimated as the number of caribou counted on a given transect divided by the transect area (Figure 13). Densities were very high in the High North Photo on all lines except lines 1-3 which occurred at the northern end of the strata. Densities were relatively high on the other 2 photo stratum of a subset of lines which may have challenged visual counting methods.

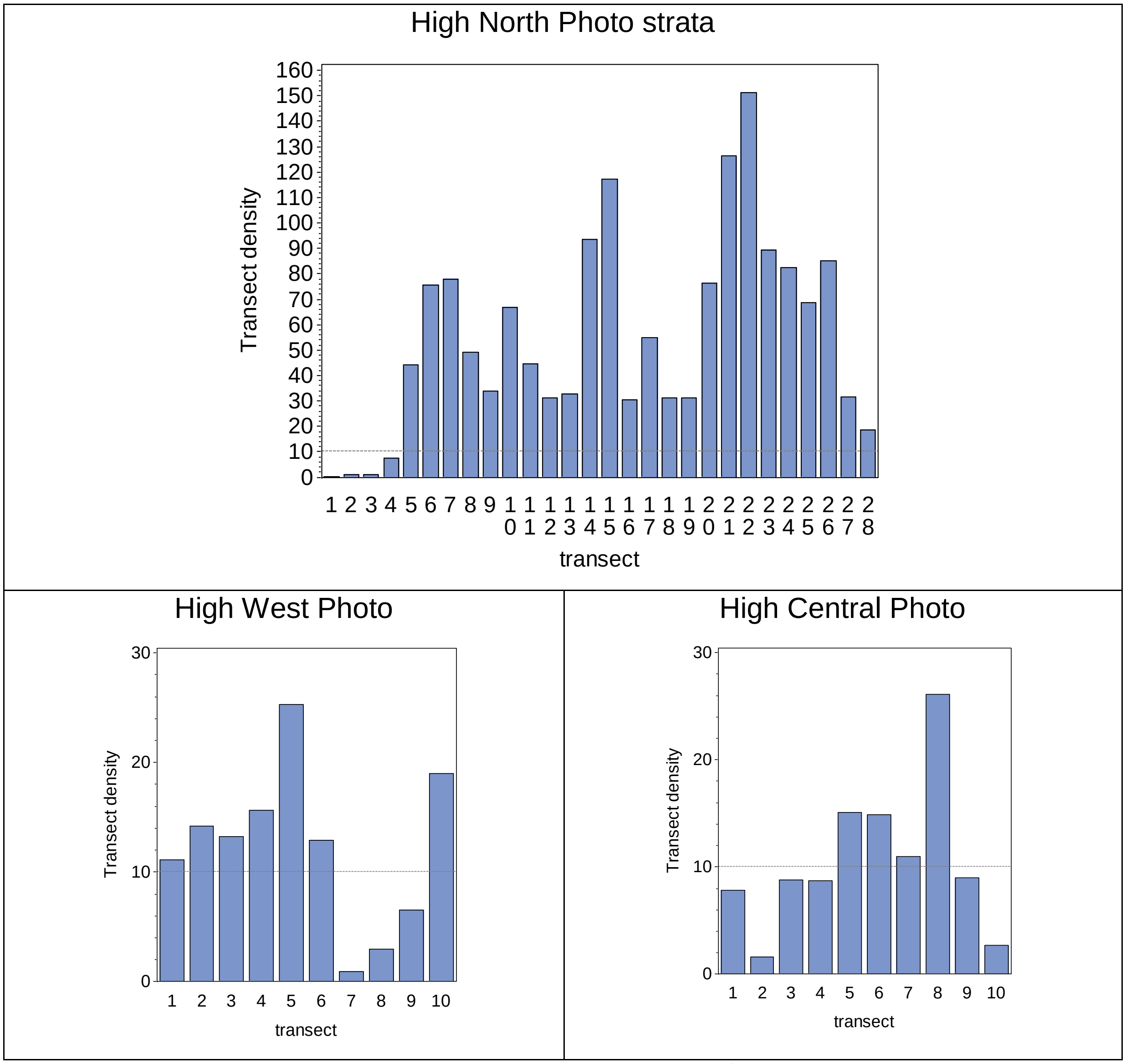

Figure 15: Estimates of caribou density (caribou per km^2) on high density photo stratum by transect.

4.1.3 Visual estimates

Density of caribou in transects was below 10 caribou per km^2 in all visual core strata with the exception of the medium central and medium north strata that had 1-2 transects with densities above the 10 caribou per km^2 (Figure 15). Two transects in the peripheral low west low northwest had densities higher than 10 caribou per km2.

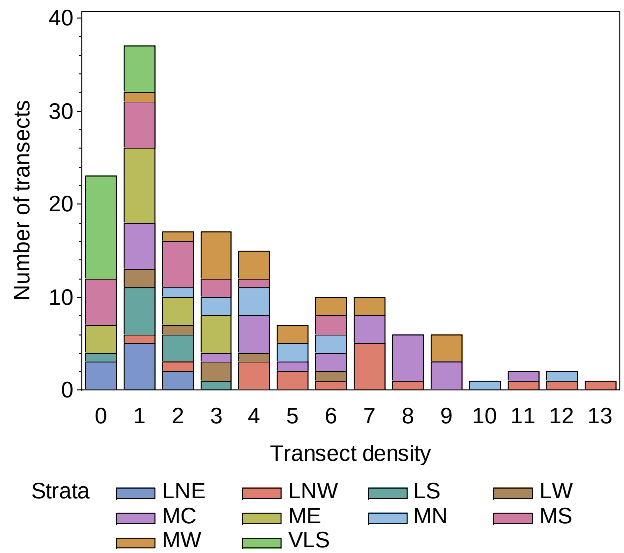

Figure 16: Estimated transect densities of caribou on visual strata during the abundance survey phase.

Double observer estimates were derived in program MRDS from Model 1 (Table 7) and compared to non-corrected count-based estimates. In general, the estimates were very close (<1% difference) with the total estimate for all strata being only 19 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 12), good survey conditions, as well as some potential sampling issues with the double observer method. Precision of double observer estimates was slightly lower since sightability parameters were being estimated in addition to other forms of variance.

4.1.4 Estimates of total caribou on the calving ground

Estimates of the total number of caribou on the core and peripheral strata using both the visual and photo survey data are displayed in Table 6. In all cases estimates were very precise with coefficients of variation of less than 10%.

Photo survey estimates were corrected for variable strip widths, however, the overall difference in estimates from uncorrected estimates (Table 2) was not large (corrected were 1.1% higher than uncorrected).

Table 7: Double observer estimates of all caribou in each strata and uncorrected count-based estimates for comparison purposes.

Strata	Double observer (MRDS)					Count-based estimate		
	N	SE	95% CI		CV	N	SE	CV
Low_North_East	552	153.4	298	1,023	27.8%	550	146.6	26.6%
Low_North_West	8,262	1017.5	6,370	10,716	12.3%	8,260	908.7	11.0%
Low_South	11,032	1821.6	7,612	15,988	16.5%	11,004	1569.8	15.6%
Low_West	13,689	1625.2	10,248	18,285	11.9%	13,675	593.5	19.3%
Medium_Central	20,430	1955.6	16,775	24,881	9.6%	20,451	1037.2	7.7%
Medium_East	4,547	661.1	3,351	6,169	14.5%	4,539	792.9	13.1%
Medium_North	8,687	1297.6	6,264	12,046	14.9%	8,708	722.5	11.9%
Medium_South	4,793	920.7	3,218	7,139	19.2%	4,812	1714.9	16.5%
Medium_West	7,785	894.4	6,121	9,903	11.5%	7,770	2636.3	9.3%
Very_Low_South	3,195	837.3	1,845	5,534	26.2%	3,186	346.1	10.9%
Totals	82,974	3913.1	75,526	91,156	4.8%	82,955	3987.6	4.7%

Table 8: Estimates of caribou (1+year old) on the calving ground from the core photo, core visual, and peripheral visual strata.

Strata	**N**	**SE**	**95% CI**		**CV**	**df**
Core Photo strata						
High_Central_Photo	11,525	1801.8	7,449	15,601	15.6%	9
High_North_Photo	148,012	14809.7	117,625	178,399	10.0%	27
High_West_Photo	9,550	1472.1	6,220	12,880	15.4%	9
	169,086	14991.3	138,271	199,901	8.9%	27
Core visual strata						
Medium_Central	20,430	1955.6	16,775	24,881	9.6%	24.0
Medium_East	4,547	661.1	3,351	6,169	14.5%	17.0
Medium_North	8,687	1297.6	6,264	12,046	14.9%	11.0
Medium_South	4,793	920.7	3,218	7,139	19.2%	19.0
Medium_West	7,785	894.4	6,121	9,903	11.5%	18.0
Low_North_East	552	153.4	298	1,023	27.8%	9.0
Low_North_West	8,262	1017.5	6,370	10,716	12.3%	16.0
Total core visual	55,057	2941.343	49,501	61,238	5.3%	73.5
Total Core strata	224,143	15277.2	192,741	255,546	6.8%	47.82
Peripheral strata						
Low_South	11,032	1821.6	7,612	15,988	16.5%	9.0
Low_West	13,689	1625.2	10,248	18,285	11.9%	6.0
Very_Low_South	3195.41	837.3	1,845	5,534	26.2%	15.0
	27,916	2580.8	23,004	33,878	9.2%	18.3
Total (Core+ Peripheral)	**252,060**	**15493.6**	**220,212**	**283,907**	**6.1%**	**39.3**

4.2 Composition surveys to determine proportions of breeding females.

Composition surveys conducted on each of the core strata (Table 9). A spatial representation of the composition data reveals strong gradients in group composition with a core area of breeding cows extending from the High West Photo through the Medium Central, High central, and High north photo strata. This group was surrounded by non-breeding cows and bulls with very few yearlings (Figure 15). Coverage in the high north photo stratum was limited to the southeastern half.

Table 9: Summary of composition data by stratum.

Strata	n	Breeders Cows[A]	Non-breeders Cows[B]	Bulls	Yearlings	Total	Total caribou Breeder & Non-breeders
High_Central_Photo	79	1516	408	206	163	777	2293
High_North_Photo	50	3478	423	291	174	888	4366
High_West_Photo	46	828	389	346	186	921	1749
Medium_Central	96	1154	491	277	182	950	2104
Medium_East	87	94	232	340	115	687	781
Medium_North	75	223	516	344	149	1009	1232
Medium_South	50	100	83	213	84	380	480
Medium_West	77	142	242	552	163	957	1099
Low_North_East	19	0	4	82	3	89	89
Low_North_West	57	80	132	506	105	743	823

[A]As indicated by presence of a calf, antlers, or an udder.
[B]As indicated by absence of calf, an udder or antlers (UC0 in database).

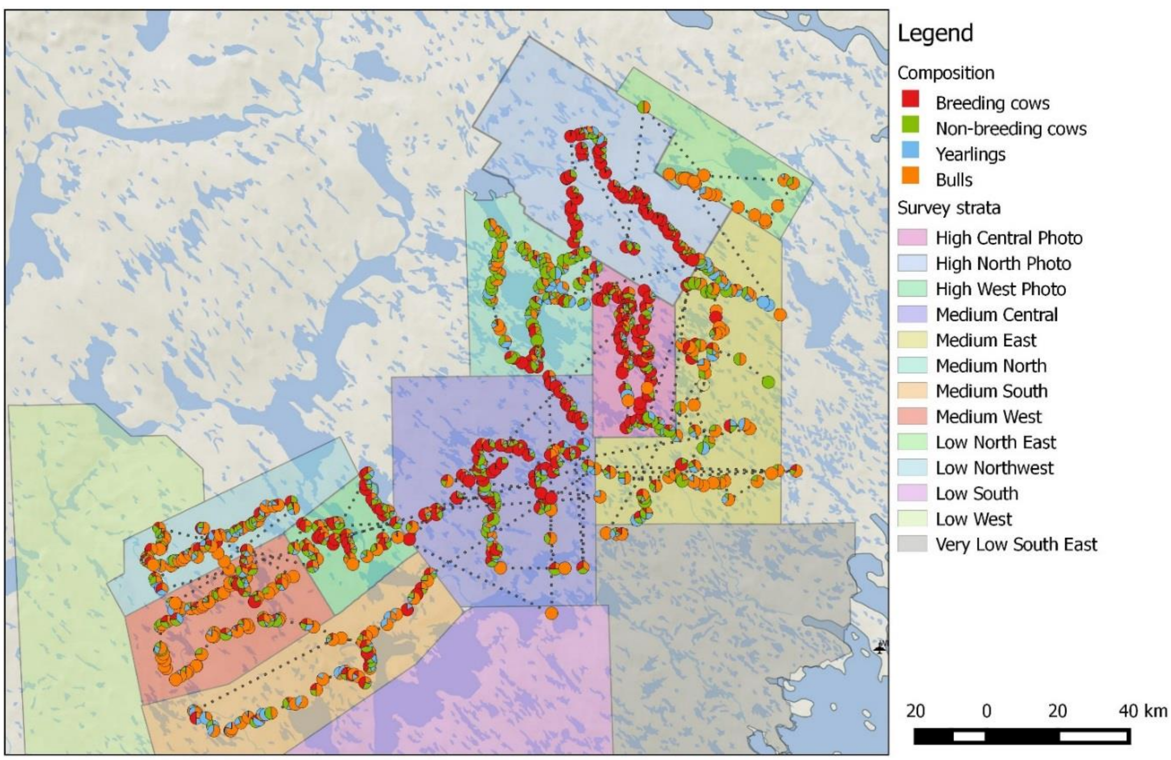

Figure 17: Summary of caribou classified for each of the core strata as listed in Table 7.

One of the striking results from the composition survey was the large proportion of adult females in the high north photo stratum (Figure 15) and the relatively low proportion of yearlings (Figure 16). For example, 89% of caribou classified in the high northern photo (HNP) stratum were adult females (breeding and non-breeding). This contrasts with 76% adult females in the high density stratum in 2014. The composition data 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 10). 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.

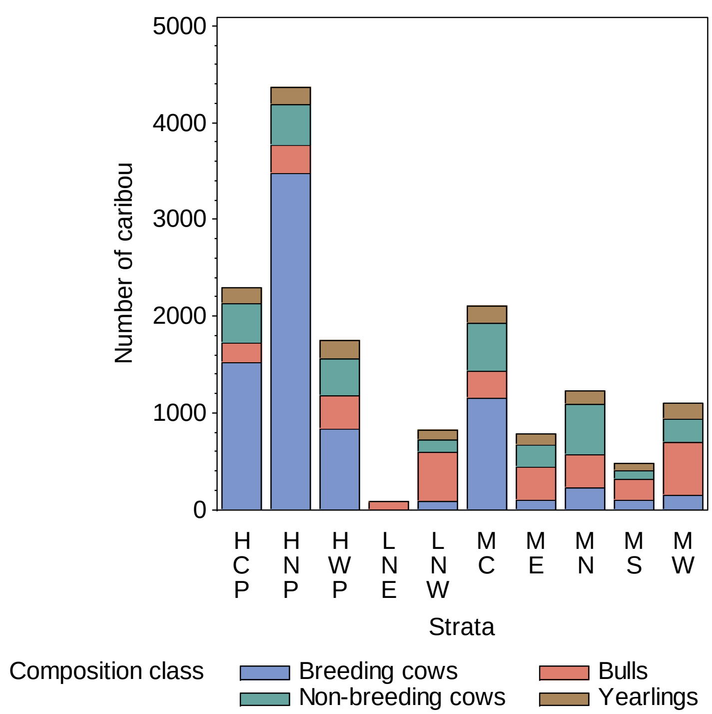

Figure 18: Counts of caribou classified by survey strata

Table 10: Estimates of proportions of various cohorts from composition surveys

Strata	Estimate	SE	95% CI		CV
Proportion breeding cows (breeding_cows/(breeding_cows+non_breeding cows+bulls+yearlings)					
High_Central_Photo	0.661	0.020	0.616	0.698	3.0%
High_North_Photo	0.797	0.019	0.756	0.829	2.4%
High_West_Photo	0.473	0.040	0.393	0.549	8.5%
Medium_Central	0.548	0.025	0.496	0.593	4.6%
Medium_East	0.120	0.023	0.080	0.167	18.8%
Medium_North	0.181	0.043	0.103	0.271	23.9%
Medium_South	0.208	0.034	0.142	0.276	16.2%
Medium_West	0.129	0.021	0.091	0.176	16.2%
Low_North_East	0.000	0.000	0.000	0.000	
Low_North_West	0.097	0.015	0.067	0.128	15.8%
Proportion adult cows (cows/(cows+bulls+yearlings)					
High_Central_Photo	0.839	0.013	0.815	0.864	1.5%
High_North_Photo	0.894	0.011	0.871	0.913	1.2%
High_West_Photo	0.696	0.030	0.633	0.750	4.3%
Medium_Central	0.782	0.017	0.745	0.813	2.2%
Medium_East	0.417	0.034	0.351	0.482	8.1%
Medium_North	0.600	0.031	0.538	0.660	5.2%
Medium_South	0.381	0.048	0.289	0.471	12.6%
Medium_West	0.349	0.031	0.293	0.416	8.9%
Low_North_East	0.045	0.022	0.010	0.095	50.0%
Low_North_West	0.258	0.031	0.197	0.319	12.0%
Proportion of adults (cows+bulls)/(cows+bulls+yearlings))					
High_Central_Photo	0.929	0.008	0.913	0.945	0.9%
High_North_Photo	0.960	0.005	0.949	0.970	0.5%
High_West_Photo	0.894	0.011	0.872	0.915	1.2%
Medium_Central	0.914	0.008	0.898	0.928	0.9%
Medium_East	0.853	0.019	0.817	0.887	2.2%
Medium_North	0.879	0.013	0.853	0.902	1.5%
Medium_South	0.825	0.020	0.780	0.859	2.4%
Medium_West	0.852	0.025	0.803	0.899	3.0%
Low_North_East	0.966	0.022	0.919	1.000	2.3%
Low_North_West	0.872	0.016	0.842	0.902	1.8%

4.3 Estimates of breeding females and other cohorts on the core breeding ground

Estimates of proportion breeders (Table 10) were then multiplied by the number of caribou on each strata (Table 8) to derive a breeding female estimate of 146,217 (CI=120,943-171,490). Overall precision of breeding female estimates was high (CV=8.4%). The estimate of adult cows (breeders and non-breeders) was 178,423 (Table 12:CI=150,468-206,377) suggesting that roughly 32,000 cows on the core calving ground were non-breeding (as determine by lack of calf, antler, or udder) (Table 10). The high north photo stratum, which was classified as having 89% adult females, contributed the most to the overall estimate. Basically, the majority of the highest density photo stratum contained adult female caribou. Finally, the number of adult caribou (cows and bulls) on the core calving ground was estimated as 209,848 (CI=179,766-239,931, CV=7.0%) suggesting that a smaller proportion (roughly 7%--15,000 caribou of 224,000) on the core calving area were yearlings. This contrasts with 2014 where roughly 24% (54,000 of 222,000) of caribou on the calving ground were yearlings.

Table 11: Estimates of breeding females from composition data for core strata. Estimates are only given for strata that had composition surveys.

Strata	Caribou on C.G.		Proportion breeders		Breeding female estimate				
	N	SE	Estimate	SE	N	SE	95% CI		CV
Photo strata									
High_Central_Photo	11,525	1801.8	0.661	0.020	7,618	1213.3	4,924	10,312	15.9%
High_North_Photo	148,012	14809.7	0.797	0.019	117,965	12137.6	93,747	142,184	10.3%
High_West_Photo	9,550	1472.1	0.473	0.040	4,517	794.3	2,942	6,092	17.6%
Visual strata									
Medium_Central	20,430	1955.6	0.548	0.025	11,196	1186.6	9,193	13,635	10.6%
Medium_East	4,547	661.1	0.120	0.023	546	129.7	402	740	23.8%
Medium_North	8,687	1297.6	0.181	0.043	1,572	443.6	1,134	2,180	28.2%
Medium_South	4,793	920.7	0.208	0.034	997	250.7	669	1,485	25.1%
Medium_West	7,785	894.4	0.129	0.021	1,004	199.4	790	1,277	19.9%
Low_North_East	552	153.4	0.000	0.000	0	0.0	0	0	
Low_North_West	8,262	1017.5	0.097	0.015	801	160.2	618	1,039	20.0%
Total	**224,143**	**15277.2**			**146,217**	**12295.3**	**120,943**	**171,490**	**8.4%**

Table 12: Estimates of adult females from composition data for core strata. Estimates are only given for strata that had composition surveys.

Strata	Caribou on C.G.		Proportion adult females		Adult female estimate				
	N	SE	Estimate	SE	N	SE	95% CI		CV
Photo strata									
High_Central_Photo	11,525	1801.8	0.839	0.013	9,669	1518.8	6,250	13,089	15.7%
High_North_Photo	148,012	14809.7	0.894	0.011	132,322	13334.4	105,157	159,488	10.1%
High_West_Photo	9,550	1472.1	0.696	0.030	6,646	1064.0	4,329	8,964	16.0%
Visual strata									
Medium_Central	20,430	1955.6	0.782	0.017	15,976	1569.3	13,118	19,457	9.8%
Medium_East	4,547	661.1	0.417	0.034	1,896	315.6	1,398	2,573	16.6%
Medium_North	8,687	1297.6	0.600	0.031	5,212	824.4	3,758	7,228	15.8%
Medium_South	4,793	920.7	0.381	0.048	1,826	419.8	1,226	2,720	23.0%
Medium_West	7,785	894.4	0.349	0.031	2,717	395.5	2,136	3,456	14.6%
Low_North_East	552	153.4	0.045	0.022	25	14.2	13	46	57.2%
Low_North_West	8,262	1017.5	0.258	0.031	2,132	367.2	1,643	2,765	17.2%
Total	**224,143**	**15277.2**			**178,423**	**13599.8**	**150,468**	**206,377**	**7.6%**

Table 13: Estimates of adult caribou (bull+cows) from composition data for core strata. Estimates are only given for strata that had composition surveys.

Strata	Caribou on C.G.		Proportion adults		Adult estimate				
	N	*SE*	Estimate	SE	N	SE	95% CI		CV
Photo strata									
High_Central_Photo	11,525	1801.8	0.928	0.008	10,707	1676.4	6,920	14,493	15.7%
High_North_Photo	148,012	14809.7	0.963	0.005	142,091	14238.6	112,920	171,263	10.0%
High_West_Photo	9,550	1472.1	0.892	0.011	8,537	1320.3	5,560	11,514	15.5%
Visual strata									
Medium_Central	20,430	1955.6	0.914	0.008	18,673	1794.5	15,333	22,742	9.6%
Medium_East	4,547	661.1	0.848	0.019	3,879	570.1	2,859	5,263	14.7%
Medium_North	8,687	1297.6	0.877	0.013	7,636	1146.0	5,506	10,589	15.0%
Medium_South	4,793	920.7	0.822	0.020	3,955	765.7	2,655	5,890	19.4%
Medium_West	7,785	894.4	0.848	0.026	6,633	786.8	5,215	8,437	11.9%
Low_North_East	552	153.4	0.966	0.022	534	148.6	288	988	27.9%
Low_North_West	8,262	1017.5	0.869	0.016	7,205	896.5	5,555	9,345	12.4%
Total	**224,143**	**15277.2**			**209,848**	**14634.9**	**179,766**	**239,931**	**7.0%**

4.4 Extrapolated estimate of total herd size.

A composition survey was conducted during the Fall of 2016 to obtain an estimate of proportion females in the caribou herd. Two hundred four groups were surveyed with 6,419 and 9,894 bulls and cows classified respectively. Estimates of bull-cow ratios, proportion of cows (cows/(bulls+cows)) are given in Table 14. In 2014 an alternative estimate of herd size was derived by assuming that all adult cow caribou were on the core calving ground. This avoided the use of a pregnancy rate since it was assumed that all non-pregnant cows (1.5 years old and older) were on the core area. In this case, the estimate of the herd is simply the estimate of females divided by the proportion of females in the herd (Table 15). This estimate still pertains to adult caribou and not yearlings (calves of the previous year). The resulting estimate is 288,244 (CI=242,121-334,367) 1.5+ year old caribou.

The traditional breeding female estimate was also derived using an assumed pregnancy rate (Dauphin'e 1976, Heard 1985) and proportion of females in the herd (Table 16). The pregnancy rate that was used for extrapolation does not consider calves of the previous year (since they could not breed) and therefore this estimate pertains to caribou that are 2+ years old on the calving ground. In this case the estimate was 328,076 (CI=239,149-417,004). We suggest that the assumption of a constant pregnancy rate is very suspect and therefore this estimate is less reliable then the estimate based solely on adult females (Table 15).

Table 14: Fall 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%

Table 15: Extrapolated population estimates for the Qamanirjuaq herd using estimates of females on the calving ground and proportion females estimated in fall composition surveys.

Survey data	Estimate	SE	CV	95% Conf. Limit	
-Number of caribou on core and peripheral cg	252,060	15493.6	6.1%	220,721	283,398
-Number of females (breeding+non-breeding) in core calving ground	178,423	13599.8	7.6%	151,063	205,782
-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	288,244	22438.6	7.8%	242,121	334,367

Table 16: Extrapolated population estimates for the Qamanirjuaq herd using breeding females and an assumed pregnancy rate.

Survey data	Estimate	SE	CV	95% CI	
Number of caribou on core and peripheral cg	252,060	15493.6	6.1%	220,721	283,398
Number of breeding females	146,217	12295.3	8.4%	121,482	170,951
Proportion females in the entire herd	0.619	0.010	1.6%	0.601	0.639
Proportion 1.5+ yr females pregnant	0.72		10.0%		
Total herd size	328,076	43178.3	13.2%	239,149	417,004

4.5 Comparison of estimates from 2008, 2014, and 2017

Table 17 provides a summary of estimates from 2014 and 2017 including extrapolated estimates using adult females. Degrees of freedom were estimated for combined estimates for each year using variances and degrees of freedom from each of the sampled stratum (Heard 1985). The difference in estimates was not significant except for breeding females. The estimate of 2008 was also considered to assess longer-term trends (Figure 17). This plot of estimates reveals higher estimates for adult females and the herd extrapolated estimate (based on adult females) in 2008 compared to 2017 and 2014. An apparent increase is suggested between the 2014 and 2017 estimates, but the 2017 estimate is still lower the 2008 estimates.

There is more variation in breeding female estimates than adult female and herd size estimates. This was due to the low pregnancy rate in 2014. An estimate of proportion females breeding can be derived from the ratio of breeding females to adult females for each survey year. This results in estimates of proportion females breeding of 0.73, 0.63, and 0.82 for 2008, 2014, and 2017 respectively. From these ratios it can be surmised that the reduction of the breeding female estimate in 2014 was due to a lower pregnancy rate rather than a numerical decrease in adult females.

Comparison of estimates from 2008, 2014, and 2017 suggests an increasing trend in 2014 to 2017. The increase in breeding females is highly influenced by increases in pregnancy rate and therefore is not a valid trend estimate for the herd. Trend estimates from adult females and extrapolated herd estimates are similar given that the proportion females in the herd was similar for 2014 and 2017. A final comparison is of the total number of caribou estimated on the core and peripheral strata in 2014 and 2017 which suggests a slight decrease. This estimate will be sensitive to yearly differences in the proportion of the herd on the calving ground. Weighted log-linear regression of the adult female estimates from 2008, 2014, and 2017 estimates suggest a non-significant decreasing trend with a yearly λ estimate of 0.98 (CI=0.94-1.01) (Table 19). This suggests a slight longer term declining trend of 2% (CI=-6% to +1%) per year. However, this estimate was not statistically significant.

A simulation approach was used to further explore potential trends. In this exercise random estimates were generated based on the confidence intervals for the 2008, 2014, and 2017 surveys. Regression lines were then fit to the randomly generated estimates for 1000 iterations. This exercise basically asks; "If this survey were repeated many times what would the distribution of trend estimates look like under the assumption of a constant rate of population change"? A graphical representation of the outcome (Figure 19) displays the simulated trends. A plot of regression estimates demonstrates the potential of a decreasing trend when the confidence limits of individual estimates are considered (Figure 18).

Table 17: Summary of extrapolated herd estimates (using females only, breeding females) and breeding female only estimates. Confidence limits, degrees of freedom, and t-values used to estimate confidence limits

Stratum	2017				2014				t-test for difference		
Metric	**Estimate**	**SE**	**CI(+/-)**	**df**	**Estimate**	**SE**	**CI(+/-)**	**df**	**t**	**df**	**p**
Herd (Females)	288,244	22438.6	46,123	27	264,718	21913.0	44,887	28	0.75	52.9	0.457
Adult females	178,423	13599.8	27,955	27	163,066	13296.4	27,236	28	0.81	52.9	0.423
Breeding females	146,217	12295.3	25,273	27	103,363	11631.5	23,826	28	2.53	52.7	0.014

Table 18: Estimates of adult females, breeding females, and herd size extrapolated from adult females for 2008, 2014, and 2017. The gross change in estimates (based on the ratio of successive N estimates) and yearly rate of change is also given.

Year	Estimate		Gross change			Yearly change (λ)		
	N	SE	Estimate	Conf. Limit		Estimate	Conf. Limit	
Adult females								
2008	215,049	17,373.9						
2014	163,066	13,296.4	0.76	0.58	0.93	0.95	0.91	0.99
2017	178,423	13,599.8	1.09	0.85	1.34	1.03	0.95	1.10
Breeding females								
2008	156,784	13,619.9						
2014	103,363	11,661.7	0.66	0.47	0.85	0.93	0.88	0.97
2017	146,217	12,295.3	1.41	1.02	1.81	1.12	1.01	1.22
Herd (adult female)								
2008	344,078	28,013.5						
2014	264,718	21,913.0	0.77	0.59	0.95	0.96	0.92	0.99
2017	288,244	22438.6	1.09	0.84	1.33	1.03	0.94	1.10
Caribou on calving ground								
2014	262,272	16746.8						
2017	252,060	15493.6	0.96	0.79	1.13	0.99	0.93	1.04

Table 19: Regression estimates of trend (2008-2017). The per capita rate of increase(*r*) is estimated as the slope term with the annual finite rate of increase (λ) estimated as the exponent of *r*

Parameter	DF	Estimate	SE	95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	12.27	0.13	12.01	12.53	8361.74	<.0001
Year (*r*)	1	-0.02	0.02	-0.06	0.01	1.61	0.2041
λ		0.977		0.942	1.013		

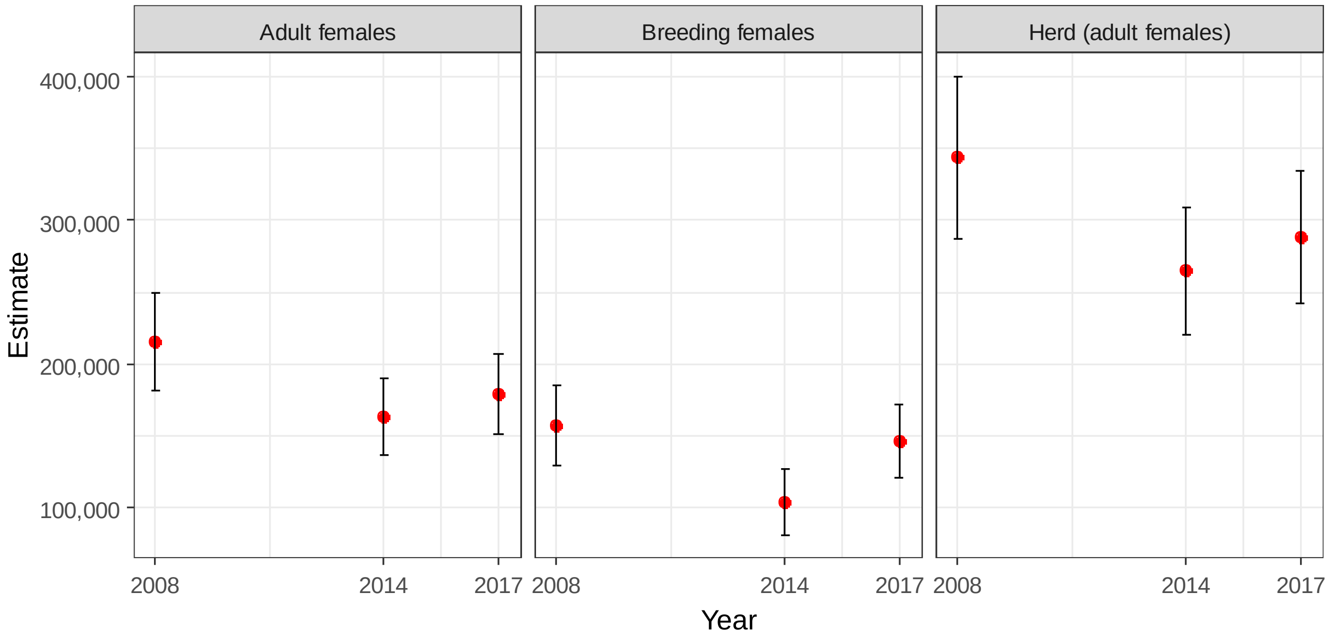

Figure 19: Estimates of adult females, breeding females, and extrapolated herd size based on adult females (Table 18 for the 2008, 2014, and 2017 surveys).

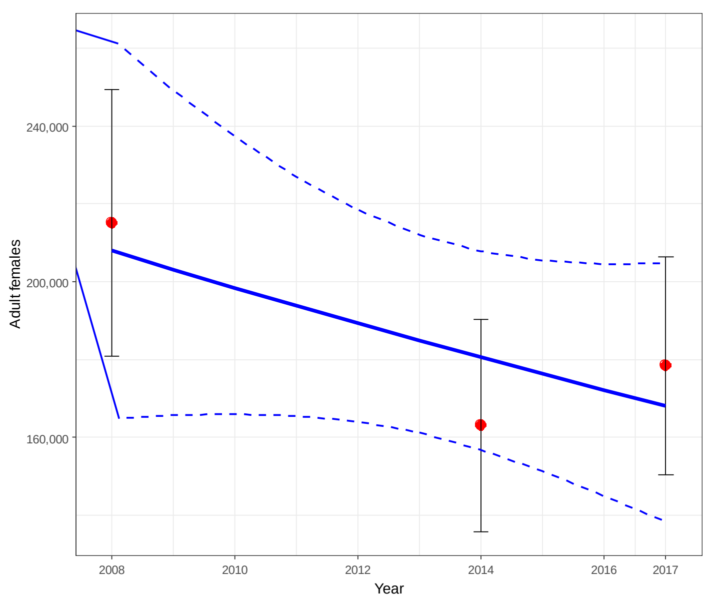

Figure 20: Predicted trends from log-linear regression. Confidence limits on regression predictions are given as hashed blue lines. Individual estimates are shown as blue points with confidence limits are also displayed.

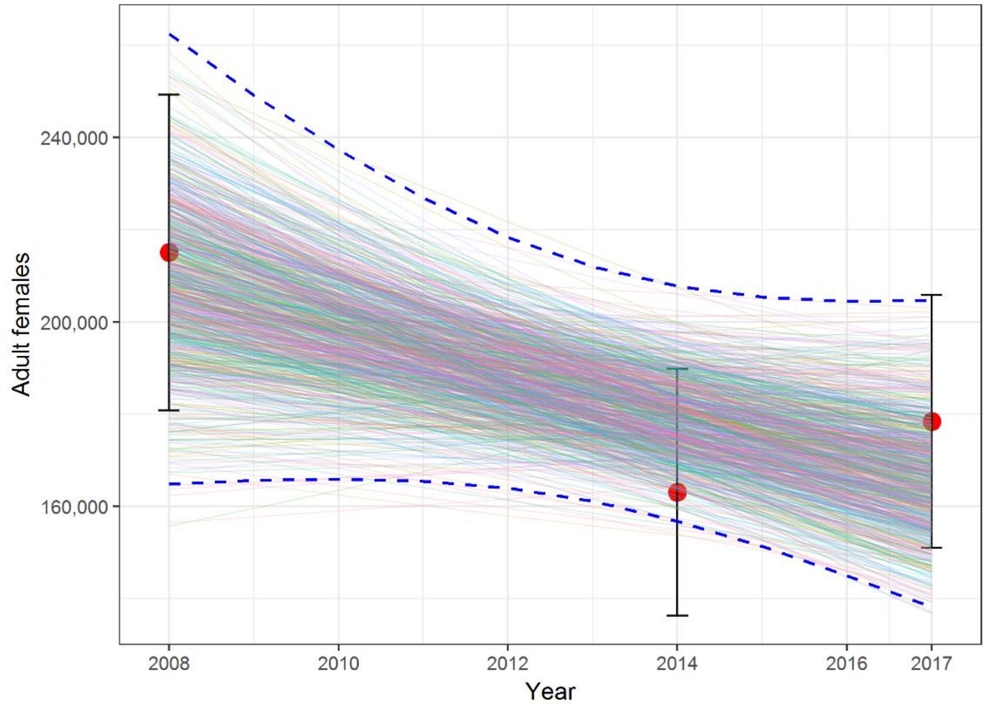

Figure 21: An example of simulation runs with regression model estimates included for reference. Each line represents a simulated trend.

The resulting distribution of trend estimates demonstrates that the majority of trend estimates suggested a negative trend (λ<1). The mean λ estimate in this case is 0.975 (percentile 95% CI=0.95-1.00) which is similar to that obtained from regression analysis (Figure 20).

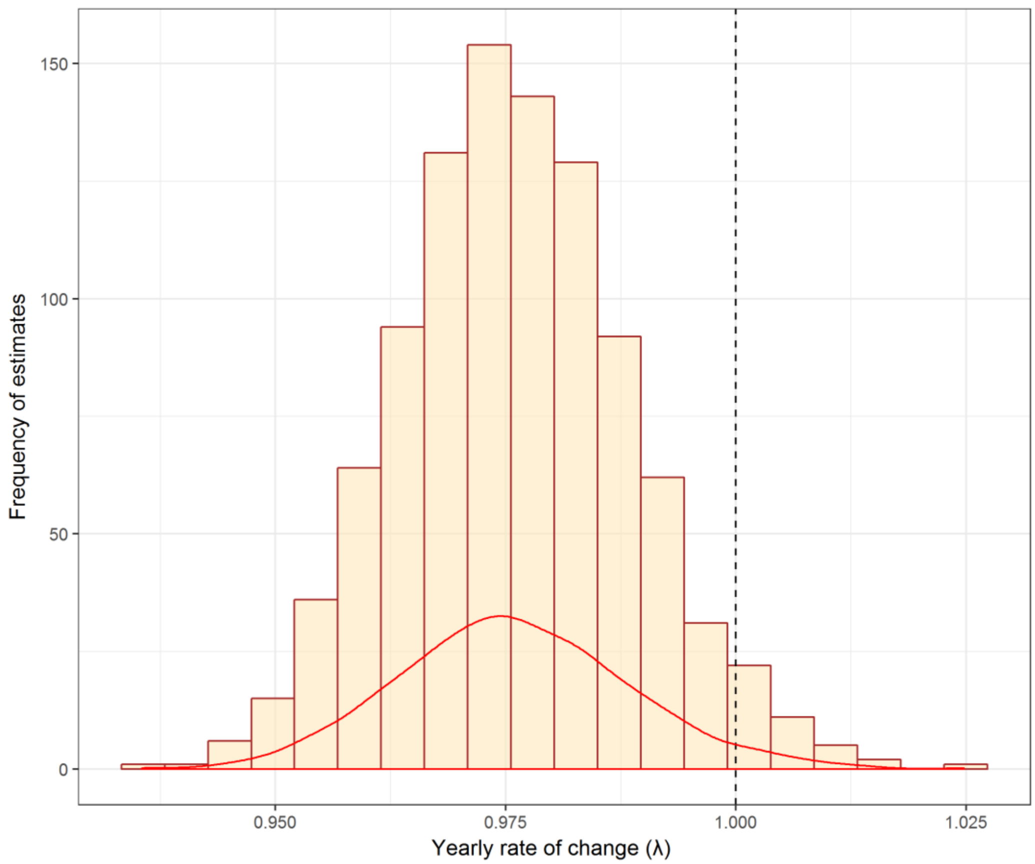

Figure 22: Distribution of trend estimates ($\lambda=N_{t+1}/N_t$). A reference line is shown at λ=1 which would suggest a stable trend.

5.0 DISCUSSION

5.1 General comments

The visual and photo phase of the survey was successful with overall estimates being precise with (CV's of less than 10% for most estimates). The higher level of precision was due to efficient layout of strata and allocation of survey effort. Assessment of collared caribou movement suggests minimal movement between reconnaissance and the visual/photo surveys. The addition of the 2 extra photo strata was justified by the higher transect densities in these strata.

Regression analysis (Figures 18-20) suggests that the Qamanirjuaq herd is in a slow decline when the 2008 estimate is considered in trend analyses. However, the 2017 estimate of herd size and adult female is higher than 2014 estimate. Part of this change could be due to sampling variation but we also consider other factors influencing the difference between the 2014 and 2017 estimates.

The number of caribou surveyed in core and peripheral strata was quite similar in 2014 and 2017 though lower in 2017 (252,060 (CI=220,212-283,907) in 2017 and 262,272(CI=227,910-296,634) in 2014). Therefore, the main changes in herd size was due to changes in composition within the calving ground (i.e. a higher number/proportion of adult females in higher density stratum). The proportion females in the herd from fall surveys was similar in 2014 and 2017 so this had little affect on the change in herd estimates. We explore the composition data from 2017 and 2014 to further assess factors causing the apparent change in composition.

5.2 Discussion of effects of composition on estimates.

Changes in composition from previous surveys was considered further to better determine how they influenced trend. Figure 21 shows trends in proportion of caribou classified in 2008, 2014, and 2017. In 2017 there was a larger proportion of bulls in the core area then previously observed in past surveys. These bull aggregations were within northern strata as well as more southern strata. In 2017 bulls comprised 21% of caribou classified during the composition survey of the core calving area whereas they were only 3% were classified in 2014. The proportion of yearlings was reduced in 2017 (8.8%) compared to 2014 (27.1%). The proportion of breeding females increased in 2017.

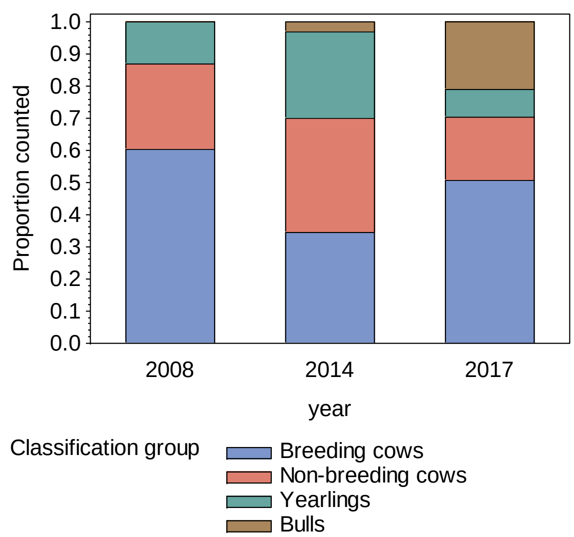

Figure 23: Comparison of proportions of groups classified by year

Figure 22 provides a closeup of the comp survey work with the visual/photo strata as a background. Note the strong gradients in composition.

- The increase in proportion bulls might be partially due to a larger area surveyed in 2017/2014 compared to 2008. However, there were a lot of bulls right around the core area in 2017 which did not occur in 2014 as explored further in this report.

- The leading edge in the High North stratum and the northern part of the medium central strata was not sampled due to logistic constraints so the assumption here would be that the composition did not change too much in the sampled and unsampled areas. Often yearlings and bulls occur at the edge of breeding female clusters. In this case, these groups may have been undersampled in the high density photo stratum.

To explore this further we extracted the proportion of calves seen on photos in the northern HD stratum as an index of breeding females and the summarized the proportion for each photo (Figure 23). The left side of Figure 23 displays proportion calves detected on photos and the right map displays relative density. From this it can be seen that the comp flights sampled areas that were high in breeding females but did not sample areas to the north that had higher densities but lower proportions of calves.

The composition and density information from photos can also be summarized by transect. Figure 22 shows the transect density and proportion calves per transect. It can be seen that proportion calves did go down in the northern lines but density was reasonably higher. Lines 1-9 were not surveyed for composition. Inspection of Figures 23 and 24 indicates that there may have been less adult females in the northern area, however, it is not possible to determine this conclusively given that this area could have also contained antlered females yet to calve, yearlings, and non-breeding adult females. One potential way to assess composition further is from the photos taken on the HD stratum. From an example photo (Figure 25), it looks like it may be possible to classify yearlings from photos but not bulls. Therefore, resampling the photos would give a potential estimate of proportion yearlings, however, it would not allow bulls to be separated and given this could not be used to estimate proportion of females on the stratum. The resolution of lines with GSD 6 resolution, which was the resolution on the northern lines of the HD north photo stratum is lower (Figure 26). Relative size could be measured in this case but it would be difficult to conduct further classification.

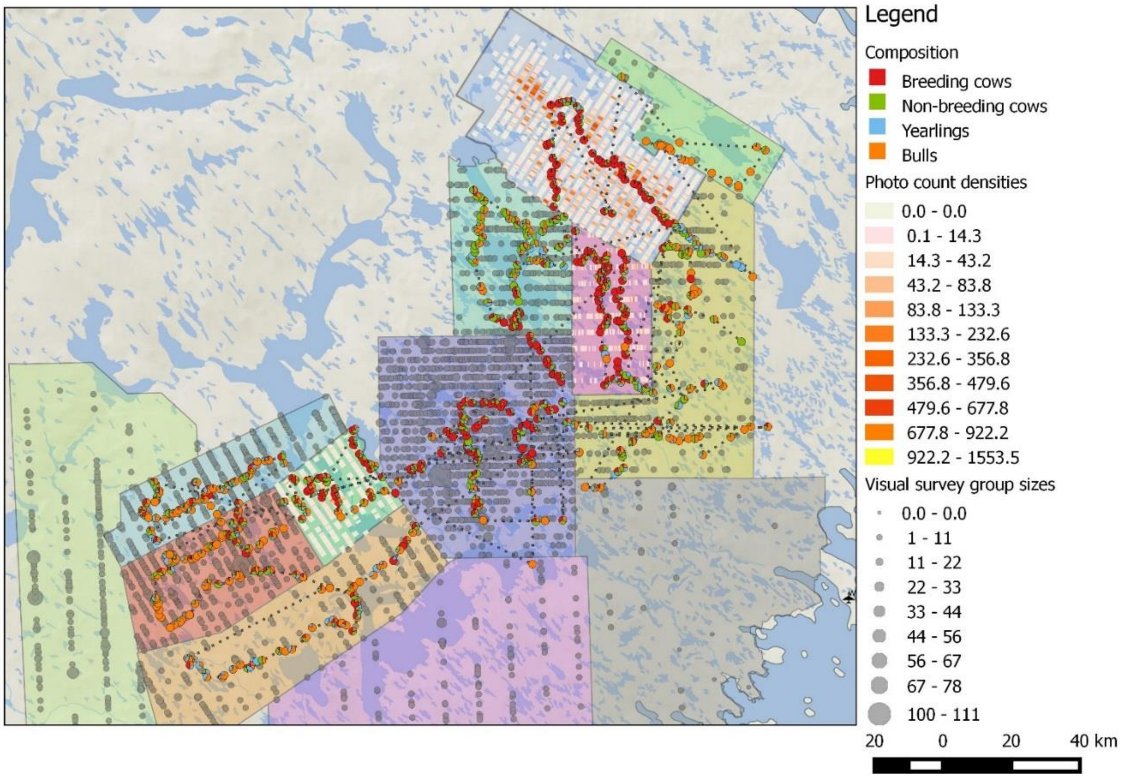

Figure 24: Close up of 2017 composition survey classification with visual/photo survey results as a background

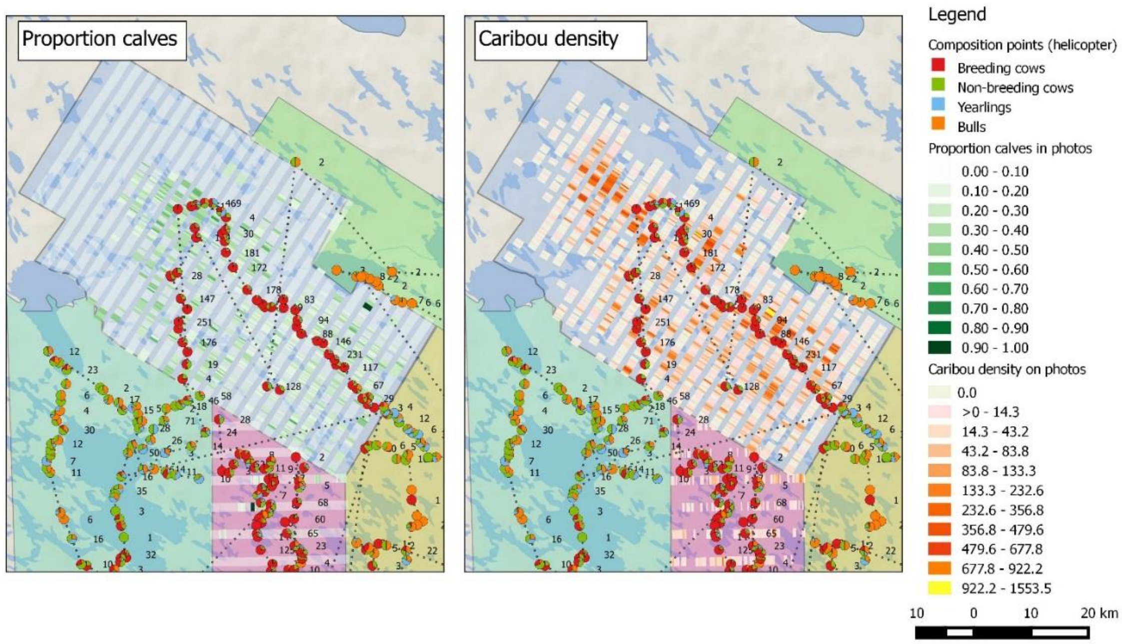

Figure 25: Proportion calves detected on photos (left) compared to caribou density on photos with helicopter composition data. Group sizes classified are also given near composition data points. The actual width of the photo coverage is shown.

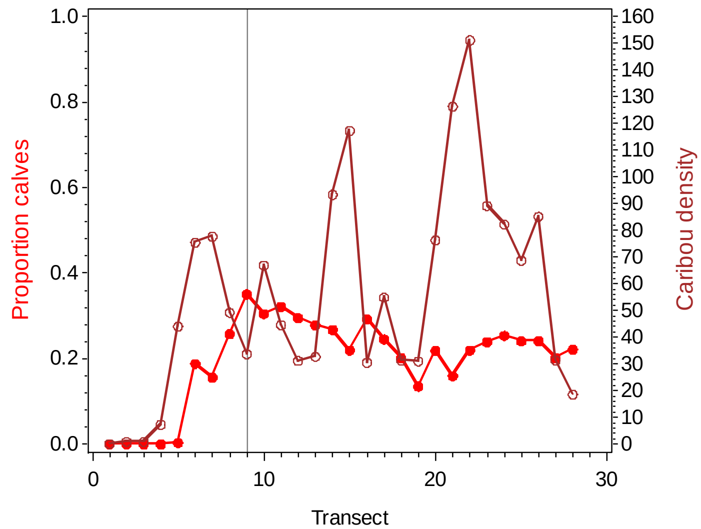

Figure 26: Transect proportion calves and caribou density from photos for the HD northern photo stratum. Lines 10-28 were surveyed for composition.

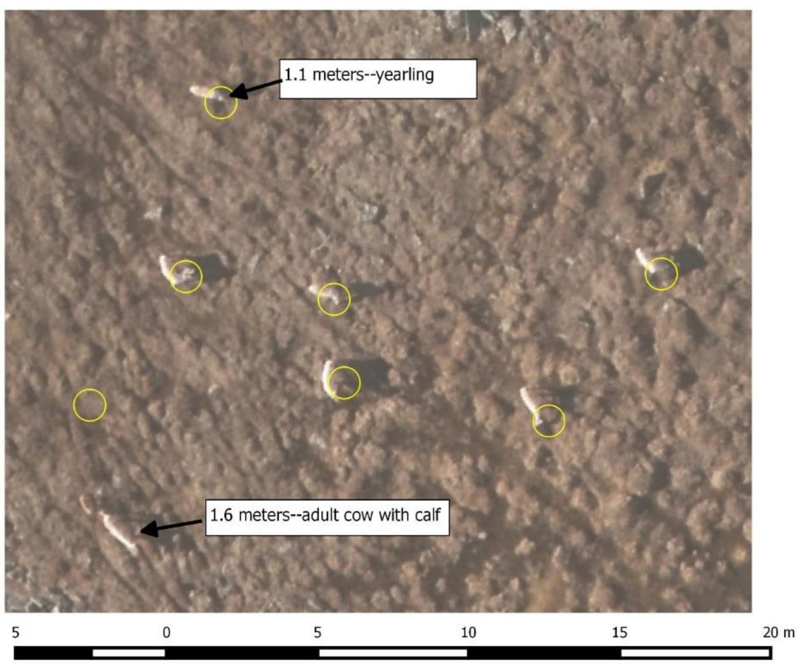

Figure 27: Example close-up photo of caribou on the calving ground from the photo plane. This photo was taken at GSD 5. The circle points are scaled to be the approximate size of a yearling.

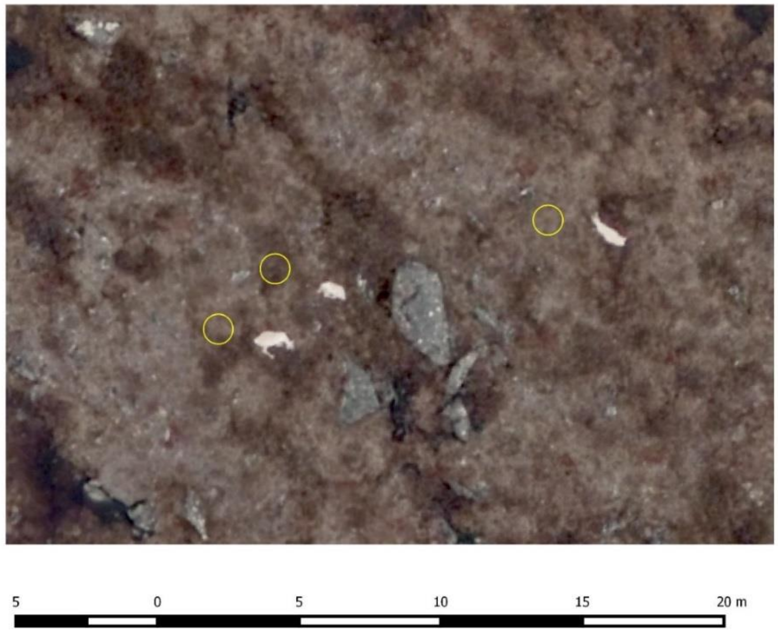

Figure 28: Example photo with GSD 6 resolution.

5.2.1 Composition coverage in the 2014 survey

One question of interest is how composition data in 2017 differed from 2014 and how this might have influenced estimates in 2014 (Figure 26). A map with pie charts suggest that the main photo stratum (the stratum in the Northwest) was primarily composed of breeding females in the central area with yearlings to the East. Very few bulls were detected in any of the stratum sampled in comparison to 2017 (Figure 22). Further scrutiny revealed that group sizes were much larger in the middle of the stratum and therefore these groups had higher influence on composition estimates (Figure 27). Therefore, it cannot be concluded that sampling coverage issues unduly influenced composition estimates from 2014.

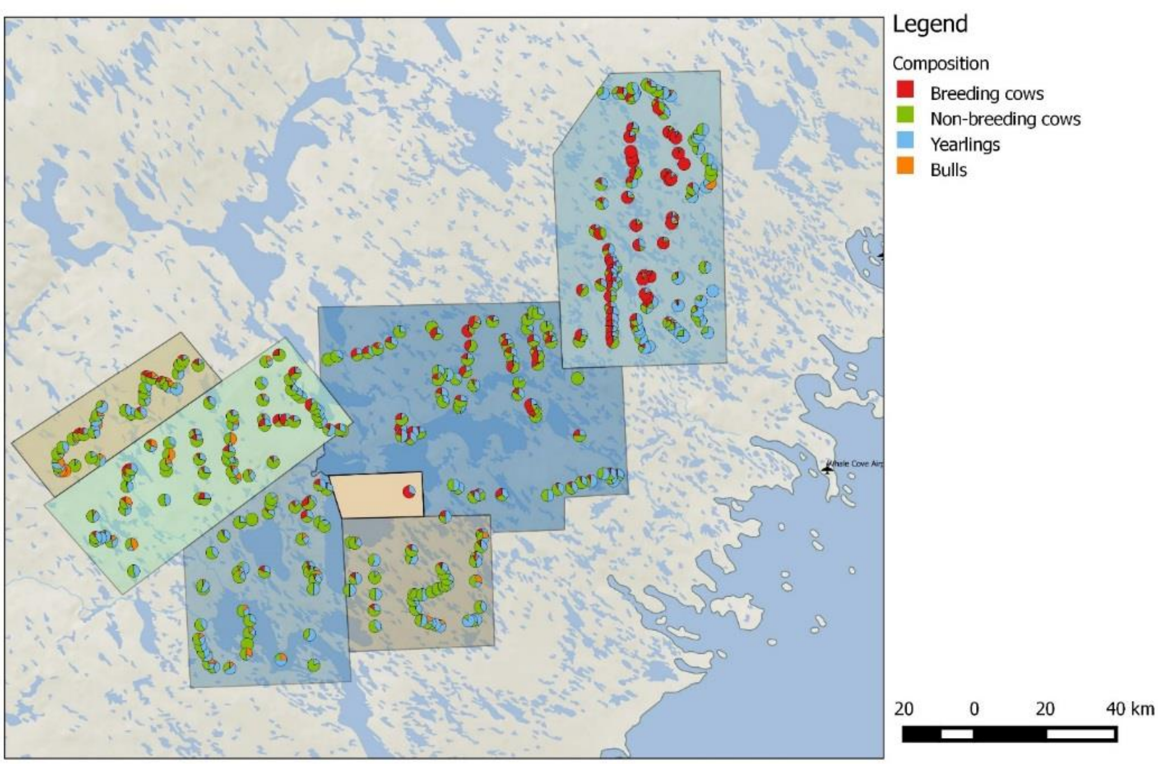

Figure 29: Composition data from the 2014 survey

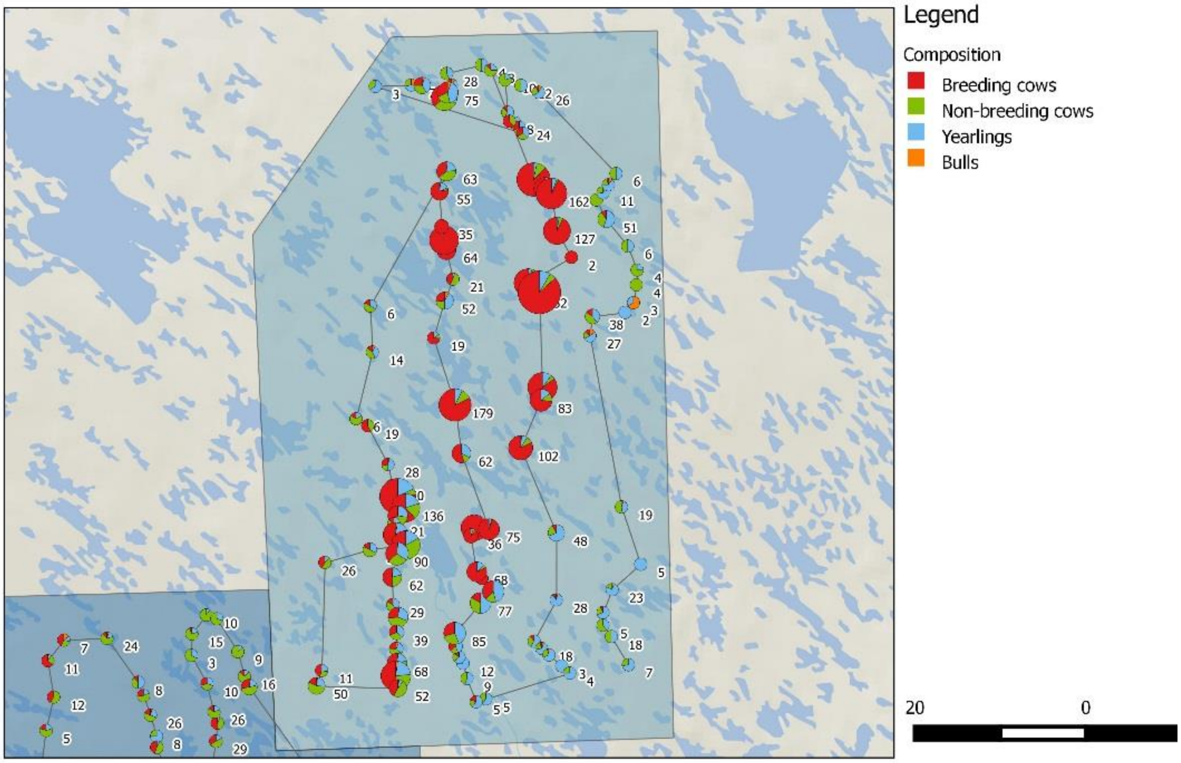

Figure 30: Close up of high density photo stratum composition in 2014

5.2.2 Overall sensitivity of estimates to composition classification in HD North stratum

We conducted a sensitivity analysis of the overall estimate of adult females to the proportion of adult females estimated in the HD North photo stratum. The estimate of adult females in 2017 was 178,423 (proportion adult females on the HD stratum of 0.895) whereas the estimate of adult females in 2014 was 163,066. An estimate of proportion females of approximately 0.79 would result in similar estimates between 2014 and 2017. The proportion females classified on the HD photo stratum in 2014 was 0.77. This sensitivity analysis demonstrates that relatively small changes in the proportion of adult females on the HD stratum has reasonable influence on estimates.

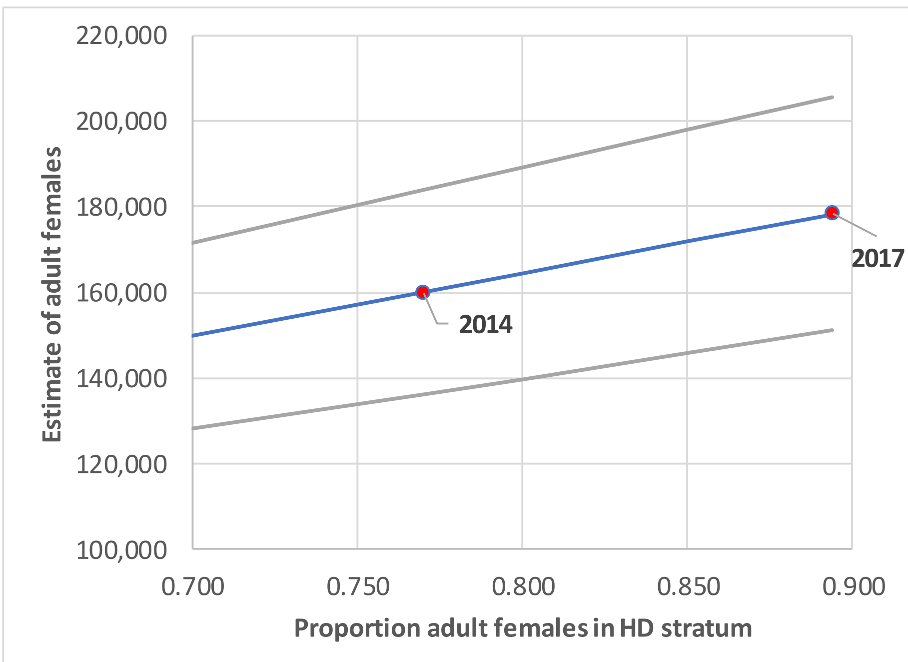

Figure 31: Sensitivity analysis of overall adult female estimates to proportion of adult females classified on the North HD stratum. The proportion of adult females classified in the high-density stratum in 2014 and 2017 are given for reference.

An additional concern based on the observed distribution of bulls within the northern extents of the calving distribution in June 2017 is the possibility of the Lorillard and/or Ahiak populations, whose ranges lie to the north of the 2017 survey area, having overlapped with the Qamanirjuaq population over the survey period. Supporting evidence of this possibility has been documented from both collar movement data and community based hunter observations indicating the likelihood of this having occourred (Lindell and Campbell, 2018). During a recent consultation tour of Kivalliq communities hunters in Chesterfield Inlet, Arviat, Whale Cove, Rankin Inlet and Baker Lake all described what they observed to be “different looking caribou” mixed in with the Qamanirjuak caribou they normally hunt (Lindell and Campbell, 2018).

An assessment of collar movements for both the Qamanirjuaq and Ahiak/Lorillard caribou herds has revealed atypical movement patterns in 2015, 2016, 2017, and 2018 (Figures 30 & 31). Within the Ahiak/Lorillard caribou, 2 of 11 cows collared north of Baker lake in the spring of 2015 and 2016 calved within the Qamanirjuaq calving extents. During spring 2018, 7 of 46 caribou cows collared north of Baker Lake calved within the Qamanirjuaq calving extents. These extra limital movements of Ahiak/Lorillard caribou cows were the first of their kind over the 15 year collaring program and suggest a mixing with Qamanirjuaq caribou over the June 2015, 2016, 2017 and 2018 calving periods. Additionally 4 of 35 caribou cows collared west of Arviat on the Qamanirjuaq spring range calved north of Baker lake outside of the Qamanirjuaq calving extents between 2015 and 2017 (2 in 2015, 1 in 2016, and 1 in 2017) suggesting they could have been Ahiak/Lorillard caribou captured on the Qamanirjuaq spring seasonal range, returning to their calving range. These findings, coupled with region wide observations by hunters of a mixing of two different types of caribou thought by harvesters to be from different herds, strongly suggest a possible mixing of Qamanirjuaq caribou with herds, whose normal calving range is north of Chesterfield Inlet, during the 2017 Qamanirjuaq calving ground survey. This mixing would increase the total number of caribou on the Qamanirjuaq calving ground beyond Qamanirjuaq cows alone in June 2017. Additionally, the observations of greater than expected numbers of bulls along the northern extents of the Qamanirjuaq caribou calving extents is suggestive of a southern movement of Ahiak/Lorillard bulls further cooberating this possible mixing of herds.

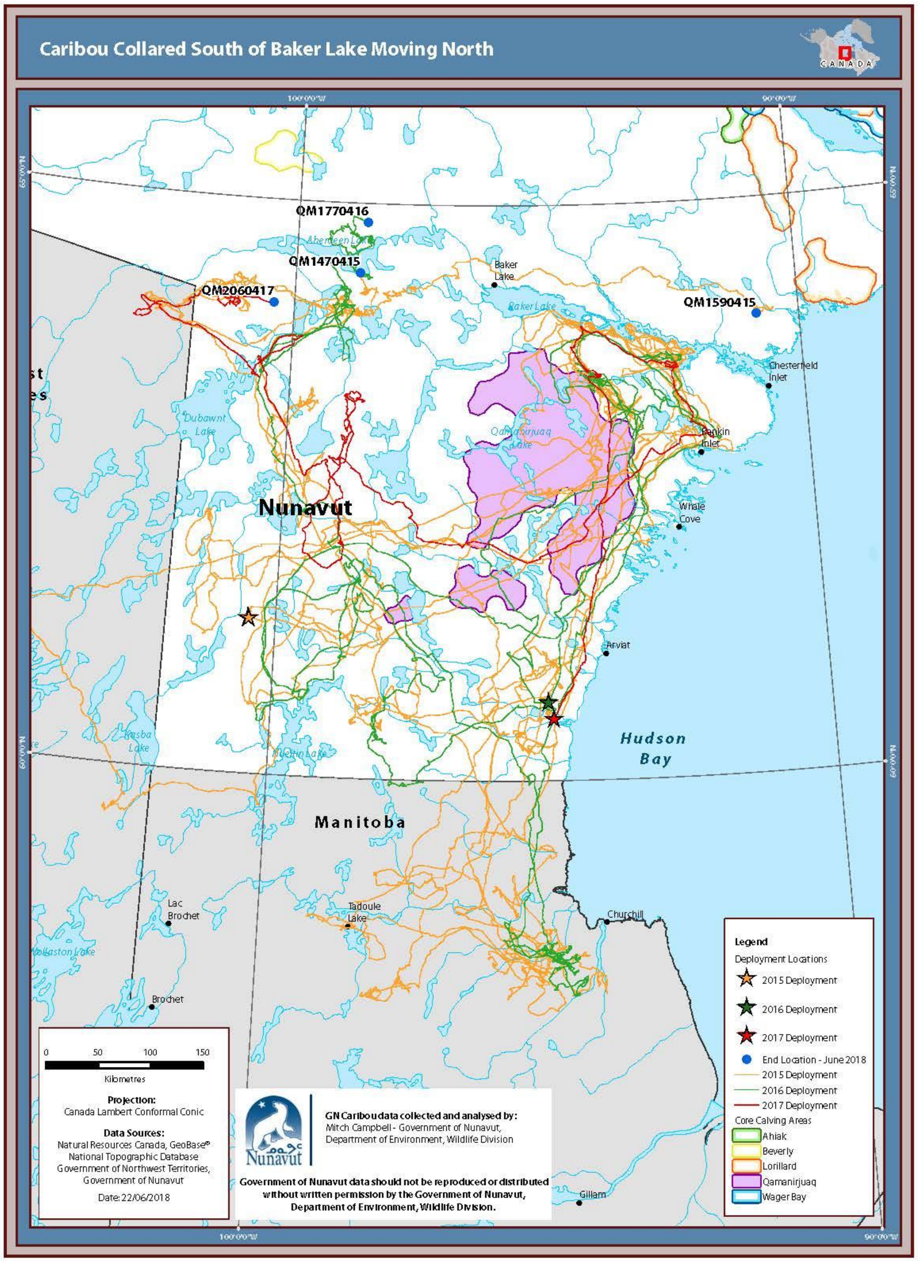

Figure 30: Caribou collared on the Qamanirjuaq spring range moving north outside of the Qamanirjuaq annual range extents across the June 2017 survey period. Collar movements suggest a mixing of herds prior to collar deployment and prior to the June 2017 survey effort.

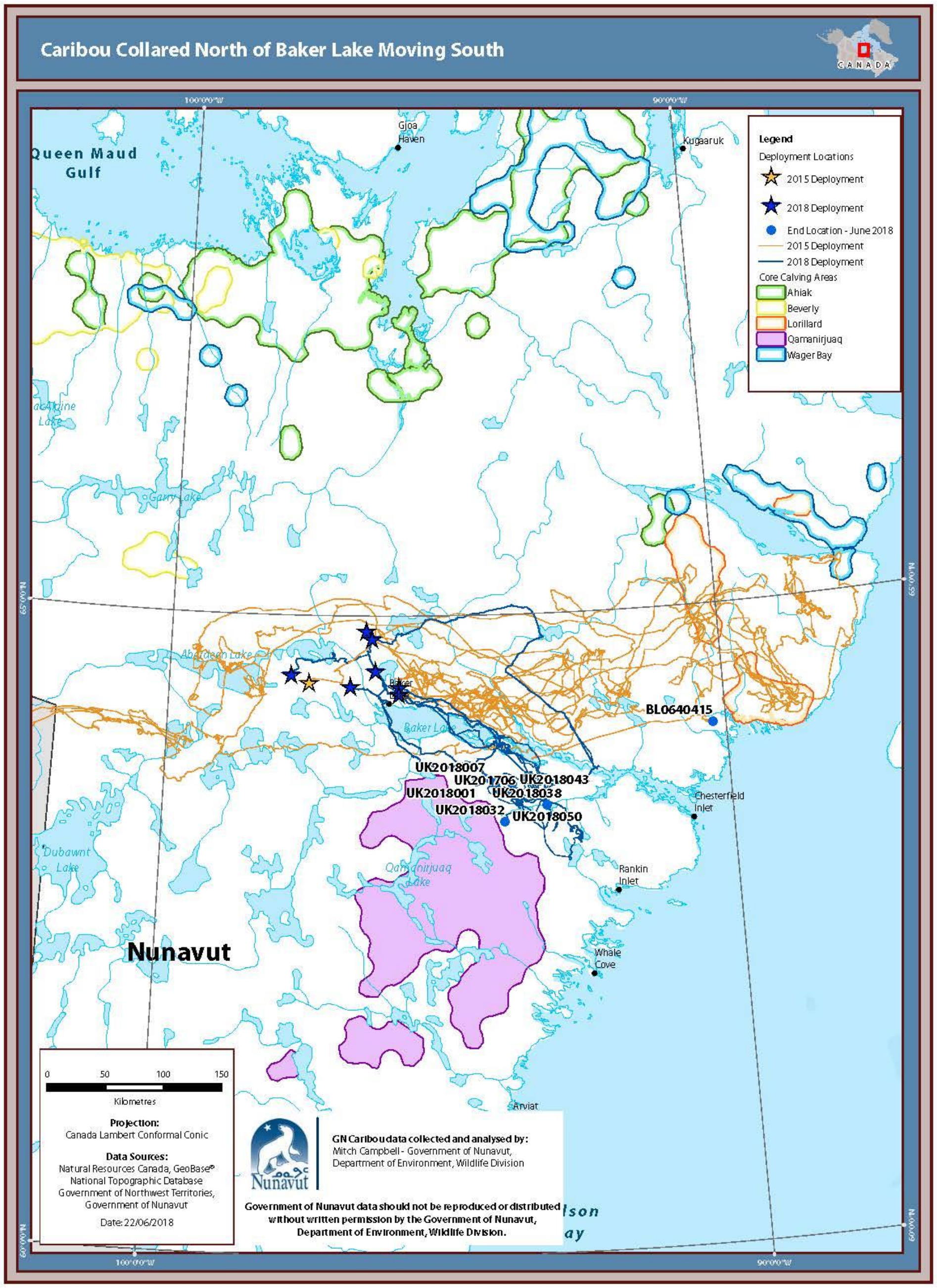

Figure 31: Caribou collared on the Ahiak and Lorillard spring range moving south to calve within the Qamanirjuaq annual calving ground extents across the June 2017 survey period. Collar movements suggest a mixing of herds prior to collar deployment and prior to the June 2017 survey effort.

5.3 Potential reasons for change in estimates

One of the main questions is whether the apparent increase is due to simple sampling variation, sample bias, or a biological change? Here are a few aspects to consider in point form.

- The regression and Monte Carlo analysis suggests that an overall slow decrease in herd size is likely occurring when all survey efforts (2008, 2014, and 2017) are included in the analysis of trend. Therefore, it is not possible to determine any significant change between the 2014 estimate and the 2017 estimate.

- As explored earlier, low coverage of the composition data in the high northern stratum in 2017 may be causing an overestimate of adult females. The overall estimate of adult females is sensitive to composition classification in the HD North stratum given the high numbers of caribou in this stratum.

- The estimates of total caribou on the calving ground for 2014 and 2017 show a decline in 2017 and therefore if a change was occurring then a different proportion of the herd would have had to been present on the calving ground in each of the survey years. The survey extent was 15% greater in 2017 (19,037 km^2) when compared with 2014 (16,163 km^2). The 2008 survey did not include peripheral strata and therefore this number cannot be compared unless the recon data in 2008 is used to construct these outside strata.

- All 74 collared caribou were within the core and peripheral strata during the 2017 survey. In 2014, 32 of 35 collared caribou were in the core and peripheral strata with 3 caribou occurring to the east, however, 2 of them had low movement rates (QM1310413, QM1320413) and could have been mortalities. One collar was to the east (BL0580413) and was moving at 9.1 km per day on June 5th. So there is a possiblity that some caribou may have not been in the calving ground area in 2014.

- An assessment of collar movements for both the Qamanirjuaq and Ahiak/Lorillard caribou herds has revealed atypical movement patterns in 2015, 2016, 2017, and 2018. These extra limital movements of Ahiak/Lorillard caribou cows were the first of their kind over the 15 year collaring program and suggest a mixing with Qamanirjuaq caribou over the calving period. This mixing would increase the total number of caribou on the Qamanirjuaq calving ground beyond Qamanirjuaq cows alone in June 2017. Additionally, the observations of greater than expected numbers of bulls along the northern extents of the Qamanirjuaq caribou calving extents is suggestive of a southern movement of Ahiak/Lorillard bulls further cooberating the possibility of mixed herds during the 2017 Qamanirjuaq caribou calving ground survey.

The change in estimates could be explored further using the following approaches.

- An integrated population/OLS model could be used to determine if changes in herd size are indicated by other demographic indicator such as spring calf-cow ratios. For example, in 2012 it appeared that the Bathurst herd had stabilized from a previous decrease (from 2006 to 2009) due to similarity of estimates of adult females and breeding cows. However, demographic analysis suggested that this apparent increase was partially due to a few years of high productivity followed by low productivity. Using this information, the overall status of the herd was categorized as “fragile” with a potential decrease still occurring. In 2015 another calving ground survey was conducted which documented further decrease in herd size (Boulanger et al. 2017).

- Determination of switching of herds based on collared caribou could assess if switching influenced herd estimates. So far there is only one documented case of a caribou switching between the Qamanirjuaq and Beverly in the interval between 2014 and 2017 however recent evidence from collared Qamanirjuaq cows and Lorillard cows suggest that herds north of Chesterfield inlet may have moved south into the Qamanirjuaq range in fall 2015 and/or spring 2016 (see above).

- An ongoing analysis of the reconnaissance data will help determine if an upward trend was indicated by these surveys. The 2008 data set which is only georeferenced at segments would need to be refined further for this purpose.

- Further scrutiny of the photo data could allow an estimate of proportion yearlings in areas that were not covered in the HD photo stratum in 2017. This would allow further inference on potential bias in composition estimates. However, this proportion could not be readily applied to correct estimates given that it is not possible to detect bulls from the photos.

5.4 Miscellaneous notes on other aspects of the survey

5.4.1 Extrapolation of herd size

One apparent result from this survey and other surveys is the large range in pregnancy rates and subsequent changes of distribution of caribou within calving ground areas. Given this trend, extrapolation based on adult females is certainly better than one using an assumed pregnancy rate which is easily biased by variation in pregnancy rates. However, extrapolation based on adult females still assumes that all adult females are adequately classified and sampled across the entire extent of the calving ground. The use of total caribou on the calving ground in core and peripheral strata is another option if it can be assumed that the same proportion of caribou (bulls and cows) appear on the calving ground in a survey year.

5.4.2 Visual survey methods.

The double observer analysis identified various factors influencing sightability, however, the actual difference between double observer and non-corrected estimates was minimal compared to previous surveys. Principal reasons for lower proportions of caribou observed by only one observer include good survey conditions (lack of snow cover) and observer skill. Other potential reasons are if the rear observer did not admit to not seeing caribou observed by the front though considerable training was undertaken with all observers to reduce this error. The best way to confront this issue is to make sure that observers trade positions during each survey day. This will identify weak observers and ensure unbiased estimates. The degree of observations collected by front versus rear observers suggests that switching did not occur evenly during the survey. It is hard to tell how much this factor influenced estimates. It is suggested that the double observer pair method continue to be reviewed thoroughly at the beginning of all surveys to minimize potential bias factors.

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