

**Abundance and Trends of the Beverly Mainland
Migratory Subpopulation of Barren-Ground
Caribou (*Rangifer tarandus groenlandicus*) June
2011 - June 2023**

NWMB FINAL REPORT#:

NWRT-2023-0018

Government of Nunavut
Department of Environment

Mitch Campbell

Department of Environment, Arviat, NU

John Boulanger

Integrated Ecological Research, Nelson, BC

23rd September 2024



ABSTRACT / SUMMARY.

The Beverly taiga wintering mainland migratory barren-ground caribou herd migrates each spring from their winter ranges in northern Saskatchewan and southeastern Northwest Territories to their annual concentrated calving area (ACCA) historically in the vicinity of Beverly Lake but in more recent years in the vicinity of the Queen Maud Gulf and Adelaide Peninsula. Abundance estimates developed over the last three decades suggest that the herd has significantly declined from an estimated 276,000 adults and yearlings in June 1994, to 136,608 by June 2011, and further to 103,372 adults and yearlings by June 2018. Additionally, survey observations and collared cow telemetry locations have also documented a general shift in the calving distribution east from the Perry River area more towards the Adelaide Peninsula's western and southern extents. These continued declines and shifts in ACCA extents provided the impetus for an updated estimate of the Beverly subpopulations abundance in June 2023. In June 2023 we estimated the abundance of the Beverly tundra wintering barren-ground caribou herd using both video and visual methods, and based on the estimated numbers of breeding and non-breeding female barren-ground caribou within the herd's ACCA extending from the Queen Maud Gulf coastline to the eastern shores of Chantrey Inlet. We further examined demographic trends for the Beverly herd using a Bayesian state space Integrated population model.

Please note that the full analysis is in preparation and as such quantitative results on Beverly Herd abundance cannot be provided at this time but will be provided to all stake holders as a Government of Nunavut file report at a later time. Similar too the June 2011 and 2018 surveys, the June 2023 survey effort was deployed in five main stages including a collar reconnaissance, Reconnaissance survey, abundance survey, calving ground composition survey, and fall composition survey. Unlike the 2011 and 2018 surveys, we also used a video survey modification to the visual method to address significant clumping of calving caribou not previously encountered. We used a systematic aerial transect visual survey technique for reconnaissance surveys to stratify the survey area by caribou density. Following reconnaissance, we flew a combination of a stratified systematic aerial transect visual and video survey to estimate the number of adult and yearling female and breeding female caribou within the Beverly ACCA. Our survey protocol employed a dependant double observer pair method developed during the 2011 abundance survey for the visual component of the abundance survey, and a novel video method used to record high density clumps of calving caribou for later assessment using newly developed digital counting techniques. Survey effort focused on estimating the number of adult and yearling caribou during peak calving. Additionally, we conducted composition surveys within all abundance survey strata to estimate the proportion of breeding and non-breeding females in each stratum. To obtain estimates of females, breeding females, males, and overall adult and yearling caribou within the the survey area, the estimated number of adult caribou (1+ year old) for each survey stratum was multiplied by the sex and age class proportions of that stratum that were estimated with the composition surveys. Finally, whole herd estamitas were extrapolated using sex ratios quantified during fall composition studies.

The June 2023 abundance survey yielded a breeding female estimate of **TBD (to be determined, in preparation)** and a total female estimate of **TBD**. The June 2011 survey estimated 67,414 (SE = 3250.5; CV = 0.048) breeding females and 80,705 (SE = 3724.3; CV = 0.046) females, and the June 2018 survey estimated 48,977 (SE = 2600.9; CV = 0.053) breeding females and 61,070 (SE = 2887.8; CV = 0.047) females. Extrapolated whole herd estimates suggest that Beverly Herd abundance declined from 136,608 (SE = 6603.3; CV = 0.048) in June 2011 to 103,372 (SE = 5109.3; CV = 0.049) by June 2018 suggesting a rate of decline, based on performed t-tests, of 4% to 5% which proved statistically significant when comparing female estimates only. Combinations of Ahiak and Beverly movement suggest that movements were relatively balanced between the 2 calving grounds with only a slight net movement into the Beverly calving-ground. However, this still had a small effect on trend. The IPM estimated roughly stable movements (i.e. 30%), however, this may have been due to sparse data obscuring trends in the data set. The Bathurst movement did occur in most years however levels were relatively low compared given the lower size of the Bathurst herd. Relatively high productivity levels are suggested for the Beverly prior to the survey effort. This type of analysis could also be repeated (using MERRA covariates) to assess if productivity was related to range and environmental conditions.

Key words: Calving ground visual survey, Caribou calving ground, Kitikmeot region, Double observer pair method, Barren-ground caribou, Beverly Subpopulation, Ahiak subpopulation, Northeast Mainland, Queen

Maud Gulf, Adelaide Peninsula, Nunavut, *Rangifer tarandus groenlandicus*, abundance, population survey, decline.

TABLE OF CONTENTS.

1.0 INTRODUCTION	8
2.0 STUDY AREA	17
2.1 QUEEN MAUD GULF LOWLAND ECOREGION.....	18
2.2 CHANTREY INLET LOWLAND ECOREGION.	19
3.0 METHODS.	24
3.1 RECONNAISSANCE AND ABUNDANCE SURVEYS.	25
<i>3.1.4 Reconnaissance Survey.....</i>	<i>28</i>
<i>3.1.6 Abundance Survey.....</i>	<i>31</i>
3.6 ESTIMATES OF BREEDING FEMALES, ADULT FEMALES, AND ADULTS.	50
4.0 RESULTS & DISCUSSION TBD.....	54
<i>4.3.1 Analysis of collar movements</i>	<i>66</i>
<i>4.3.2 Video Assisted Counts in High-Density Strata.....</i>	<i>72</i>
<i>4.3.3 Estimation of abundance using Jolly N with video- assisted counts</i>	<i>79</i>
<i>4.3.4 Double observer</i>	<i>82</i>
<i>4.3.5 Composition survey results</i>	<i>90</i>

4.3.6 Estimation of breeding females, adult females, and bulls
94

4.3.7 Extrapolated herd estimates95

4.4 ABUNDANCE TRENDS96

4.5 COLLAR ANALYSIS.....97

4.5.1 *Movements between calving grounds97*

4.6 SURVIVAL ANALYSIS108

**4.7 INTEGRATED POPULATION MODEL DEMOGRAPHIC
ANALYSIS.....112**

4.7.1 *Data sources.....112*

5.0 CONCLUSIONS TBD- 113 -

6.0 ACKNOWLEDGEMENTS.....114

7.0 LITERATURE CITED.....116

1.0 INTRODUCTION

Please note that results for the Beverly Herd abundance survey have yet to be finalized due to ongoing analysis. A final Government of Nunavut File Report will be provided upon completion of analysis.

Following the last glacial period, caribou (*Rangifer tarandus*) in North America recolonized their range from several refugia, resulting in the emergence of multiple ecotypes (Yannic et al., 2014). Although Inuit have relied on several caribou subpopulations and ecotypes for survival over centuries, the first written reference to barren-ground caribou was likely that of Martin Frobisher in 1576 (Banfield, 1951). Hearne recorded the earliest detailed account of migratory behavior, distribution and movements, and the use of caribou by subsistence harvesters, in 1795 (Banfield, 1951). Early reports and interviews with residents, however, yielded little insight into the dynamic nature and distributions of barren-ground caribou (*Rangifer tarandus groenlandicus*) subpopulations west of Hudson Bay (**Figure 1**).

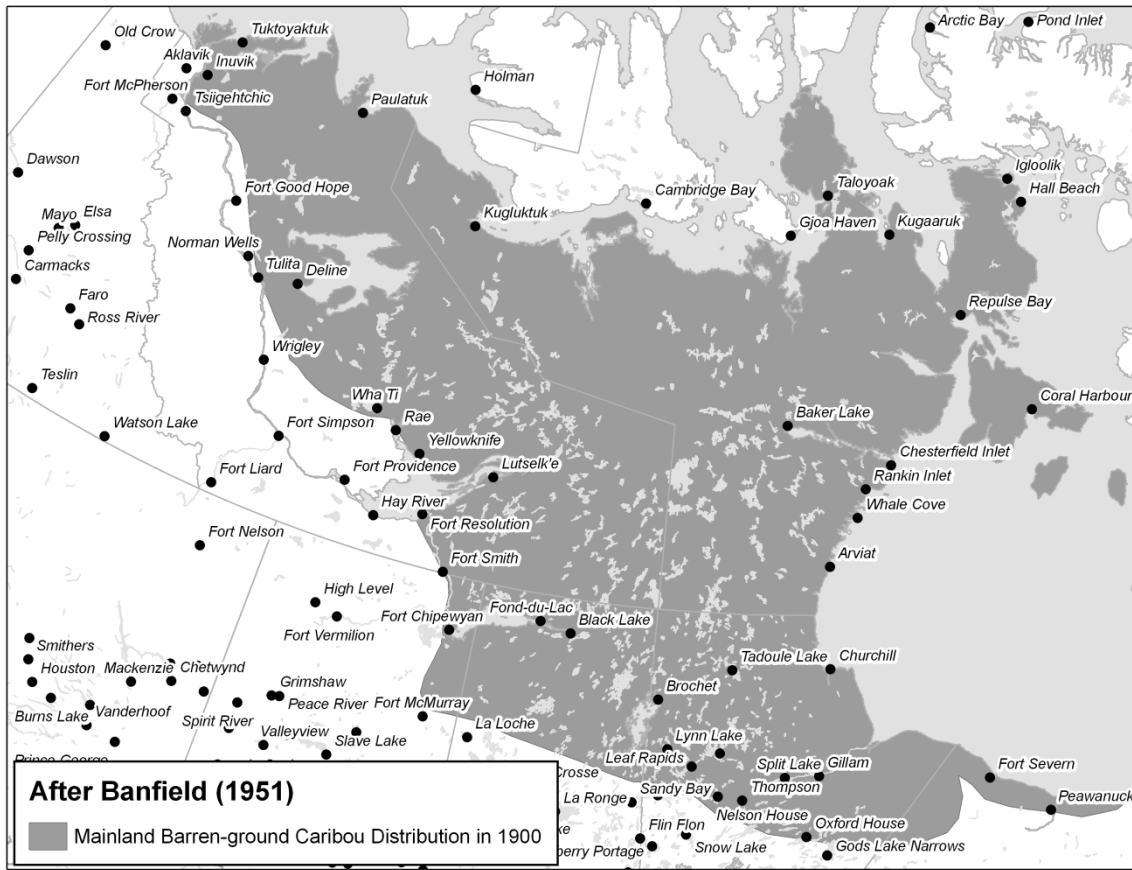


Figure 1. Mainland barren-ground caribou distribution based on local observations and studies from the early 1900s (after Banfield, 1951).

It wasn't until the the mid 1900's that we saw an increase in demographic studies of the barren-ground caribou herds east of the Hudson Bay (Calef, 1979). Eight major barren-ground caribou herds were identified within the then Northwest Territories (NWT), now the NWT and Nunavut (NU), during this period. Together these herds likely exceeded 600,000 caribou (Calef, 1979). In addition to the more prominent mainland migratory Bathurst, Beverly, and Porcupine herds (then thought to be stable), and the Qamanirjuaq and Baffin Island herds (then thought to be declining), work during this period also identified other more poorly understood subpopulations of the time including the Melville Peninsula, Wager Bay, Cape Bathurst, and Bluenose herds (then thought to be increasing) (Calef, 1979; Heard and Jackson, 1990; Thomas, 1969; Rippin, 1971; Moshenko, 1974; Gunn and Decker, 1982; Stephenson et al., 1984; Gunn, 1984; Heard, 1982; Gunn and Sutherland, 1997; Williams and Heard, 1990; Williams et al., 1989; Thomas and Kiliaan, 1985; Thomas and Barry, 1990).

Our study focuses on the Beverly subpopulation, which migrates annually into Nunavut from winter ranges in northern Saskatchewan and the southeastern Northwest Territories (**Figure 2**). Abundance estimates suggest that the herd has declined from an estimated 276 000 individuals in 1994 to approximately 103,372 adults and yearlings by 2018 (Campbell et al. 2020). Since 2011, reconnaissance surveys conducted in 2013, and 2016, and 2018 have indicated further declines in relative densities as well as a general shift in the calving distribution east toward the Adelaide Peninsula.

The survey history of the Beverly herd has been irregular, and most recently complicated by apparent distributional shifts within the herds spring, calving, and post-calving seasonal range. For example, a June 2007 calving ground survey found too few breeding females on the

“traditional” Beverly calving area near Beverly and Garry lakes (175 observed on transect; relative density of 0.40 caribou/km²) to conduct a photo-survey (Johnson et al., 2008). In the following years, the GNWT continued to observe lower densities of caribou during reconnaissance surveys flown over the same area in June 2008, 2009, and 2010 (90 - 100 caribou observed on transect in June 2010; relative density of 0.20 caribou/km², unpublished GNWT data). At the time, these results suggested a severe decline in the Beverly subpopulation. However, despite all indications from reconnaissance surveys up to June 2010 suggesting a population crash with the threat of extirpation, local knowledge and an assessment of collar movements over the same period suggested another possible reason for the decline. Collar relocations suggested a shift in the Beverly annual concentrated calving area (ACCA) of some 200 to 250 km north of their previous “traditional” ACCA, to the western Queen Maud Gulf Lowlands (QMGL) and south and western extents of Adelaide Peninsuls (Nagy et al. 2011; Campbell et al., 2012; Campbell et al., 2020). The knowledge of local hunters (Baker Lake, Gjoa Haven, and Kugaaruk Hunters and Trappers Organisation [HTO] meetings and pers. comm.) agreed that the Beverly herd had been calving further north in recent years. Still, competing views suggested that the primary mechanism was a major decline coupled with a distributional shift, ending with a switching to the QMGL ACCA to maintain the advantages of gregarious calving (Gunn et al, 2010; Gunn et al. 2012, Adamczewski et al. 2015). Small sample sizes of collars deployed prior to 2002, and the lack of reproductive assessments associated with these initial captures, render a quantitative assessment of this period unreliable, making it difficult to conclude which mechanisms were responsible for the numbers observed on the traditional calving area prior to 2007. However, quantitative evidence from more recent telemetry and aerial survey work, combined with local knowledge, strongly support the theory of a distributional shift in the

ACCA, and provides an explanation for the observed increases in breeding female and female abundance in the QMGL during calving. Though inconclusive, we believe that the movement northward from the southern calving area began much earlier than 2005. Reconnaissance data from June 2016 suggested that the shift was not temporary as observations continued to show no re-establishment of calving within the previously recognized ACCA near Beverly and Garry lakes.

In addition to monitoring movements of individuals from the surveyed herd, it is also important to consider the potential for movements of animals from other herds into the study area during a survey. This is particularly true for surveys in the QMGL area, where historically other caribou subpopulations have also calved. The Bathurst herd has previously calved annually within the western extents of the current Beverly QMGL ACCA. Prior to the shift of their calving area to the west of Bathurst Inlet (Williams and Heard, 1990; Sutherland and Gunn, 1996; Gunn et al, 2000), the Bathurst herd calved across an area west of the Perry River extending to the eastern shore of Bathurst Inlet (Gunn, 1996; Heard et al., 1986; Sutherland and Gunn, 1996). GNWT collected Bathurst adult cow telemetry data from the last seven years has shown a small proportion of Bathurst collared cows returning to the east side of Bathurst Inlet and mixing with calving Beverly cows over most years. Furthermore, a small number of caribou from the Ahiak subpopulation (a tundra wintering caribou ecotype part of the Northeast Mainland group including the Wager Bay and Lorillard herds) also calve in close proximity to the Beverly ACCA along its eastern extents in the vicinity of Adelaide Peninsula. Overall, however, analyses of collar movements suggest that in most years the majority of the Ahiak herd tend to calve further to the east of Adelaide Peninsula (Sutherland and Gunn, 1996; Gunn et al., 2000; Gunn, 1996; Gunn et al, 2008; Campbell et al., 2020, Campbell et al., 2022). Nagy et al. (2011) and Nagy and Campbell

(2012) delineated caribou subpopulations calving east of the Beverly subpopulation and within the eastern part of the QMGL. The Ahiak subpopulation's main calving areas extend from the Adelaide Peninsula to the west coast of Simpson Peninsula with the majority of calving occurring east of Chantrey Inlet suggesting conspicuous separation between the herds. Though variable from year to year, there is some spatial overlap between the adjacent Beverly and Ahiak subpopulations as well as between the Beverly and Bathurst subpopulations during the calving season since 2017 (Campbell et al. 2020).

Calving ground aerial survey methods have been improving since the first barren-ground caribou surveys were flown in the mid to late 1960s. Early estimates often varied in reliability, making precise comparisons through time challenging. Photographic methods were first deployed for Beverly calving-ground abundance surveys in 1982, and were then used consistently thereafter (June 1984, 1988, 1993, and 1994 with the exception of June 1987). Photographic methods improved count accuracy and abundance estimate precision where high animal densities made accurate counts by observers difficult or unmanageable. We first deployed the dependent double-observer pair visual observation method for caribou in June 2011 to estimate the abundance of the Beverly herd following several years of reconnaissance surveys indicating consistent low relative densities of Beverly caribou on the calving grounds (Campbell et al. 2012; Campbell et al., 2020). Where densities permit, this method employs more local survey observers, is far less complicated logistically, and improves precision by correcting visual counts for sightability biases thereby allowing efficient, unbiased estimates without the use of the photo plane. This visual method can effectively be used when densities of less than 15 caribou/km² are encountered (Cook and Jacobsen, 1979; Buckland et al., 2010). When caribou densities are not too high, the dependent double-observer pair

visual method has proven to be more cost effective than traditional photographic methods without compromising accuracy or precision. However, when caribou densities are in excess of 15 caribou/km², either through population growth or clumping, visual methods are more likely to be insufficient in terms of their ability to accurately and/or precisely estimate abundance within effected strata. This condition can be difficult to predict for future surveys without reliable information on trends between surveys, and/or environmental changes that can modify caribou movements and distributions. For this reason, communication with aerial photography charter companies is always developed and maintained during any planned Beverly calving-ground abundance survey including the June 2023 Beverly abundance survey program.

Reconnaissance survey observations flown by the GNWT Government between 2007 and 2010 all reported group sizes and associated densities of well below the 15 caribou/km threshold with very rare exceptions, while Government of Nunavut reconnaissance surveys flown between June 2010 and 2018 showed similar densities with only rare groupings of greater than 15 caribou/km² observed. For this reason, and with all quantitative evidence confirming a statistically significant declining trend up to June 2018, the 2023 Beverly calving ground survey was planned using the double observer pair visual method with the request to have a photo plane standing by in case of any unexpected change that may drive general observational densities above the threshold 15 caribou per km².

Our main objective for the June 2023 survey was to obtain an estimate of Beverly caribou calving within the QMGL from the eastern shore of Kent Peninsula to the western shore of Chantrey Inlet and the Back River, including Adelaide Peninsula (**Figure 3**). We used retrospective analysis and published studies both prior to, and following the survey for the purposes of delineating subpopulations from the survey strata. The

main contents of this report are the survey results and the challenges both environmental and logistical that had to be overcome to meet the assumptions and objectives of the survey method deployed. We emphasize that the main objective of this study is to provide an abundance estimate for the Beverly herd to address the status of caribou subpopulations in the region and to inform interjurisdictional co-management efforts. The large geographic scale of the observed spatial shifts described above, the lack of information of population trend prior to 2005, combined with the socioeconomic importance of this herd, made this work a priority for the jurisdictions of Saskatchewan, Northwest Territories and Nunavut.

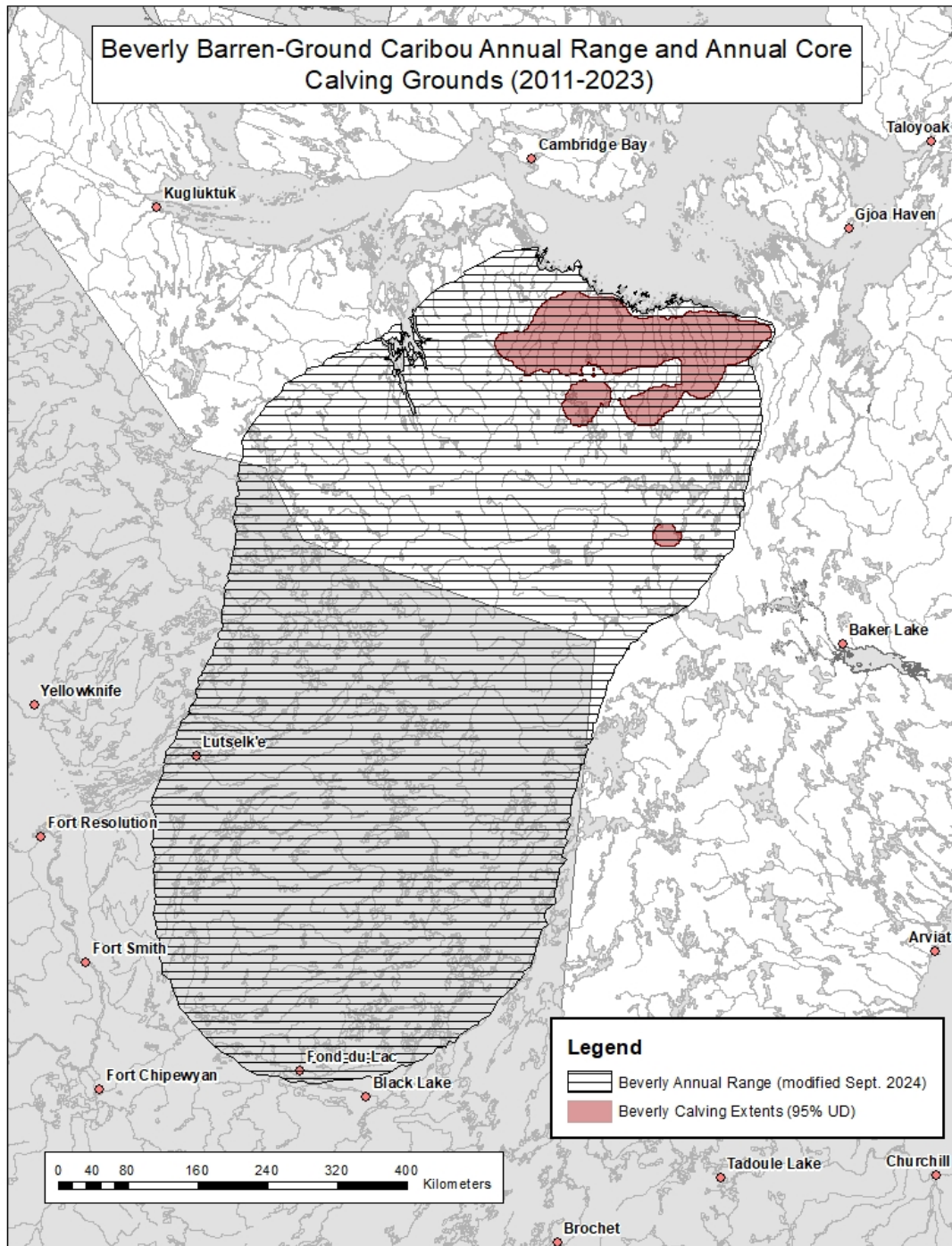


Figure 2. The annual range and concentrated calving grounds of the Beverly barren-ground caribou subpopulation. Calving polygons based on kernel analysis of all available telemetry data current to July 2023 and representing the 95% utilization distribution. Annual range extents modified from

Nagy and Campbell (2012) to reflect calving data current to July 2023.

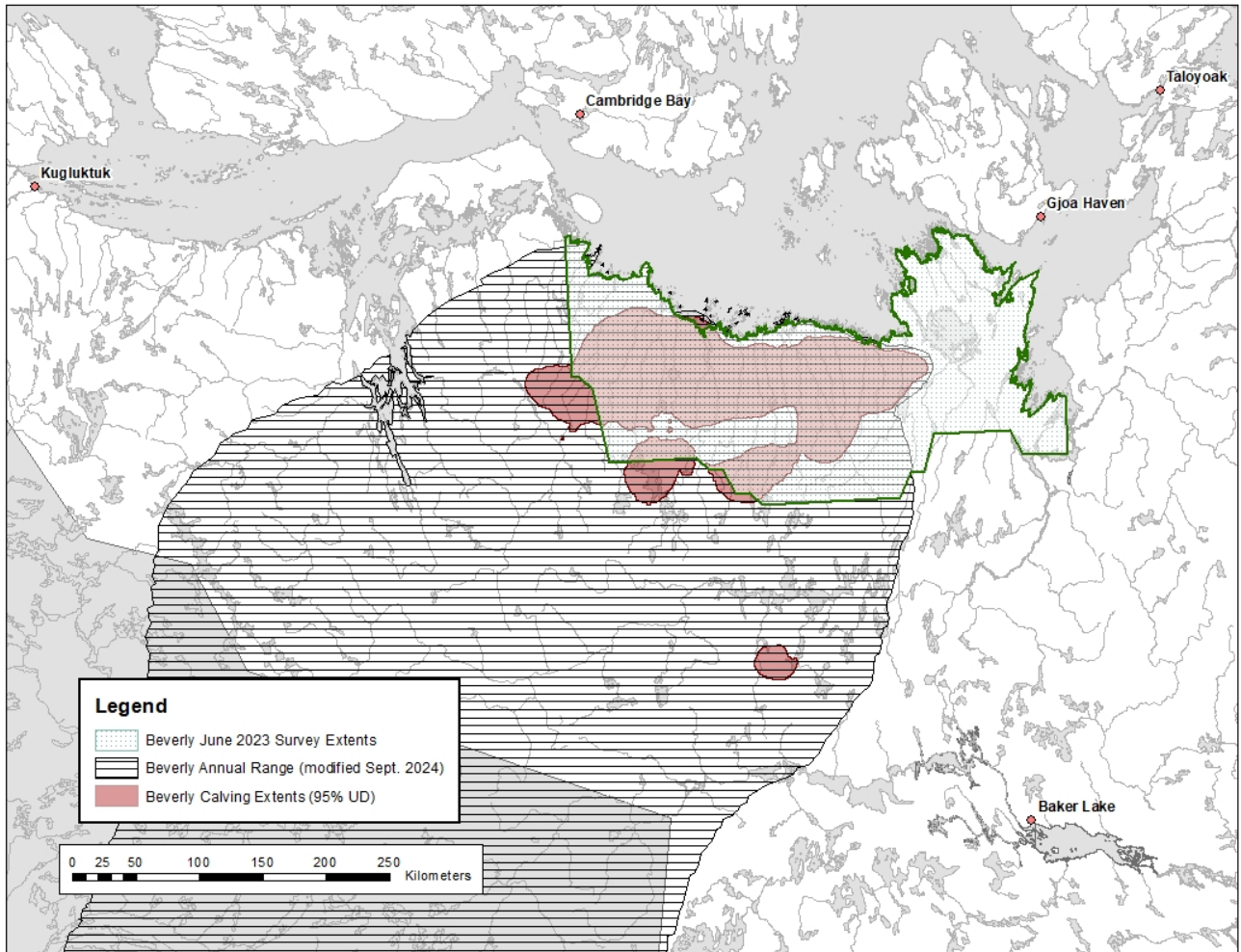


Figure 3. The June 2023 calving-ground abundance survey extents (Green) including annual core calving grounds (red) and annual range (Black). Calving polygons based on kernel analysis of all available telemetry data current to July 2023 and representing the 95% utilization distribution. Annual range extents modified from Nagy and Campbell (2012) to reflect calving data current to July 2023.

2.0 STUDY AREA

The estimated annual range of the Beverly herd, based on satellite-collar location data collected between 2000 and 2011, is approximately 426,160 km² (Nagy et al. 2011, Nagy 2011, Nagy and Campbell 2012, Campbell et al. 2014). The Beverly 2011 to 2023 annual concentrated calving area (ACCA), including both the Garry Lakes and Queen Maud Gulf calving extents, was estimated using kernel analysis, and found to be 38,491 km², of which the 2011 Beverly Lakes calving proportion represented an estimated 16,131 km² (Nagy et al. 2011, Nagy and Campbell 2012, Campbell et al. 2014). The majority of the calving extent, fall and spring range, including the spring and fall migratory corridors, and the majority of the post-calving habitat, lie within Nunavut (**Table 1**). The annual range of the Beverly subpopulation spans across Nunavut, Saskatchewan, and the NWT. The communities of Black Lake and Fond-du-Lac in Saskatchewan, Lutselk'e in the Northwest Territories, and Baker Lake, and Gjoa Haven, in Nunavut, are all within the Beverly subpopulation's annual range.

The June 2023 Beverly calving ground survey area covered an estimated 73,184 km². It extended south from the shores of the Queen Maud Gulf and northern shores of Adelaide Peninsula to a latitude of approximately 66.5°N, and east from the Ellice River to the western shore of Chantrey Inlet and the Back River (Wiken, 1986**Error! Reference source not found.**). The Beverly subpopulation's annual range extends from the Southern Arctic Ecozone south through the Taiga Shield Ecozone (Wiken, 1986**Error! Reference source not found.**) crossing a total of nine

Ecoregions including the Queen Maud Gulf Lowland, the Takijua Lake Upland, the Garry Lake Lowland, the Back River Plain, the Coppermine River Upland, the Dubawnt Lake Plain/Upland, the Kazan River Upland, the Tazin Lake Upland and the Selwyn Lake Upland **Error! Reference source not found.**(Wiken, 1986; Ecological Stratification Working Group, 1996) (**Figure 4**).

The Beverly subpopulation's late-winter range lies predominantly within the Tazin Lake Upland and Selwyn Lake Upland Ecoregions; spring and fall migration corridors lie wholly or partially within the Kazan River Upland, the Dubawnt Lake Plain/upland, the Takijua Lake Upland (western extents) and the Garry Lake lowland (Campbell et al. 2012, Campbell et al. 2014). Post-calving range varies but lies predominantly within the Garry Lake Lowland, the Back River Plain, and the Takijua Lake Upland to the west.

2.1 QUEEN MAUD GULF LOWLAND ECOREGION.

The majority of the survey area covering the Beverly annual concentrated calving area (ACCA), lies within the Queen Maud Gulf Lowland Ecoregion with its eastern boundary extending into the Chantrey Inlet lowland within the last 15 years (**Figure 5**). The Queen Maud Gulf Lowland extends eastward along the Arctic slope, from Bathurst Inlet to near Chantrey Inlet and is associated with the lowlands south of the Queen Maud Gulf. The mean annual temperature of this ecoregion is approximately -11°C with a summer mean of 5.5°C and a winter mean of -27°C . The mean annual precipitation of the ecoregion

varies according to latitude, ranging from 125 mm within its northern extents, to 200 mm within its southern extents.

The Queen Maud Gulf Lowland Ecoregion is classified as having a low Arctic ecoclimate and is characterized by a cover of shrub tundra vegetation, consisting of dwarf birch (*Betula glandulosa*), willow (*Salix spp.*), northern Labrador tea (*Ledum decumbens*), mountain avens (*Dryas spp.*), and Ericaceous shrubs (*Vaccinium spp.*). Tall dwarf birch, willow, and alder (*Alnus crispa*) occur on warm sites; while wet sites are dominated by sphagnum moss (*Sphagnum spp.*) and sedge (*Carex spp.*) tussocks. Geologically the region is composed of massive Archean rocks that form broad, sloping uplands that reach about 300-m above sea level (ASL) in the south, and subdued undulating plains near the coast. The coastal areas are mantled by silts and clay of postglacial marine overlap. Bare bedrock is common, and turbic and static cryosols, developed on discontinuous thin sandy moraine with level alluvial marine deposits, are the dominant soils. Permafrost is continuous and deep with low ice content. The Queen Maud Gulf Lowlands are an important habitat for waterfowl and shorebirds, and the Queen Maud Gulf Bird Sanctuary covers most of the ecoregion (Wiken, 1986; Ecological Stratification Working Group, 1996).

2.2 CHANTREY INLET LOWLAND ECOREGION.

The eastern extents of the Beverly ACCA lie within the Chantrey Inlet Lowland Ecoregion (**Figure 5**). The Chantrey Inlet lowland is associated with lowlands surrounding Chantrey Inlet and Adelaide Peninsula. The

mean annual temperature of this ecoregion is -12°C , with a summer mean of 4.5°C and a mean winter low of -28°C . The mean annual precipitation is similar to the western extents of the Beverly ACCA, and ranges from 125 mm to 200 mm. The Chantrey Inlet Lowland Ecoregion is classified as having a low Arctic ecoclimate characterized by large areas of exposed, sparsely vegetated bedrock in association with shrub tundra vegetation, consisting of dwarf birch, willow, northern Labrador tea, *Dryas spp.*, and *Vaccinium spp.* Tall dwarf birch, willow, and alder occur on warm sites while wet sites are dominated by sphagnum moss and sedge tussocks.

Near the coast of this ecoregion the surface is mantled by silts and clay of postglacial marine overlap, and is underlain by massive Archean rocks that form a level to undulating plain that reaches about 300-m ASL within its southern extents. Turbic and static cryosols developed on discontinuous, thin, sandy moraine, and level alluvial and marine deposits, are the dominant soils in the ecoregion. The east and west sides of Chantrey Inlet are underlain by continuous permafrost with low ice content. The northern half of the Adelaide Peninsula is characterized by continuous permafrost with medium to high ice content in the form of ice wedges and massive ice bodies (Wiken, 1986; Ecological Stratification Working Group, 1996).

Table 1. Beverly mainland migratory barren-ground caribou seasonal range areas within the Northwest Territories and Nunavut based on telemetry data current to 2013 (Campbell et al. 2014). Note that though the annual range of the Beverly subpopulation crosses into Saskatchewan, the 95% utilization distribution of all Beverly seasonal ranges do not.

Season	Total Area (km²)	NU Area (km²)	NWT Area (km²)	NU %	NWT %
Spring	53,287	36,858	16,428	69%	31%
Calving	16,131	15,951	179	99%	1%
Post-calving	35,119	34,808	311	99%	1%
Summer	176,940	151,380	25,560	81%	19%
Fall	27,781	8,344	19,437	32%	68%
Rut	96,953	24,581	72,372	25%	75%
Winter	91,459	19,024	72,436	21%	79%

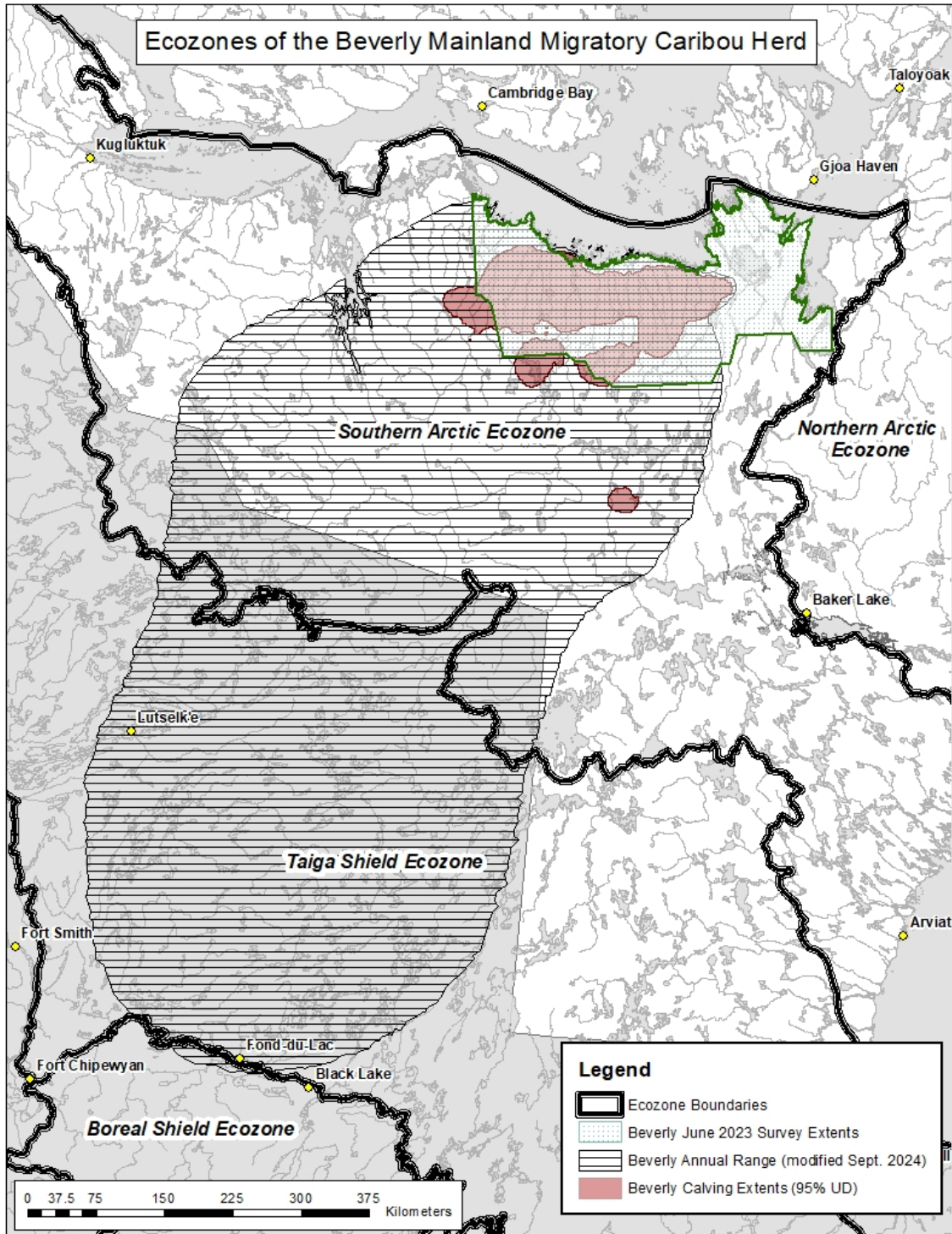


Figure 4. Ecozones of the Beverly barren-ground caribou subpopulations annual range extents and annual concentrated calving areas (ACCA) (Wiken, 1986, Ecological Stratification Working Group 1996, Campbell et al. 2014 & 2019).

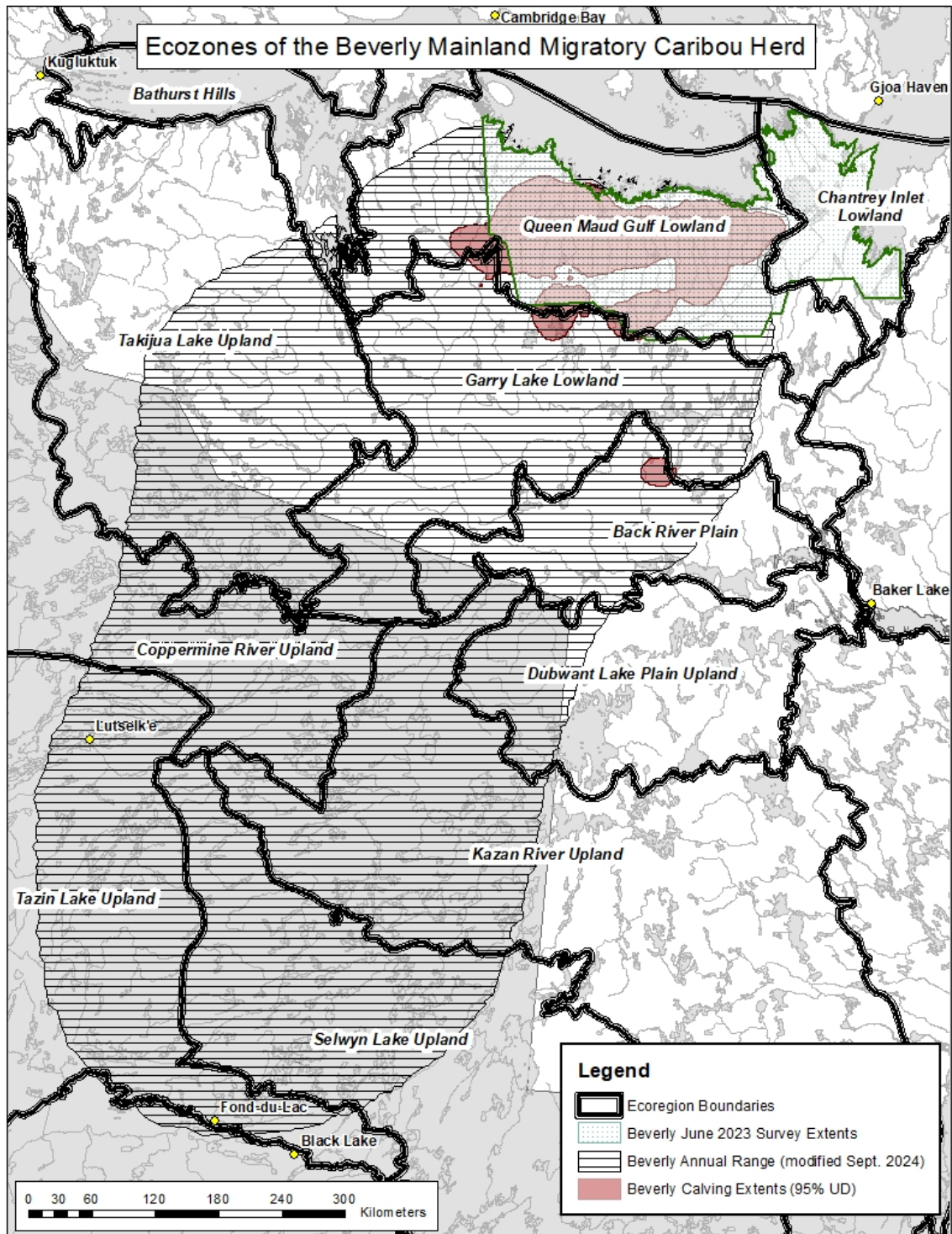


Figure 5. Ecoregions of the Beverly barren-ground caribou subpopulations annual range extents and annual concentrated calving areas (ACCA) (Wiken, 1986, Ecological Stratification Working Group 1996, Campbell et al. 2014).

3.0 METHODS.

The June 2023 Beverly barren-ground caribou herd stratified random transect survey was designed to be based out of the communities of Cambridge Bay, and Gjoa Haven, however, aviation fuel shortages in Gjoa Haven necessitated a redesign of survey logistics with Cambridge Bay as the sole base of operations. This change did not impact survey quality but rather increased survey costs and ferrying time at the beginning and end of each flying day. The abundance estimate utilized a cooperative double observer pair visual method, and a novel videographic method, to count caribou along pre-determined transect lines. The inclusion of a photographic method was necessary due to the previously undocumented and uncharacteristic clumping of calving Beverly caribou observed on the 2023 calving ground. Though a contingency to utilize a photo-plane should such an event occur was in place, the plane that was required was unable to position to Cambridge Bay due to mechanical issues, necessitating the development of an alternative photographic option.

Both the visual and videographic portions of the reconnaissance and abundance surveys utilized two high-wing, turbine, fixed wing Twin Otter aircraft for transect counts, and one Eurocopter B-2 rotary wing aircraft for abundance strata composition counts. The multiple aircraft were used to shorten the survey period, take maximum advantage of good weather windows, ensure that there were at least two experienced observers on each plane while remaining inclusive to HTO selected observers, and reduce the probability of either double counting and/or

under counting (due to movement over time) caribou within the study area. At the same time as the video and visual survey's, the rotary wing aircraft was used to classify both visual and video groups of breeding and non-breeding female caribou, yearlings, calves, young bulls, and mature bulls. To extrapolate to a whole herd estimate, we utilized fall composition data collected during the rutting period in October 2022 by GNWT Biologists. The Fall data provides information on herd sex ratio as all ages and sexes of caribou gather together within their breeding range in and around mid to late October.

The visual portion of the survey utilized a dependent double-observer pair method. The typical configuration was comprised of the pilot, two data recorders (rear left and front right) and four observers (two on the left side of the aircraft and two on the right side). Only caribou observed within the strip, as defined by the inner and outer streamers attached to the left- and right-wing struts, were recorded. Survey timing relied predominantly on a daily assessment of collared cow movement rates.

3.1 RECONNAISSANCE AND ABUNDANCE SURVEYS.

The June 2023 Beverly calving-ground survey used both reconnaissance and abundance surveys, which in turn, utilized two observational methods to count caribou. These methods included a double observer pair visual method for moderate to low densities, and a videographic method to address higher densities (above the ability to accurately count visually) due to clumping. Both surveys used two Twinn Otter Dehaviland high wing survey aircraft equipped with radar altimeters to

ensure that an altitude of 121.92 m (400 feet) above ground level (AGL) was maintained. The strip width on each side of the aircraft was 400 meters, for a total transect width of 800 m. Survey strip widths were marked by streamers attached to the wing struts (**Error! Reference source not found.**) and were calculated using the formula from Norton-Griffiths (1978):

3.1.1 Double Observer Pair Method

The double-observer method involves one “primary” or “front” observer who sits in the front left- or right-hand side of four observer seats centered around the wing struts, and one “secondary” or “rear” observer who sits behind the primary observer on the same side of the plane (**Figure 7**). 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. 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 are calling out the same groups or different groups and to ensure accurate counts of larger groups; **4** - The data recorder categorized and

recorded counts of caribou groups into “primary only”, “secondary only”, and “both”, entered as separate records; **5** - The observers switched places approximately half way through each survey day (i.e. during re-fueling) to monitor and account for observer ability. The recorder noted the names of the primary and secondary observers.

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 influenced by other individuals, then the caribou were considered a group.

3.1.2 Video Assisted Counts of High-Density Strata

Unlike previous Beverly calving-ground surveys, larger than expected group sizes (>100) of caribou were observed during the 2024 survey which challenged the ability of observers to visual count caribou within the 400m survey strip. Though a back-up Photo plane was put in place as a contingency prior to the start of the abundance survey, it was not available during the abundance phase do to mechanical problems necessitating an alterior means of accurately counting the observed clumped aggregations of caribou. To accomplish this a video-assisted strategy was implemented. The basic procedure involved data recorders positioning cell phones so that observations were recorded using video when large groups were encountered (**Figure 8**). To collect video data, we mounted two Samsung S22 smartphones, and two iPhone 12 smartphones on each on the left and right sides of plane one and plane two respectively. The field of view of the video spanned the entire strip width allowing a secondary count of caribou (**Figure 9**).

3.1.3 Survey Timing

We used daily movement rates of collared Beverly caribou cows and to a lesser extent, collar reconnaissance observations, to identify the onset of peak calving for the purposes of beginning the Reconnaissance survey. From collars, we estimated peak calving as the dates where female daily movement rates were at their lowest. The examination of 20 years of daily movement rates of collared Beverly females have been shown to accurately predict the beginning of peak calving when movement rates drop below 5 km per day (Campbell et al. 2012; Boulanger et al. 2018). Collar reconnaissance flights provided an additional index of the onset of peak calving when the proportion of calves per 100 females observed across the extents of the Beverly ACCA reach 15% or higher (Campbell et. al. 2012, Boulanger et. al. 2018).

3.1.4 Reconnaissance Survey.

We initiated the reconnaissance survey when daily movement rates dropped below 5 km per day and/or observed calves per 100 cows equalled or exceeded 15 percent. The reconnaissance survey is a low coverage survey (9%) and its purpose is to survey beyond known calving extents to ensure all possible aggregations of females are located and included in the abundance survey to follow. This phase of the study collects data to generate relative densities of caribou and their general composition (such as breeding and non-breeding females). We can use the results of the reconnaissance survey to calculate and to plot relative densities of females for the purposes of stratification, with areas of similar density grouped together into strata for the visual abundance

phase of the survey. Defining strata in this way increases precision of the population estimate.

In total, fifty-one north-south oriented reconnaissance survey transects ranging from 50 to 180 km long were distributed systematically at 10-km spacing across the northern mainland from Bathurst Inlet to Committee Bay (**Figure 10**) using UTM coordinates and the WGS 84 datum. Reconnaissance transects covered 5,090 linear kilometers and observed an estimated 4,000 km². Each transect had associated transect station points that were located at 10-kilometer intervals (**Figure 10**). Each station had an alphanumeric identifier (e.g. Bv83) allowing it to be easily referenced. Each 10-kilometer transect segment was named after its northern station. Transects were created using Environmental Systems Research Institute (ESRI) ArcMap Geographic Information System (GIS) software and were based on the UTM zone 15 World Geographic System and the (WGS) 1984 coordinate system.

Following the systematic reconnaissance but prior to the initiation of the visual abundance survey, we entered all observations into ESRI ArcMap GIS software to calculate relative densities of breeding females using a tool utility. 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 (1,000m in this survey; i.e., 800m strip width and 200m blind spot under the aircraft) yielding polygons that were 10 km² (i.e., 1.0 km wide x 10 km long).
2. The survey observation 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 (# of 1+ year old caribou/km²).
4. The relative density (#obs/km²) was thematically displayed on a map based on pre-defined classes or bins.

We then used the resulting graphics to stratify the breeding female distribution into high, medium and medium/low-density strata.

3.1.5 Allocation of Effort

The main objective of the survey was to obtain a precise and accurate estimate of female caribou on the calving ground and assess their breeding status. To achieve this, the survey area was stratified following the results of the systematic reconnaissance survey, a procedure in which neighboring segments with similar density were grouped into contiguous areas so that each stratum enveloped distributions of similar caribou densities. In addition, stratification was used to determine if stratum density summaries were high enough to require the use of a photo survey plane, or if visual observation methods could be used. In this survey, two higher-density strata were identified; these strata were planned for survey at least in part, using photographic methods. Other strata that had lower densities of caribou were flown using visual survey methods alone. Given that the objective of the survey was to estimate breeding females and total females, priority was given to those delineated strata showing evidence of female caribou.

Once the survey strata were delineated, an estimate of caribou numbers was derived from the reconnaissance data (Jolly 1969). The relative population size of each stratum and the degree of variation of each

estimate were used to allocate the number of transects allocated to each stratum. Transects within each stratum were aligned at right angles to the longitudinal axis of the stratum to maximize the total number of transects (N). For each stratum, an initial transect was randomly placed perpendicular to the longest stratum boundary and the remaining transects systematically placed at regular intervals according to the allocation of survey effort. During the allocation of effort process, we also had to consider available resources in the final determination of strata total coverage (Heard 1987, Campbell et. al. 2012).

Two potential strategies for allocation were considered for this aerial survey. First, optimal allocation of survey effort was considered based on sampling theory (Heard 1987, Thompson 1992, Krebs 1998). Optimal allocation basically assigned more effort to strata with higher densities given that the amount of variation in counts is proportional to the relative density of caribou within the stratum. Optimal allocation was estimated using the above-mentioned derived estimates of population size for each stratum and associated survey variance.

If strata were reasonably small, then optimal allocation was further adjusted to ensure an adequate number of transect lines. In particular, power analysis of previous surveys suggested that there should be a minimum of 10 transects per stratum with closer to 20 transects being optimal for higher density areas. In general, coverage should be at least 15% with coverage starting at a minimum of 25% for higher density strata. In the context of sampling, increasing the number of lines in a stratum is “insurance” in that it minimizes the influence of any one line on estimate precision. As populations become more clustered/clumped, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998). Transect orientations within strata, transect shape files, and coverage estimates, were generated and cross-validated using the *dssd* R package (Marshall, 2021).

3.1.6 Abundance Survey.

The abundance and coordinated abundance strata composition surveys immediately followed the reconnaissance survey in order to minimize changes in caribou distribution and densities observed during the reconnaissance phase of the survey. The abundance survey began June 13th, and was completed June 16th, following the completion of the reconnaissance survey on June 12th (**Table 2**). The abundance survey used the same survey methods deployed during the reconnaissance survey, with the exception that we did not collect composition data from the fixed wing aircraft. Both the abundance and composition surveys were completed as quickly as possible, and were highly dependent on weather. The study area within which all survey phases were flown, covered 288,312 km² and encompassed the known extent of caribou calving in the area of the Queen Maud Gulf and Adelaide Peninsula ACCA (Johnson and Mulders 2002; Johnson et al. 2008; Johnson and Williams 2008; Kelly in prep. 2010; Nagy et al. 2011, Campbell et al. 2012).

3.1.7 Composition Survey of Abundance Strata

June composition surveys were timed to begin concurrently with visual abundance surveys from 13 - 16 June 2023 to ensure minimal movement of animals occurred between strata. We used a B2 Eurocopter to complete abundance strata composition. Sampling was structured to begin at a fuel cache and then proceed 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) encountered in a

zigzag pattern using the proximity of transect stations to equally distribute composition effort (**Error! Reference source not found.**). At times, observed groups of caribou “pulled” the aircrew from the pre-planned flight path. When sampling caused deviation from the preplanned flight path, the aircrew, when possible, would stop sampling caribou groups that were seen greater than 5 kilometers perpendicular to the original flight path. From this point, only caribou groups observed within this five-kilometer buffer would be sampled and an attempt to rejoin the original flight path made. During re-positioning flights from the stratum to the fuel caches, caribou encountered within a maximum of 2 km inside of target stratum boundaries were classified opportunistically and variation of flight paths was held to within 2 km to reduce deviation from the planned flight paths and fuel caches.

During surveys, caribou were classified as yearlings (≥ 1.0 years and < 2 years of age), bulls, cows with calves (calves $< one month old$), 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, we estimated the proportions of breeding females, adult females and adults for each stratum surveyed on the calving ground.

$$w = W * h/H$$

Where **W** is the required strip width (400 m), **h** is the height of the observer's eye from the tarmac and **H** is the expected flying altitude (400 ft)

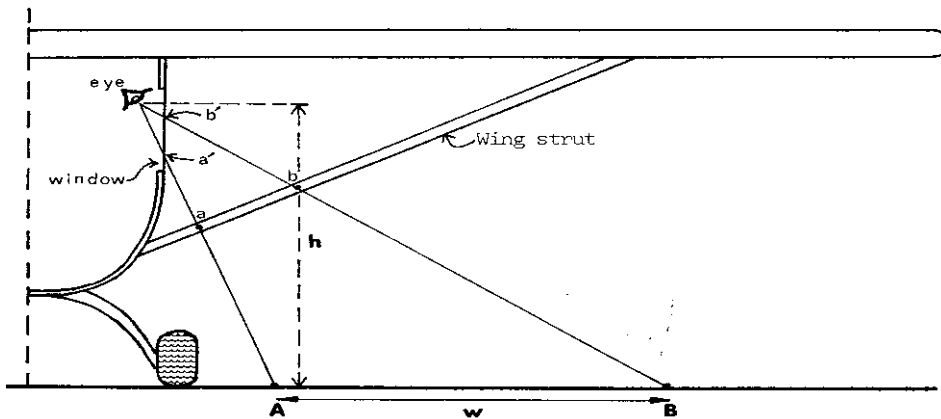


Figure 6. Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978). **W** is marked out on the tarmac, and the lines of sight **a' - a - A** and **b' - b - B** established. The streamers are attached to the struts at **a** and **b**, and **a'** and **b'** are the window marks.

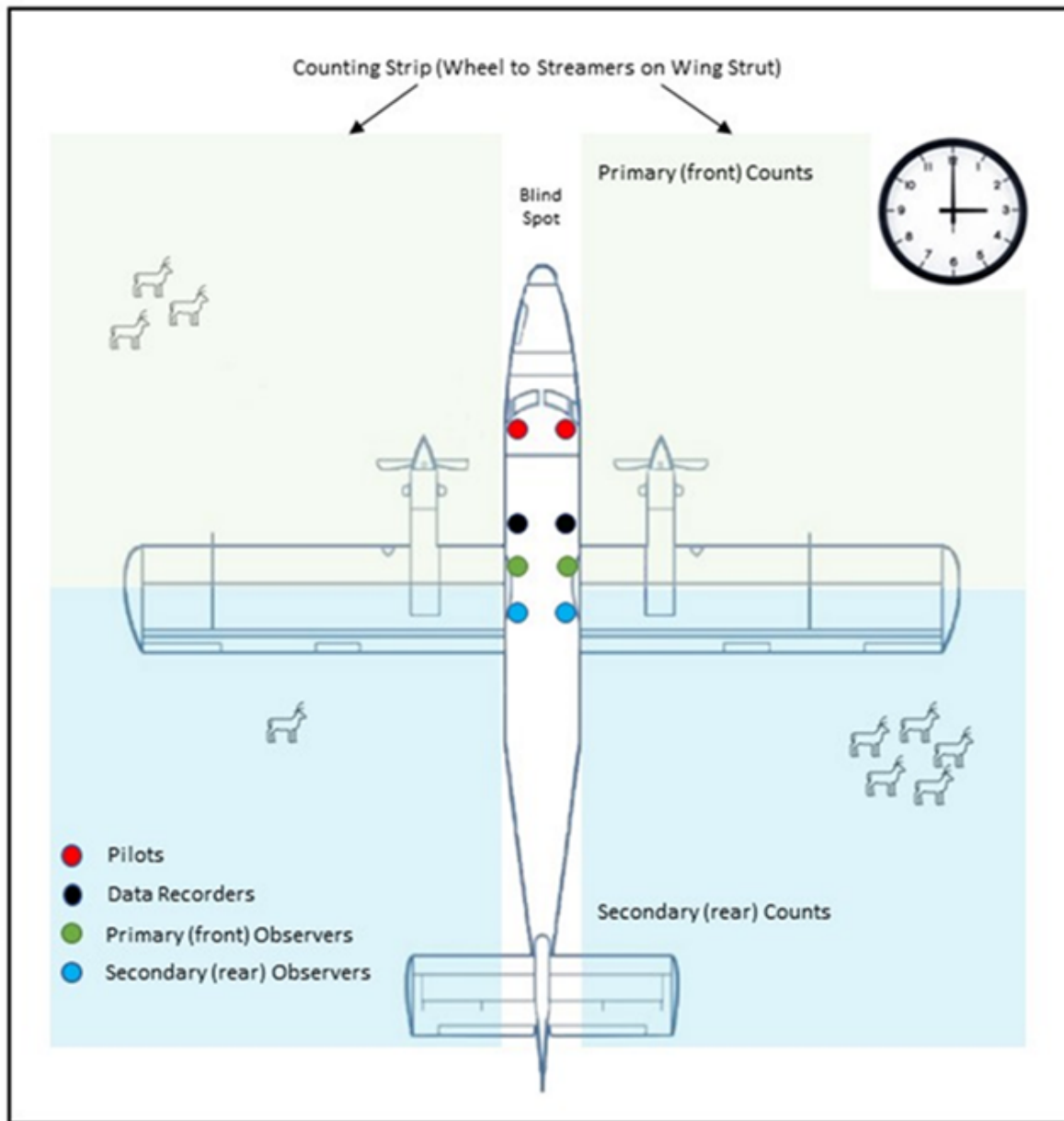


Figure 7. Observer position for double observer methods. The secondary observer calls caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock is used to reference relative locations of caribou groups (eg. “Caribou group at 1 o’clock”).



Figure 8. A Samsung S22 smartphone mounted on the window on the right side of the data recorder's seat (Right), and the camera's view of the ground and strut from this same position (left).



Figure 9. Screen shot from videos used for secondary counts of caribou (note caribou within both video frames). Excellent sightability conditions are evident with clear skies and no snow cover.

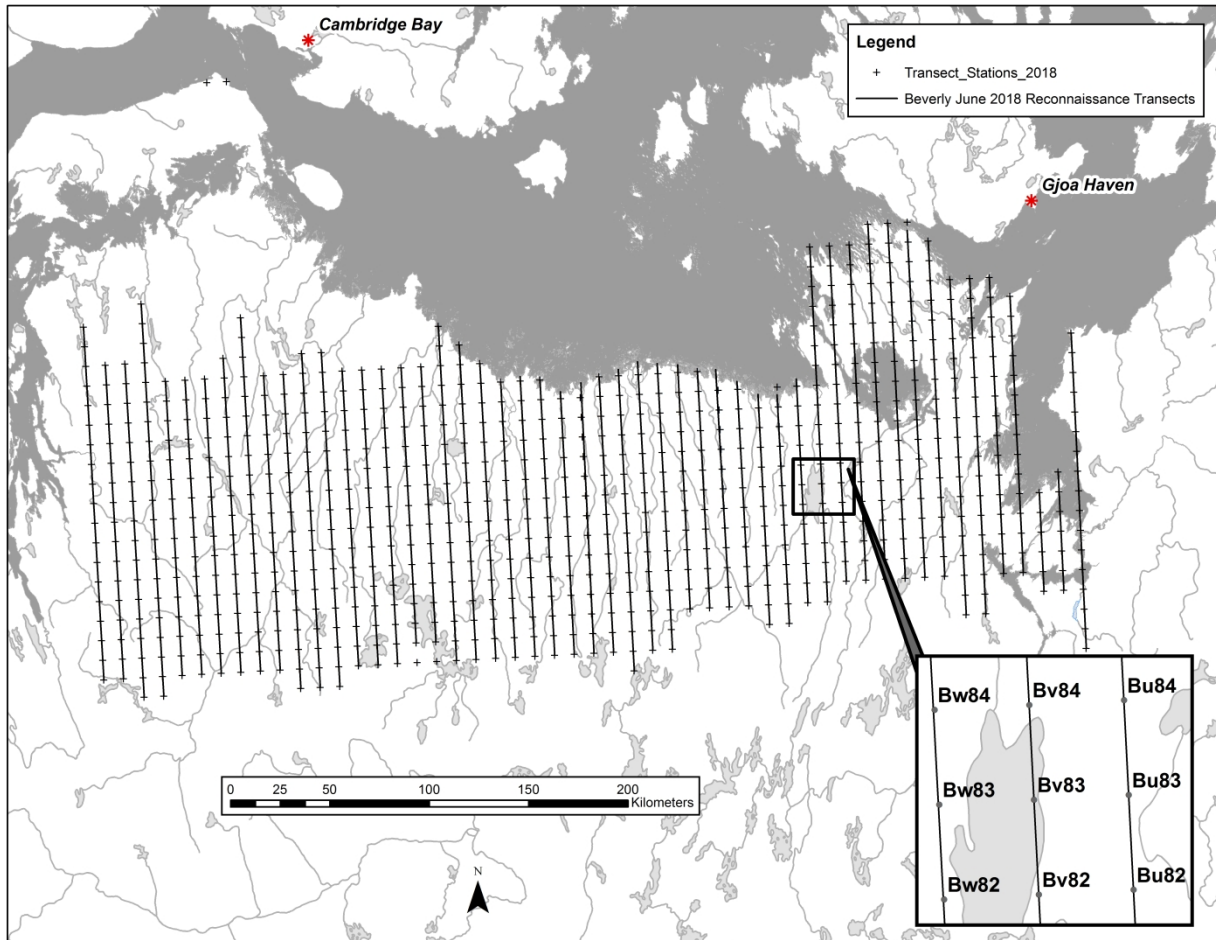


Figure 10. Reconnaissance transects and transect stations of the Beverly 2023 calving ground abundance survey. Transects placed to cover the known extents of female caribou based on real-time observations of the Beverly subpopulation of barren ground caribou.

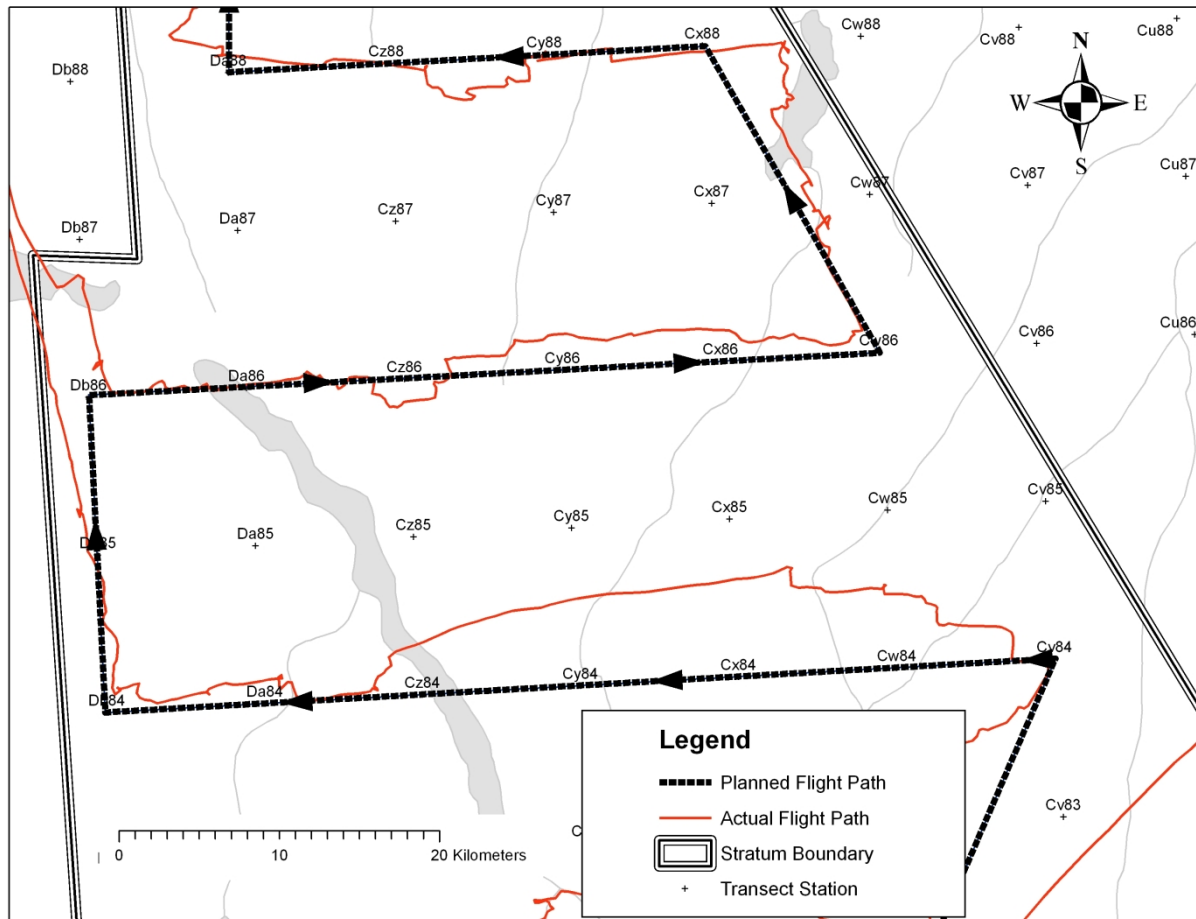


Figure 7. Stratum composition flight methods used during the 2023 Beverly calving ground survey vs. planned routes. Actual track deviations (red line) away from planned routes (black lines) were required to classify all observed caribou groups. The next nearest group would be classified up to a maximum of 5 km perpendicular to the planned route (half way between transect stations).

3.2 SURVEY ANALYSIS

3.2.1 Video Interpretation and Analysis

Transect videos were converted to orthomosaic images using a process that extracted overlapping video frames that were then imported into Agisoft Metashape for photogrammetric processing. These orthomosaic's were generated without georeferencing information due to the data capture method so manually georeferencing was achieved using landscape features from basemap imagery, and an approximate location from the video capture time and aircraft GPS data. The orthomosaic's and videos were then reviewed by interpreters in tandem to locate caribou resulting in the point dataset with a waypoint for each counted caribou. Due to the low resolution of the video, one of the key ways interpreters increased their confidence in identifying caribou was through observing movement in the video and identifying the same suspected caribou point in the orthomosaic. One challenge was that the video cameras mounted in the survey aircraft windows were not stabilized with a fixed field of view and as a result, the orthomosaic was influenced by the aircraft pitch, roll, and other movements, unlike a human observer that can compensate on the fly for these three-dimensional movements and maintain a relatively geographically stable observation strip in their mind. As a result, it was possible that some caribou waypointed on videos occurred outside of the actual 400m survey strip. For this reason, a 400m survey strip was overlaid on the orthomosaic to account for potential caribou counted on videos outside the survey strip. Both the left and right side 400m survey strips included a 182-meter blind spot under the survey plane. A tally of

caribou counted within and outside the survey strip was then calculated for each orthomosaic (**Figure 12**).

An additional challenge with comparison and reconciliation of visual and video counts was that developed polygons often spanned many visual observations which precluded exact matching of visual observations with counts on each orthomosaic. Orthomosaic's often did not overlap the actual transect line due to the blindspot under the survey plane. Therefore, waypoints of visual observations did not occur in the ortho polygon. In addition, it was likely there was a time lag between the time an observation occurred and the time it was entered in the tablet by the data recorder leading to some visual waypoints occurring past end of an orthomosaic. To confront this uncertainty, the distance from each tablet waypoint to the nearest orthomosaic (on the same side of the plane of the waypoint) was estimated. Tablet waypoints were then paired with orthomosaic's based on a series of threshold distances of the waypoint from the polygon ranging from 200 to 1500 meters. Sensitivity analyses were then conducted to assess the optimal cutoff threshold.

Once an appropriate distance threshold was determined, transect counts were tallied for each survey line using counts within each orthomosaic, and visual counts that were outside the orthophotos. The resulting counts for each line were then used to estimate abundance for the video/photo strata. The proportion of counts from photos and visual observations, were also tallied for each line to assess the proportion of caribou on the line that were counted in the photos versus visual counts. It was not possible to apply double observer methods to lines that had both visual and photo counts. For these strata, the Jolly strip transect estimator was applied (Krebs 1998).

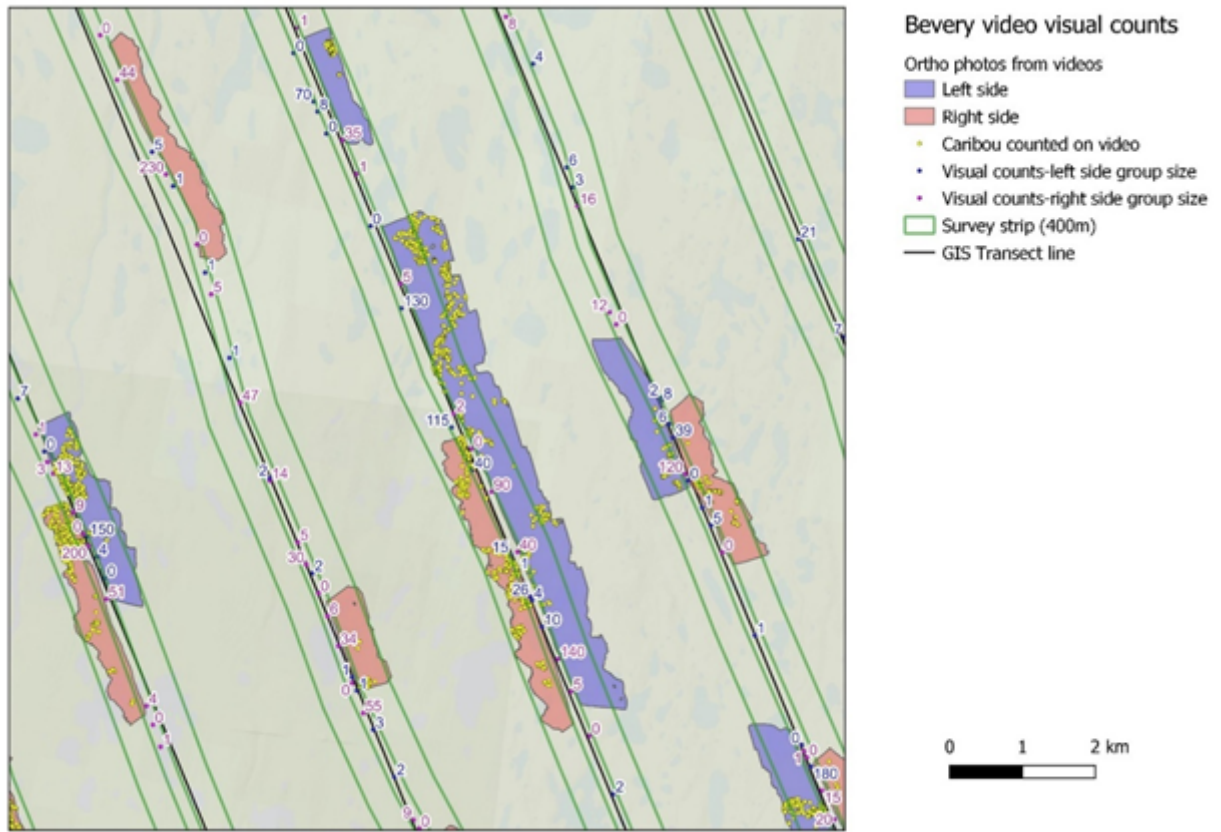


Figure 12. Example of orthomosaic polygons compared to visual observations. The 400m survey strip is outlined in green. The count of caribou groups from the survey plane is labelled next to each waypoint with caribou counted on orthophotos delineated by yellow points.

3.4 ANALYSIS OF ABUNDANCE

Estimates of herd size and associated variance were developed using the mark-recapture distance sampling (MRDS) package (Laake et al. 2012) in program R program (R Development Core Team 2009). In MRDS, a full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, Laake et al. 2008b) was used therefore making it possible to derive double observer strip transect estimates. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002). Estimates from MRDS were cross checked with strip transect estimates (that assume sightability=1) using the formulas of Jolly (1969)(Krebs 1998). Data was explored graphically using the ggplot2 (Wickham 2009) R package and QGIS software (QGIS Foundation 2020).

3.4.1 Modelling of Sighting Probability Variation

One assumption of the double observer method is that each caribou group observed had an equal probability of being sighted. To account for differences in sightability we also considered the following sightability covariates in the MRDS analysis (**Table 2**). Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. Previous analyses (Campbell et al. 2012, Boulanger et al. 2014, Campbell et al., 2020) 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 2**). Changes in cloud and snow cover were recorded

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 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.

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

Covariate	Acronym	Description
observer pair	observers	each unique observer pair
group size	size Log(size)	size of caribou group observed Natural log of group size
snow cover	snowcat snow	snow cover (0,25,75,100) continuous
cloud cover	cloudcat cloud	cloud cover (0,10,25,75,100) continuous

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 (involving the fewest assumptions), 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.

3.4.2 Estimates of Breeding Females, Adult Females, and Adults on the Calving-Ground

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, bulls, and adults was estimated for each stratum surveyed on the calving ground. Bootstrap methods were used to obtain variance estimates. In this case, 1,000 resamplings of the data were generated, and the mean and standard deviation from resampling were used, as point estimates for the proportion of breeders, and the associated standard error (Manly 1997).

Estimates of proportions of each target group (breeding females, adult females, and bulls) were then multiplied by the visual estimate of all caribou for each stratum to obtain an estimate of the abundance of the given target group. 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).

3.4.3 Analysis of Fall Composition Data

Composition surveys were conducted in the fall of 2022 by the Government of the Northwest Territories. These surveys were used to determine bull-cow ratios and the proportion adult cows, needed for extrapolated whole-herd 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, 1,000 bootstrap resamplings were conducted on the original data set (Manly 1997).

3.4.4 Estimation of Herd Size

Total herd size (adults at least two years old) was estimated by using a recent estimate of the bull:cow ratio from a fall composition survey survey conducted in October 2022 (Adamczewski et al. 2023b) to extrapolate or “add on” the bulls to the estimate of adult females (Adamczewski et al. 2017). This method of extrapolation was first used in the 2014 Qamanirjuaq caribou herd survey (Campbell et al. 2016), and has been used in other recent calving photo surveys for the Bluenose-East and Bathurst herds (Adamczewski et al. 2022, Boulanger et al. 2022). This estimator uses the estimate of total adult females divided by the proportion of adult females in the herd (sex ratio) from one or more fall composition surveys. This accounts for the bulls in the herd, very few of which are on the calving grounds in June. It makes no assumption about the pregnancy rate of the females and does not include the yearlings.

An alternative herd size estimate was also derived by adding the estimate of adult cows and bulls in the survey strata. This estimate assumes that the majority of bulls occurred on the surveys strata and that all bulls were from the Beverly herd. This assumption was investigated by comparing the locations of collared bulls known to be Beverly (from previous years and seasons) during the calving ground survey (mid-June), post-calving (mid-July) and during the rut (mid-October). The question of interest was how locations of bulls compared on the calving ground versus mid-July when herds are more commonly segregated, and the rut when composition surveys occur, when the herds are the least segregated (to obtain bull-cow ratios for extrapolated estimates). This analysis was done in collaboration with Jan Adamczewski and Judy Williams (Environment and Natural Resources, Government of Northwest Territories) using the ENR database of bull records (Adamczewski et al. 2020, Adamczewski et al. 2023b).

3.5 COLLAR ANALYSIS

3.5.1 Movement Between Calving-Grounds

Further analyses were conducted to assess overall movements of caribou between the Bathurst, Beverly, Ahiak, Lorillard, and Wager Bay herds to assist in interpretation of estimates. For this analysis, the June location of collared females was classified based on calving ground location. Using this information, movements between calving grounds as well as fidelity to the same, were assessed graphically. Multi-state models (Hestbeck et al. 1991, Brownie et al. 1993) in program MARK

(White and Burnham 1999) were then used to estimate movement (transition probabilities) between calving ground areas for females that were monitored for more than one calving season.

3.5.2 Survival Rate Analysis

Collar data for female caribou 2011-2023 were compiled for the Beverly caribou herd by GNWT Environment and Natural Resources staff. Fates of collared caribou were determined by assessment of movement of collared caribou, with mortality being assigned to collared caribou based on lack of collar movement that could not be explained by collar failure or device drop-off. The data were then summarized by month as live or dead caribou. Caribou whose collars failed or were scheduled to drop off were censored from the analysis. Data were grouped by “caribou years” that began during calving of each year (June) and ended during the spring migration (May). The Kaplan-Meier method was used to estimate survival rates, accounting for the staggered entry and censoring of individuals in the data set (Pollock et al. 1989). This approach also ensured that there was no covariance between survival estimates for the subsequent demographic model analysis.

3.5 INTEGRATED POPULATION MODEL ANALYSIS

The most direct measure that indicates the status of breeding females is their survival rate, which is the proportion of breeding females that survive from one year to the next. This metric, along with productivity

(recruitment of yearlings to adult breeding females) determines the overall population trend. For example, if breeding female survival is high then productivity in previous years can be relatively low and the overall trend in breeding females can be stable. Alternatively, if productivity is consistently high, then some reductions in adult survival rate can be tolerated. The interaction of these various indicators can be difficult to interpret. A population model can help increase our understanding of these various indicators and in turn, of herd demography.

We used a Bayesian state space Integrated Population Model (IPM) (Buckland et al. 2004; Kery and Schaub, 2012; Schaub and Kery, 2022) based upon the original (OLS) model (White and Lubow, 2002) developed for the Bathurst herd (Boulanger et al. 2011) to further explore demographic trends for the Beverly herd. A state space model is basically a model that allows separate modelling of field sampling estimates and demographic processes. This work was in collaboration with a Bayesian statistician/modeller (Joe Thorley-Poisson Consulting) (Thorley 2017; Ramey et al., 2018; Thorley and Boulanger, 2019).

We used adult female estimates, as well as calf-cow ratios, bull-cow ratios, estimates of the proportion of breeding females on the calving ground, and adult female and bull survival rates from collared caribou to estimate the most likely adult female survival values that would result in the observed trends in all of the demographic indicators for the Beverly herd. Calf cow ratios were recorded during fall (late October) and spring (late March to April) composition surveys whereas the proportion of breeding females was measured during composition surveys conducted on the calving ground. Breeding female proportions were estimated as the ratio of breeding females to adult females from each calving ground survey used in the analysis.

The Bayesian IPM model is a stage based model that divides caribou into 3 age-classes, with survival rates determining the proportion of each age class that makes it into the next age class (**Figure 13**); this structure is identical to the OLS modeling done previously on the Bathurst and Bluenose-East herds (Boullanger et al. 2019). We note that the underlying demographic model used for the Bayesian state space model is identical to the previous OLS model. However, the Bayesian IPM method provides a much more flexible and robust method to estimate demographic parameters that takes into account process and observer error. One of the biggest differences is the use of random effects modelling to model temporal variation in demographic parameters. For random effects models, it is assumed that there is a central mean value for a parameter (ie. Cow survival) with a distribution of values created over time based on temporal variation. This contrasts with the OLS method where temporal variation was often not modelled or modelled with polynomial terms which assumed an underlying directional change over time.

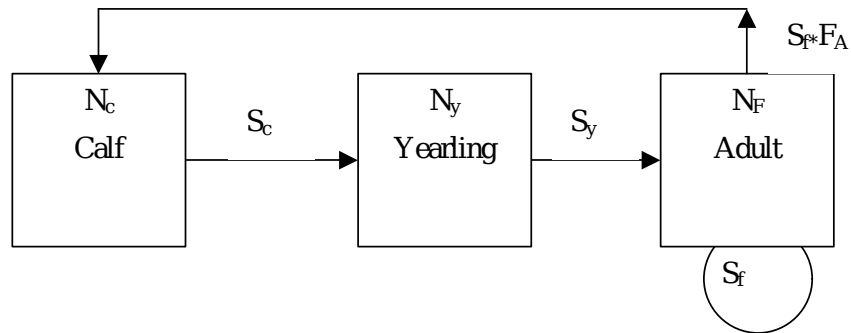


Figure 13. Underlying stage matrix life history diagram for the caribou demographic model used for Bluenose-East and Bathurst caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates of calves (S_c), yearlings (S_y) and adult females (S_f). Adult females reproduce dependent on fecundity (F_A) and whether a pregnant female survives to produce a calf (S_f). The male life history diagram was similar with no reproductive nodes.

3.6 ESTIMATES OF BREEDING FEMALES, ADULT FEMALES, AND ADULTS.

We used bootstrap methods to obtain variance estimates of composition proportions for all abundance strata. Additionally, we used the bootstrapped mean and standard deviation as point estimates, and associated standard error of the proportion of breeders and females (Manly 1997).

Variances for composition survey's and abundance estimates for each strata 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). Estimates of the proportion of breeding females were then multiplied by the double-observer estimate of all adult caribou and yearlings for each stratum to obtain an estimate of the number of breeding females. Variances were obtained for the combined estimate using the delta method (Seber 1982; Williams et al. 2002), again, assuming that there is no correlation between the two estimates.

3.7 AERIAL WILDLIFE SURVEY-OBSERVATION COLLECTOR (AWS-OC).

To increase data entry speed without reducing accuracy, and to reduce the time required to perform preliminary analysis of reconnaissance data for abundance stratification, a digital data entry system, termed the “Aerial Wildlife Survey - Observation Collector” (AWS-OC), was developed and utilized for this survey. The software was originally developed by the Government of Nunavut, Wildlife Research Division, in collaboration with Integrated Ecological Research, Caslys Consulting Ltd, and Nunavut Tunngavik Inc (NTI), in 2011, and originally deployed on the June 2011 Beverly mainland migratory barren-ground caribou calving ground abundance survey (Campbell et al. 2012). Since its original launch, improved hardware, and some enhancements to the AWS-OC software had been undertaken prior to its deployment in June 2018 (Boulanger et al. 2018).

The AWS-OC software operates with Windows editions 7 through 10 and was developed specifically for use in both independent and dependent double-observer pair aerial caribou surveys, including distance-sampling applications, to facilitate the collection of field data, and the subsequent management of the resultant observation dataset. This tablet-based system allows for the instantaneous entering of caribou group waypoints (observations) directly into a digital database. Data entry time was cut by approximately 50% over standard hand written datasheets, with the added benefits of continuous back up onto a USB drive into a digital database with no additional data entry required. The application includes two modules:

1- The **AWS-OC Field Collection Module** is designed for



collecting observation data while airborne. The application is spatially enabled to connect with a Global Positioning System (GPS), and displays the current location on maps that are compatible with ESRI's ArcGIS software. Minimal training is required to operate the system;

2- The **AWS-OC Data Manager Module** is designed for use on the ground or in the office for data management and field planning tasks. Advanced user functionality is focused on tabular data accessible with MS Access database software and integration with ESRI ArcGIS.

The AWS-OC is designed for use on windows touch screen tablets and has been designed and tested to integrate with the internal (integrated) GPS signal of the Xplore (Motion) R12 touch screen tablet. Configuration still allows for external GPS connections if required. For added durability and stability in severe turbulence, the tablets have been equipped with solid-state hard drives. The tablets also included swappable batteries that allow for uninterrupted operation during a flight, and USB ports to allow for data transfer following field collection. Additional equipment and tools that complete the AWS-OC field kit include a spare battery to provide added insurance for power supply for a full day of fieldwork, USB flash memory stick, and two software utility applications to merge text files and merge shapefiles to assist with data management tasks.

The data entry page of the *Survey Session Details* form (**Figure 14**) allows the entry of common details (i.e., unique aircraft ID, crew assignments, and appropriate transect file, which enables the auto-completion of transect details based on the GPS signal). Additionally, the software automatically records altitude, ground speed. Input fields for the entry of co-variate data such as cloud cover, snow cover,

alternate species, and habitat type are also provided.

Figure 8. The data entry screens of the AWS-OC tablet interface used during the June 2018 Beverly mainland migratory barren-ground caribou abundance survey. Screen shots include the Survey Session Details (Top), and Primary Data Collection display (Bottom).

4.0 RESULTS & DISCUSSION.

Full results and discussion have yet to be finalized due to ongoing analysis. Final Government of Nunavut File Report will be provided upon completion of analysis.

The geographic distribution of calving caribou observed during the June 2023 Beverly calving-ground abundance survey were atypical when compared to June reconnaissance and abundance surveys flown between 2008 and 2018. Between June 2008 and 2018, caribou cows had arrived onto the Queen Maud Gulf calving grounds, between the Ellice River east to McNaughton River near Adelaide Peninsula, in such a way as to occupy the areas extents at densities well within the ability of visual observers to accurately count, avoiding the need for more costly photographic methods (**Figure 15**). This, however, was not the case in June 2023. During the 2023 June survey effort, unseasonably high air temperatures and an associated early spring melt of the areas snow pack and river and lake ice covers, caused Rivers and creeks within the calving grounds to surge, creating high-water volumes that developed high and dangerous currents, causing rivers and creeks to overflow their banks. These high volumes of fast-moving water appeared to have created an effective barrier to the movement of migrating calving caribou onto their previously delineated annual core calving areas, with many caribou clumping up into high-density groups within the forks of surging creeks and rivers. This reduction in the spread of calving

caribou into their extended annual calving extents in June 2023 is also represented in the lower overall area of the known calving extents (an estimated 30% reduction) occupied by calving caribou when compared to June 2018 calving extents. This situation moderated on or about June 14th and 15th. As the Beverly abundance survey is set up as a visual survey, this clumping posed counting problems, whereby some groups were too large and dense to accurately count using visual methods alone. Though a photo plane was kept on standby for such events, the aircraft ended up being unavailable due to mechanical issues. With a reduction in river water levels as the survey progressed past the reconnaissance phase, and the possibility of the movement of calving caribou out of developed strata as water levels dropped, we were unable to wait for the mechanical issue to be resolved so proceeded with a video option to specifically assess the high-density clusters of caribou. The collection and counting of video data represented a novel approach, requiring the development of new spatial and quantitative methods to produce accurate counts.

The start of the reconnaissance survey was initially scheduled for June 6th but was postponed to June 8th due to low cloud and fog in the survey area over June 6th and 7th (**Table 3**). The earlier proposed start of the reconnaissance survey compared to the June 2011 and 2018 surveys is thought to have been a result of the earlier snowmelt in June 2023. The June 2023 calving grounds in the vicinity of the Armark River approximately 30 kilometers east of the Simpson River, within the center of the Beverly annual concentrated calving area, was relatively snow free in early June 2023 when compared to the same general area in mid-June 2011 (**Figure 16**).

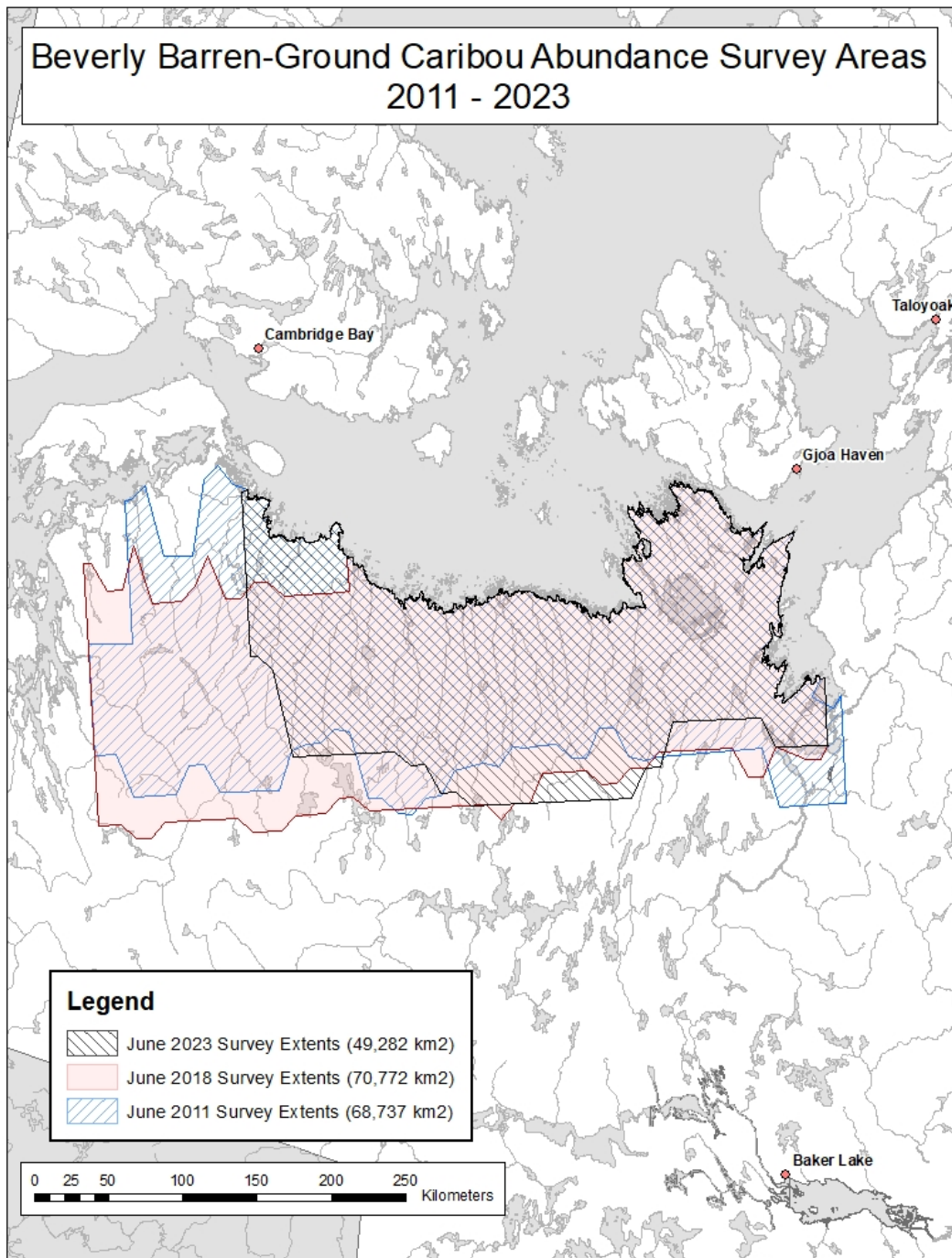


Figure 15. Beverly Herd Reconnaissance survey extents for the 2011, 2018, and 2023 Beverly Herd calving-ground surveys (June 2023 survey extents in black).

Table 3. A comparison between the June 2011, 2018, and 2023 Beverly mainland migratory caribou subpopulation abundance survey timing. Survey timing based on a reduction of daily movement rates below 5 km/day.

Survey Activity	Date (2011)																	
	Jun-04	Jun-05	Jun-06	Jun-07	Jun-08	Jun-09	Jun-10	Jun-11	Jun-12	Jun-13	Jun-14	Jun-15	Jun-16	Jun-17	Jun-18	Jun-19		
Systematic Reconnaissance						X	X	X	X		Ice Fog & Freezing Rain							
Abundance										X			X	X				
Composition													X	X	X	X		
Survey Activity	Date (2018)																	
	Jun-04	Jun-05	Jun-06	Jun-07	Jun-08	Jun-09	Jun-10	Jun-11	Jun-12	Jun-13	Jun-14	Jun-15	Jun-16	Jun-17	Jun-18	Jun-19		
Systematic Reconnaissance		Ice Fog & Freezing Rain			X	X	X	X	X									
Abundance										X	X	X	X					
Composition											X	X	X	X	X			
Survey Activity	Date (2023)																	
	Jun-04	Jun-05	Jun-06	Jun-07	Jun-08	Jun-09	Jun-10	Jun-11	Jun-12	Jun-13	Jun-14	Jun-15	Jun-16	Jun-17	Jun-18	Jun-19		
Systematic Reconnaissance			Ice Fog & Freezing Rain	Ice Fog & Freezing Rain	X	X	Ice Fog & Freezing Rain	X	X									
Abundance											X	X	X	X				
Composition													X	X	X			

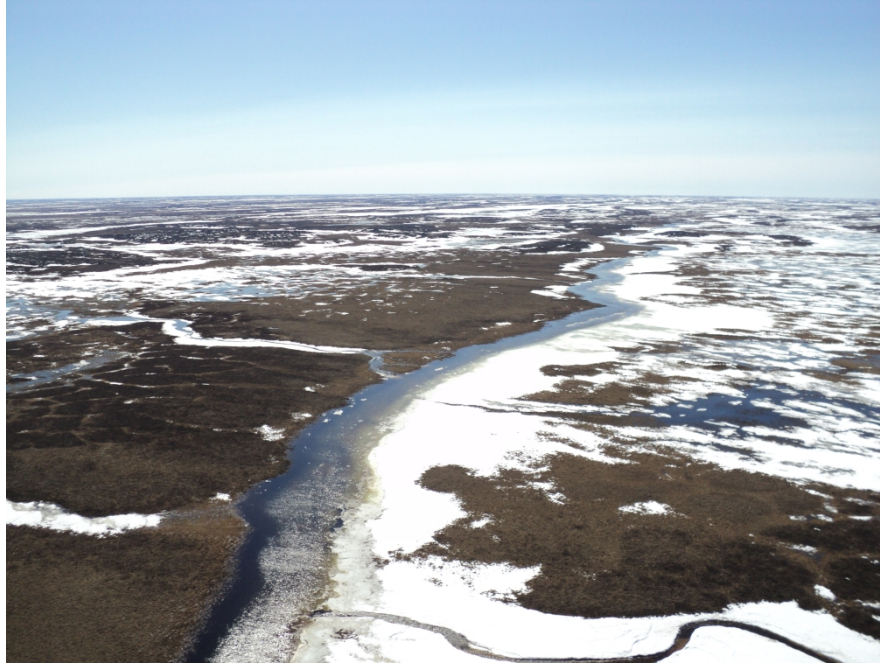


Figure 16. The Queen Maud Gulf Lowlands in the vicinity of Armark River June 12th, 2011 (Above), and in the same general vicinity June 8th, 2023 (Below).

4.1 RECONNAISSANCE SURVEY

Reconnaissance flights occurred from June 8th to June 12th 2023 at which time large aggregations of caribou were observed to the southwest of the Adelaide Peninsula. Recon crews observed high water levels and fast currents in the Simpson River and associated creeks and smaller rivers within the watershed, due to the late spring melt and early breakup. These high-water conditions appeared to create an effective barrier to migration of calving cows east of the Simpson River, funnelling them between large river systems and restricting movement into the more northern extents of their annual calving grounds (**Figure 17**). The reconnaissance data was then summarized by segment revealing many segments with high densities and 6 segments with extremely high densities (>50 caribou/km²) (**Figure 18**). Strata development was achieved by first overlaying strata boundaries over reconnaissance segment based relative densities, and secondarily by adjusting based on recon summary composition observations (**Figure 19**). Two strata (Very-high east and Very-high west) had segments with very-high densities over 50 caribou/km² with the majority of caribou being breeding females. Other strata, notably to the southwest, had high densities, however, the majority of caribou in these strata were bulls and non-breeding caribou (**Figure 20**). Remaining strata had medium to low densities of caribou and were delineated accordingly. Inspection of segment composition revealed that the very-high-density strata all contained breeding females with mixed breeding females and non-breeders in remaining medium and low-density strata.

Strata effort was defined based on survey logistics and relative densities of caribou within strata (**Table 4**). The total number of transect

kilometers was restricted to 5,000 kilometers (km) based on survey logistics. An additional constraint was ensuring that the very high-density strata could be flown in less than two survey days given the increasing risk of high level of movement based on the movements of collared caribou in the area. The highest effort (km) was given to the two very high-density strata which also had the highest concentration of breeding females. Effort to the remaining strata (that contained a lower proportion of breeding females) was set to coverage levels of approximately 15% to accommodate higher effort within the very high-density strata. Two additional Very Low-density strata based on reconnaissance flights were added for reference but were not reflown due to the lack of evidence of movement within these strata apparent from composition observations made concurrent with abundance survey observations. The final strata dimensions are shown in **Table 5**. The Very High-density east stratum was split into two strata to accommodate a change in aircraft navigation systems and revisions to the Very High-density east strata to ensure it could be flown in a single survey day.

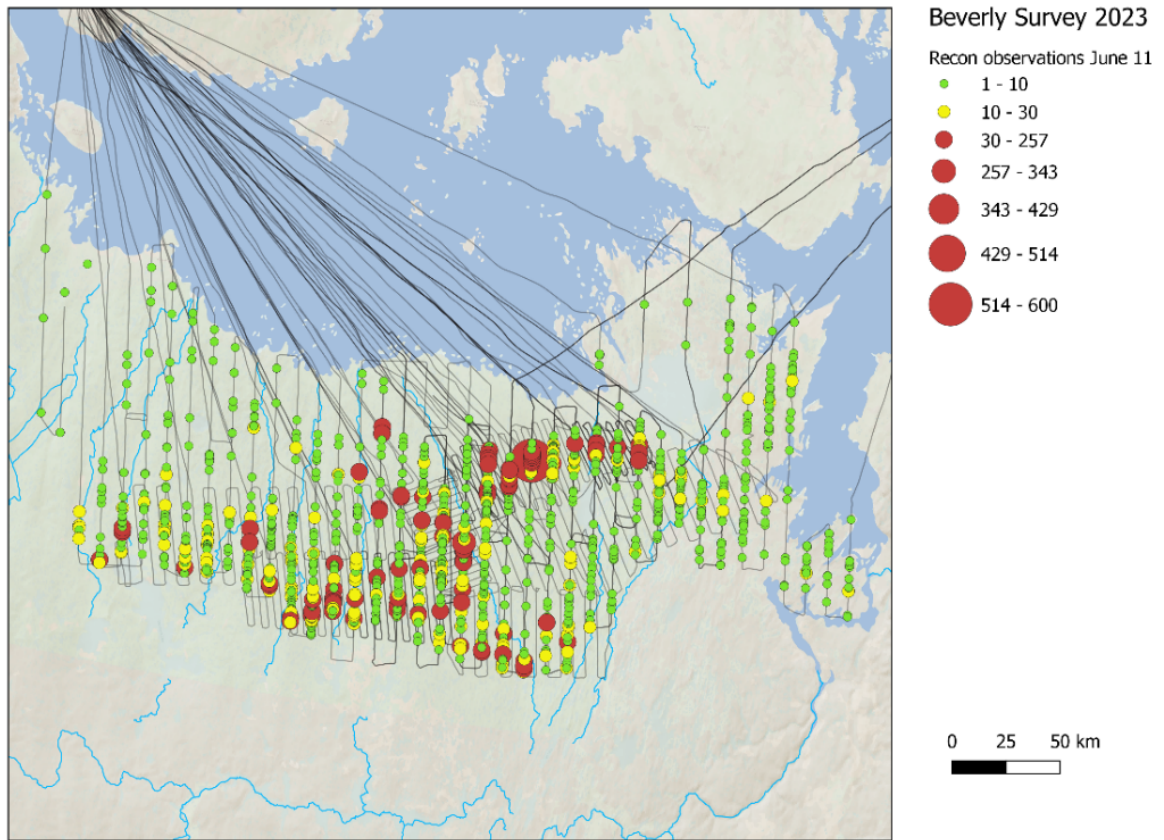


Figure 17 Flight lines and reconnaissance observations. Observations are color and size coded based on the number of caribou observed.

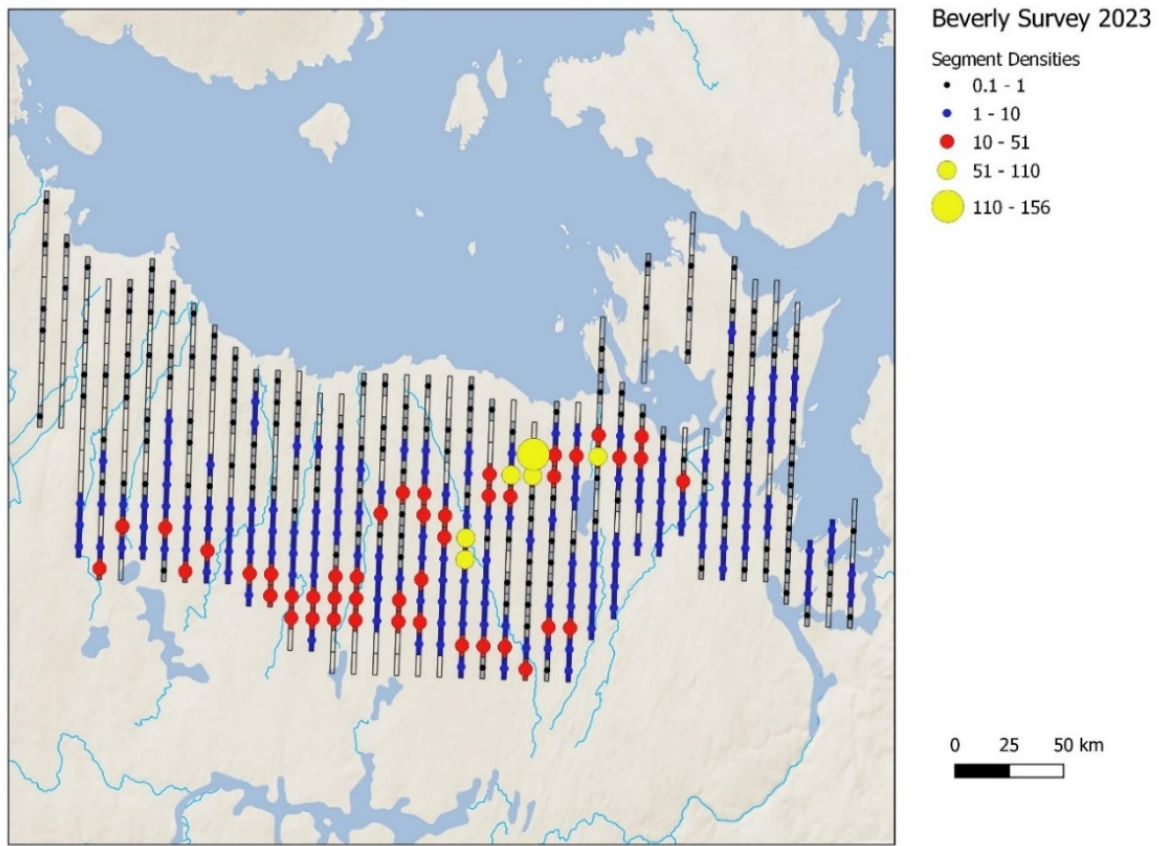


Figure 18. Summary of reconnaissance survey segments.

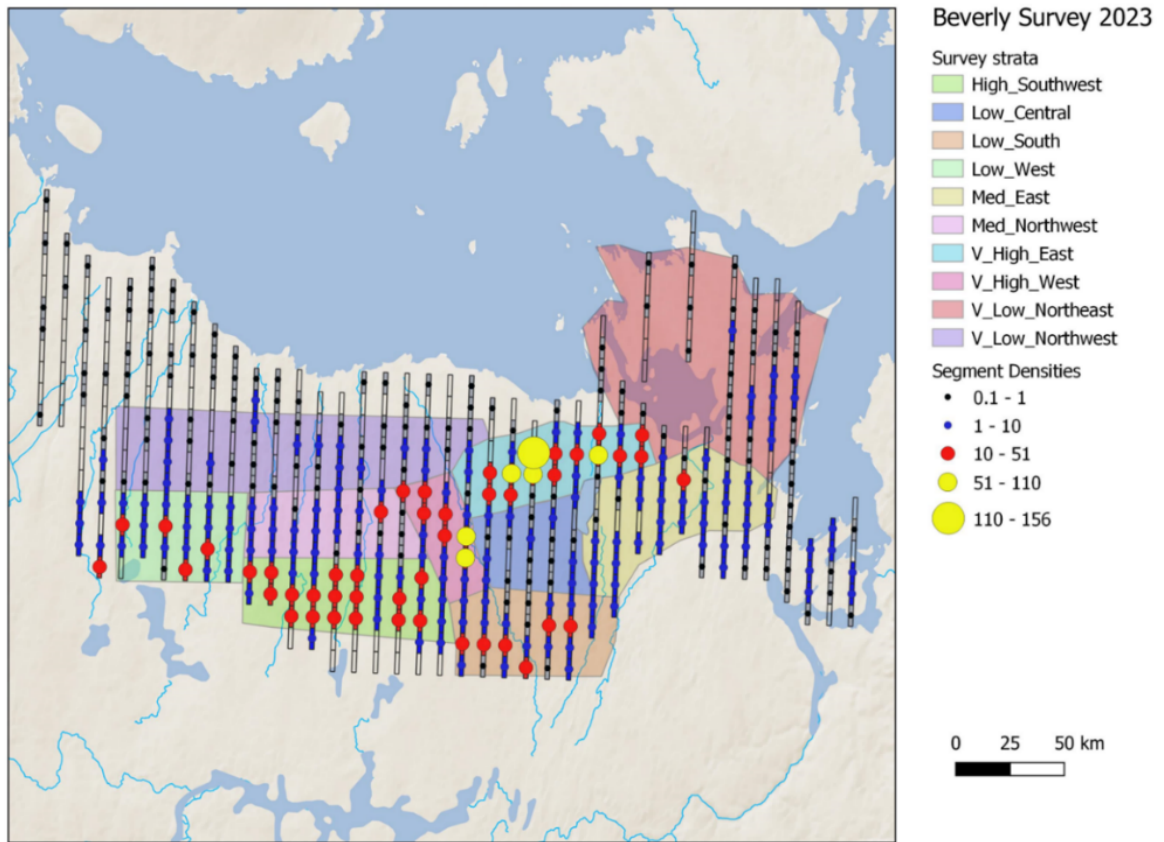


Figure 19. Summary of reconnaissance survey segment density with developed abundance strata overlaid.

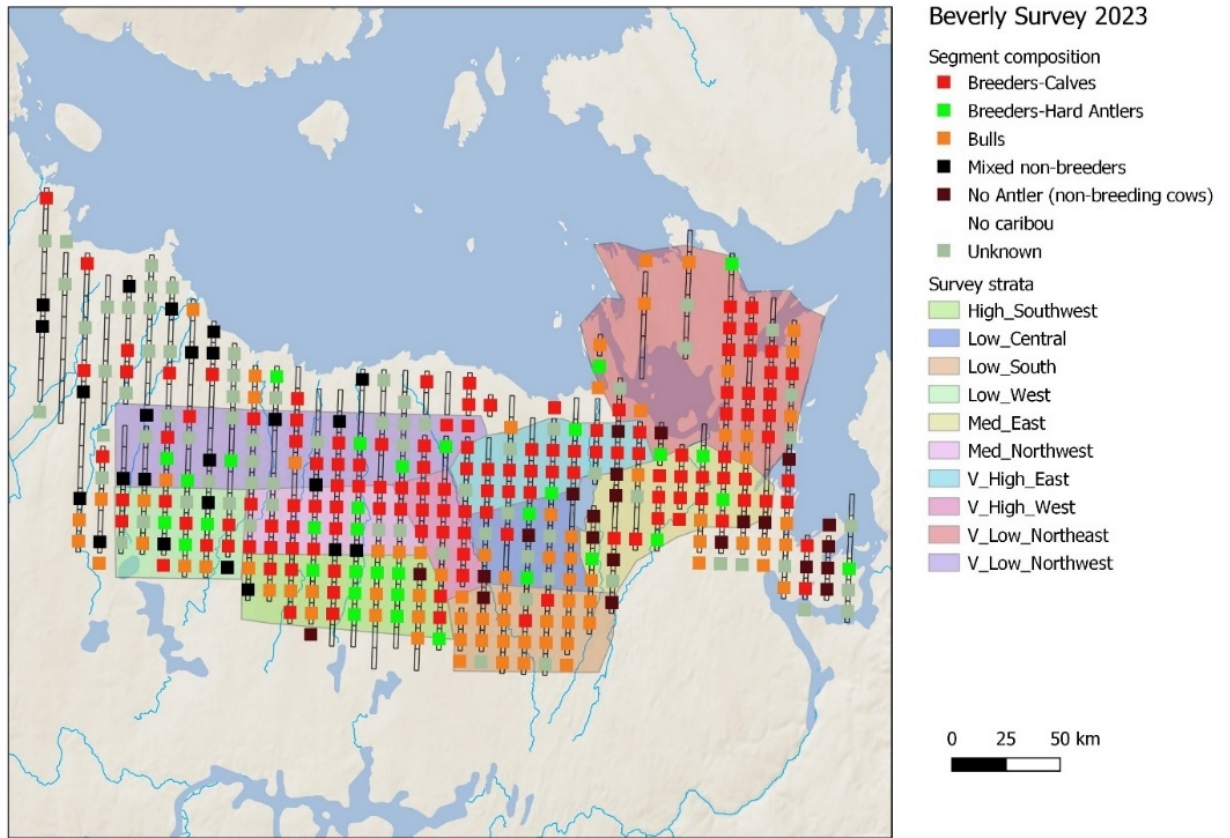


Figure 20. Summary of reconnaissance survey segment composition.

Table 4. Allocation of effort for strata. Allocation was based on Density/abundance or variation CV in density/abundance. Allocation lines were adjusted to ensure adequate coverage for all strata.

Strata	Dimensions		Recon Density		Allocation (transects)				
	baseline	Average Length	D	cv(D)	Using CV(D)	Using D	Adjusted	km	coverage
V_High_East	89	31.7	24.63	0.24	59	45	36	1066	0.30
V_High_West	57	24.0	20.17	0.35	25	27	19	439	0.25
High_Southwest	96	34.1	14.93	0.11	19	28	30	816	0.25
Med_East	82	42.1	2.48	0.22	5	4	18	639	0.15
Low_South	56	45.3	7.09	0.06	2	7	14	446	0.14
Med_Northwest	80	30.4	4.61	0.28	10	8	20	428	0.19
Low_Central	49	35.2	1.15	0.28	1	1	10	374	0.16
Low_West	60	42.0	5.58	0.15	5	6	12	468	0.15

Table 5. Strata dimensions for the June 2023 Beverly calving-ground survey.

Strata	Area (km²)	transects	Average transect width (wi)	Baseline length	Total transect km	Total area surveyed (km²)	Coverage
V_High_East1	1947.5	23	32.5	59.9	747.6	598.1	30.7%
V_High_East2	716.5	14	23.2	30.8	325.3	260.3	36.3%
V_High_West	1376.8	19	23.1	59.7	438.4	350.7	25.5%
High_Southwest	3236.7	30	33.5	96.7	1004.6	803.7	24.8%
Med_East	3416.9	18	35.5	96.2	639.5	511.6	15.0%
Low_South	2822.0	14	34.6	81.6	484.0	387.2	13.7%
Med_Northwest	2425.8	20	28.4	85.5	567.4	453.9	18.7%
Low_West	2487.6	12	38.6	64.4	463.4	370.7	14.9%
V_Low_Northwest	5595.5	17	34.1	164.1	579.7	463.7	8.3%
V_Low_Northeast	8245.1	11	75.7	108.9	832.7	666.2	8.1%
Low_Central	1885.5	10	37.3	50.5	373.1	298.5	15.8%

4.3 ABUNDANCE SURVEY

Visual surveys were conducted in a second “abundance survey” phase with the exception of all Very Low-density strata and the Low-density South stratum (**Figure 21**) which were based on original reconnaissance data (**Figure 20**). It can be seen that high densities occurred in the two Very high-density strata. A group of higher density caribou also occurred in the low-density central stratum, however, this group likely moved from the Very High-density east strata based on collar movements discussed later in this report.

4.3.1 Analysis of collar movements

Migration paths of collars reveal an eastern path for female caribou with most ending up in the two very high-density strata (**Figure 22**). In contrast to previous abundance surveys very little northern movement within the Beverly herds annual calving extents was observed in June 2023. Bulls mainly occurred in the southern strata. The monitoring of caribou movements onto the calving-ground suggests that there was no defined period of reduced movements in June 2023 that would typically indicate the peak of calving (**Figure 23**). There was a drop in movement rates from June 2nd to 6th which corresponded to the approximate time when some caribou arrived on the main calving ground, which may explain the reduction in movement rates. We suggest that calving cows were stopped at swollen rivers and creeks and/or were forced along swollen rivers until they could go no further, which could explain the atypical movement rates during calving and as a result, were likely not entirely representative of the peak of calving.

Median movement rate of caribou varied from 7 to 10 kilometers per day from June 12 to 15 when sampling was occurring. During this time movement in the high-density areas was within strata (**Figure 24**) with the exception of a burst of movement out of the High East strata into the Central Low on June 15 when this area was flown. For this reason, estimates from Central Low were not used in estimates of adult females due to likely double counting of caribou.

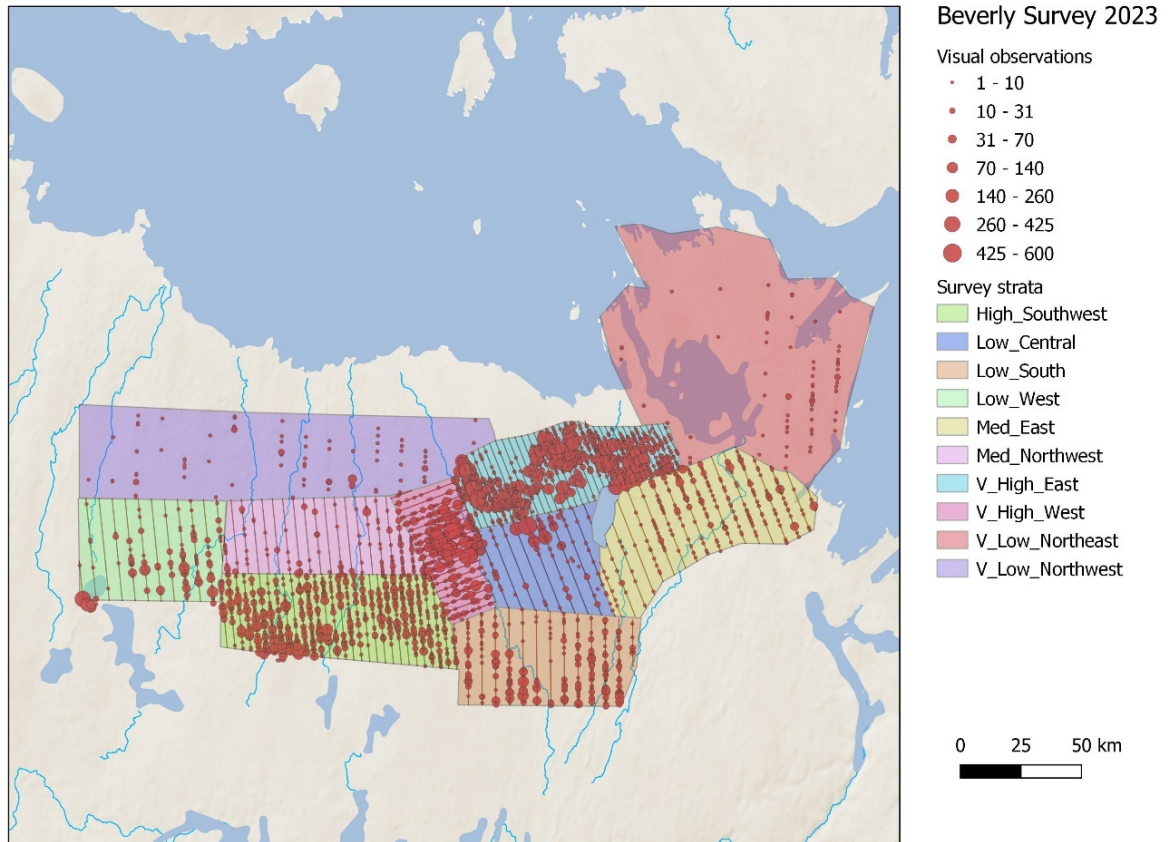


Figure 21. Visual survey transect lines and observations.

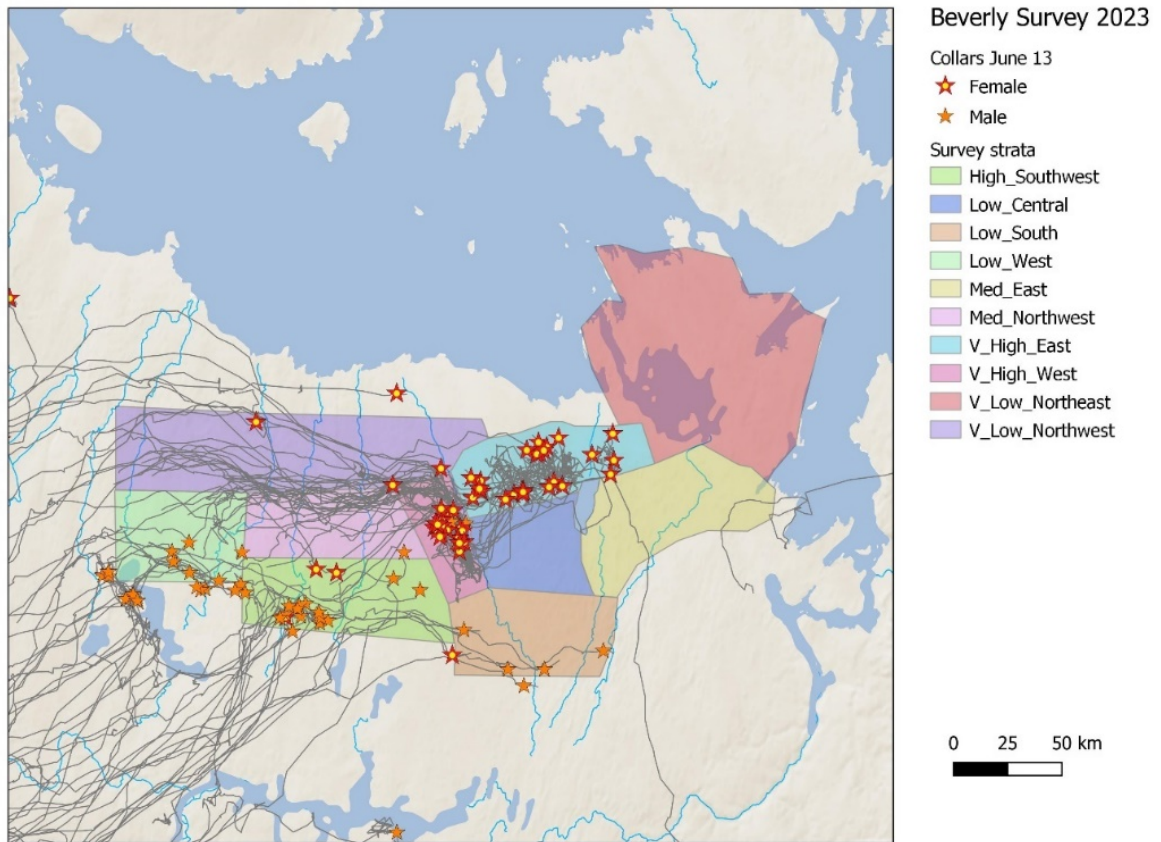


Figure 22. Collar migration paths up to June 13th when visual surveys occurred.

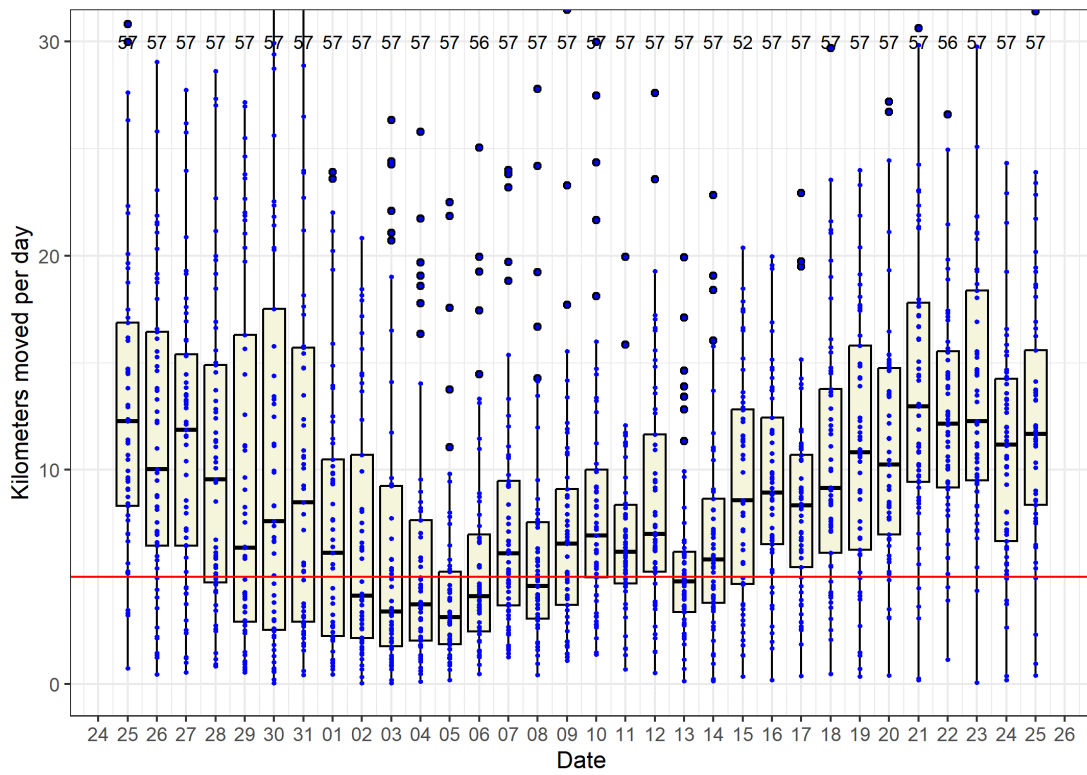


Figure 23. Movement rates of Beverly caribou during the survey.

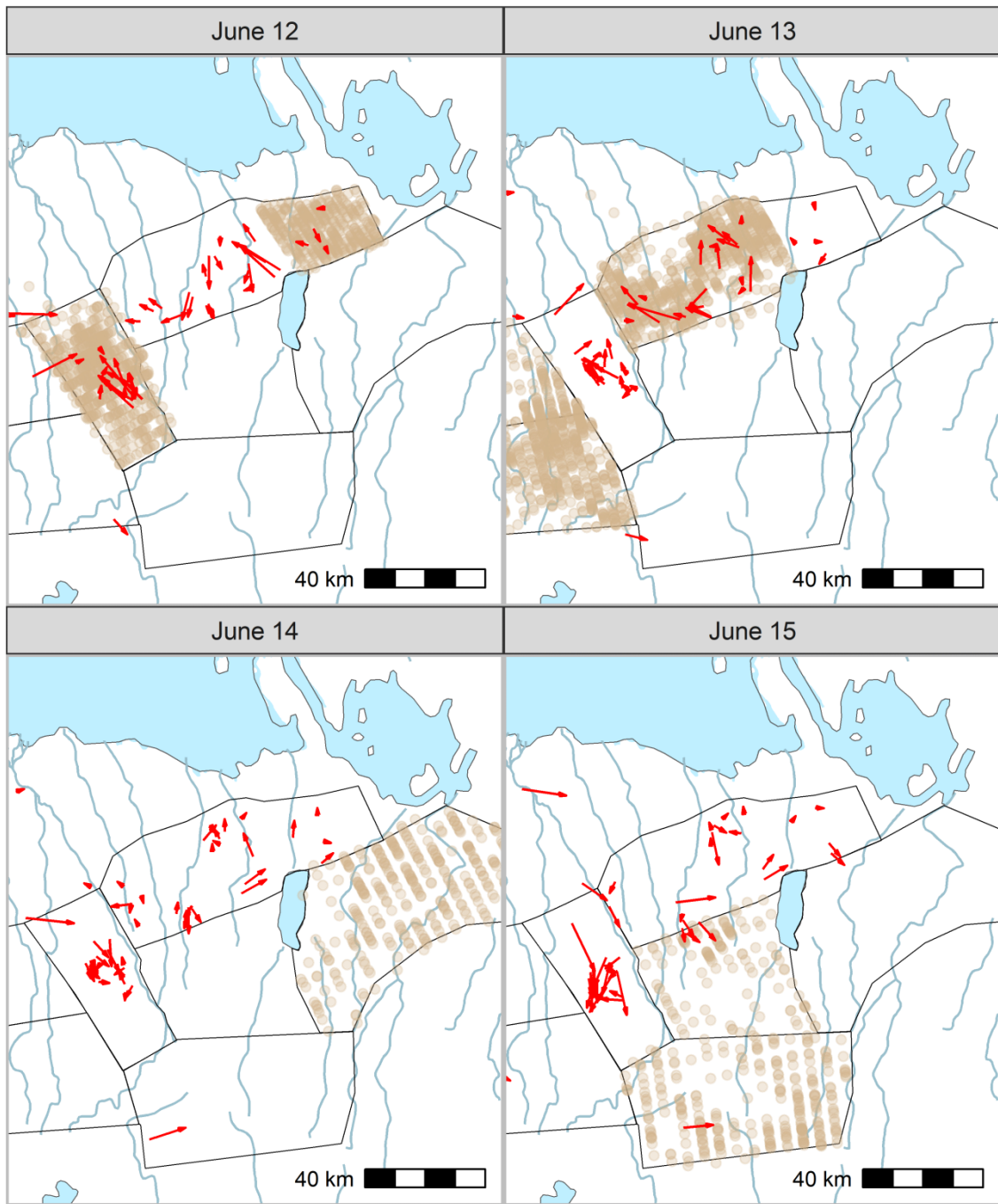


Figure 24. Directional daily movements of collared females relative to transects flown (brown circles) for the main days in which central high-density strata were flown. The direction of daily movement of caribou is indicated by arrows.

4.3.2 Video Assisted Counts in High-Density Strata

In total, 123 video/orthomosaic's of the three very high-density survey strata were taken during the survey (**Figure 25**). Of the 125 orthomosaics, 61, 18, and 44 occurring in the Very-high-density-east-1 (VHDE-1), Very-high-density-east-2 (VHDE-2), and Very-high-density-west strata respectively (VHDW). Comparison of visual observation group sizes and ortho-photo locations suggests that in excess of 98% of the larger groups seen on transect were within the orthomosaic's.

During the review of visual and video caribou counts, waypoints from visual observations were counted as the same caribou as orthophotos based on an assumed distance of the waypoints from the edge of the orthophotos. Reconciliation of orthophotos and visual observations was considered across a range of buffer distances. In general, the buffer distance did not affect the general relationship between visually counted, and caribou counted on photos (**Figure 26**). The difference in estimates between the two approaches varied by approximately (plus or minus) 5% across the range of buffer distances with visual counts increasing with increasing buffer distances. We chose a buffer distance of 1,000 meters which balanced inclusion and exclusion of visual counts from each of the orthophotos. At a survey speed of 160 kilometers per hour, 1,000 meters would represent approximately 20 seconds of time. Therefore, using 1,000-meter buffers assumes that recorders recorded observations within approximately 20 seconds of the end of the video recording. When 1,000 meters was used as the buffer distance the mean number of waypointed observations within a photo was 3.7 (SD = 2.7; min = 1, max = 16, n=121). The mean group size of caribou counted for each visual observation waypoint within the 1,000-meter buffer was 42.3 caribou (SD = 68.6; min = 1, max = 440, n = 450).

Caribou were counted on photos that were approximately within the 800-meter (400 meters per side) survey strip, however, pitch and movement of the plane affected the survey strip distance and thus the total area within photos within which caribou were counted. A comparison of visual and photocounts using all the caribou on the photos suggested that visual counts were slightly higher when total counts were less than 100 but then became less than photos counts as higher numbers (densities) of caribou were encountered (**Figure 27**). When the 400-meter strip width was imposed (for each of the left and right-hand sides of the aircraft) (**Figure 28**), visual counts were higher than photo counts up to counts of 400 caribou. This result suggests that an additional factor influencing visual counts was inclusion and exclusion of caribou within the survey strip, suggesting that visual observers had difficulty maintaining their outer strip boundaries when caribou numbers were high. This result makes intuitive sense when considering the increased work load of an observer when high numbers of caribou have to be counted causing less attention to be directed to strip boundaries. This finding could also be due to factors such as pitch of the plane, difficulties in discerning proportions of groups within the strip, and short-term observer fatigue. We also note that this comparison assumes that sightability of caribou on the photos was similar to visual observations from the plane. Using the 400-meter strip-corrected photo counts reduced the count of caribou by 4,353 (approximately 13% lower) compared to uncorrected visual counts.

Comparison of visual surveys in 2011, 2018, and 2023 reveals large differences in the contribution of different group sizes to overall caribou counts (**Figure 29**). In 2011 and 2018, the majority (>95%) of caribou counted were in relatively small group sizes (<30 caribou). In contrast, the majority (70%) of caribou counted in 2023 were larger groups (>30 caribou) illustrating the large difference in densities observed during the

2023 survey and the necessity to augment visual counts with photo-counts. By design the majority of larger group sizes occurred within video/orthomosaic polygons, meaning that the more accurate and precise video-based counts were used instead of visual counts for these observations and for the final estimates of abundance.

|

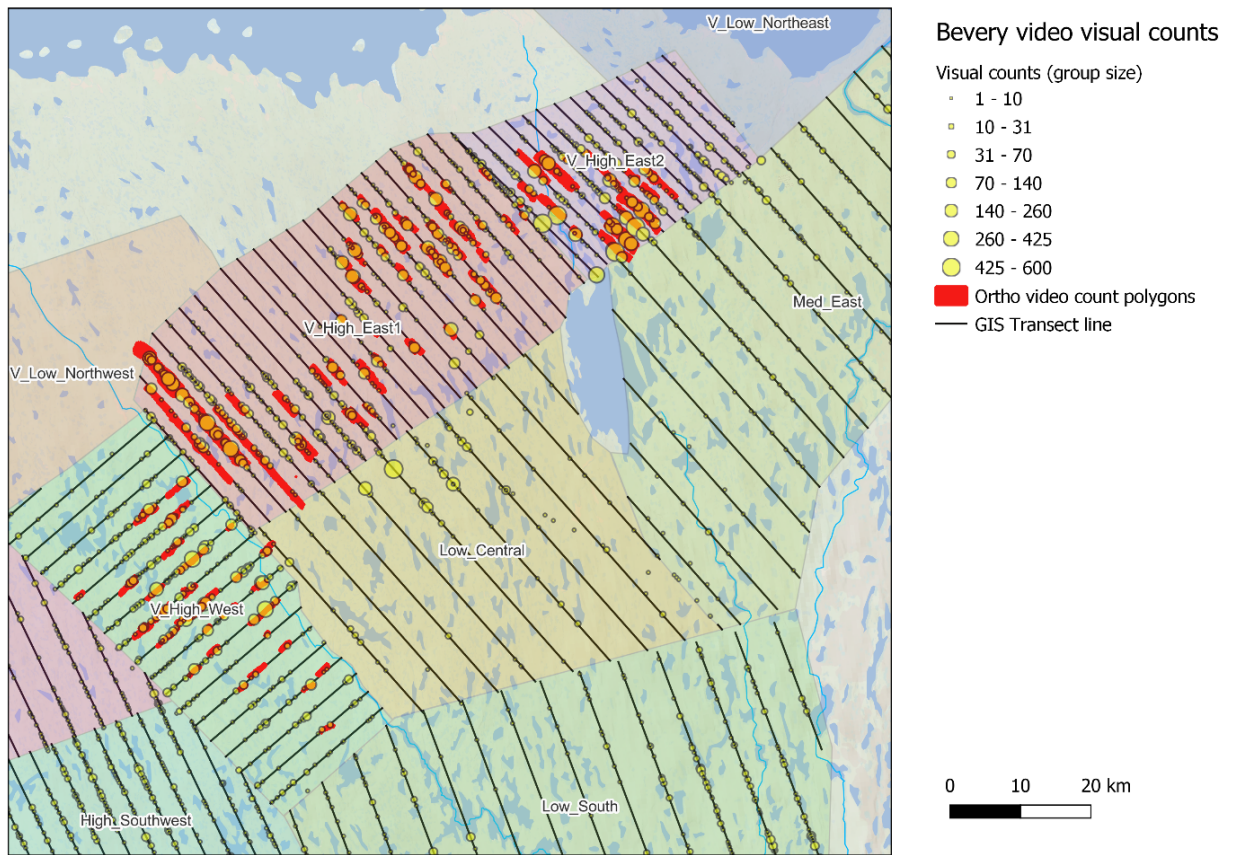


Figure 25. Coverage of ortho photos relative to visual observations in the Very-High-Density West and East strata.

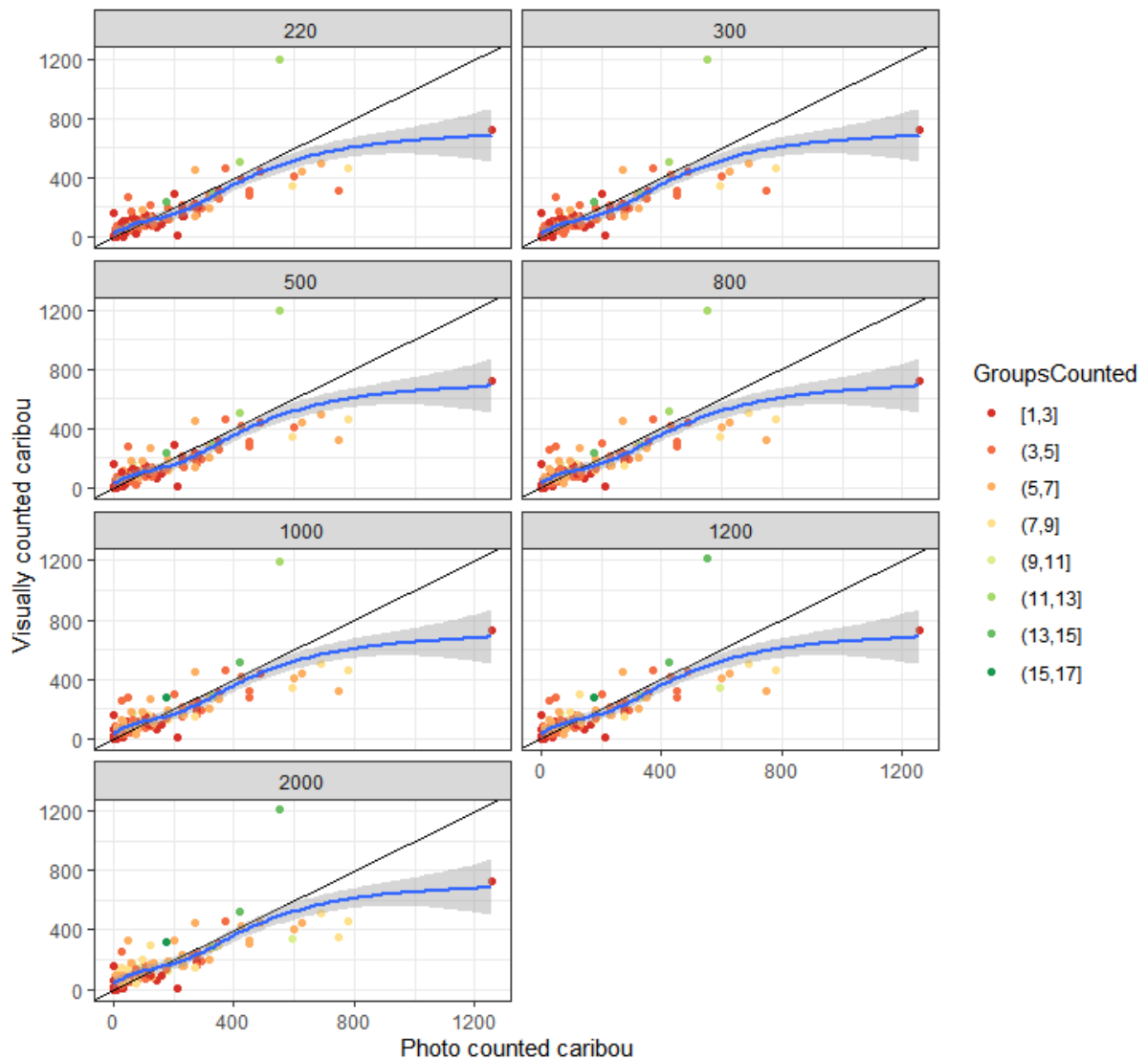


Figure 26. Relationship between visually counted caribou (assumed to be within the ortho photo video) and the number of caribou counted on each orthophoto. The number of visual group waypoints within each photo is also displayed by color of point.

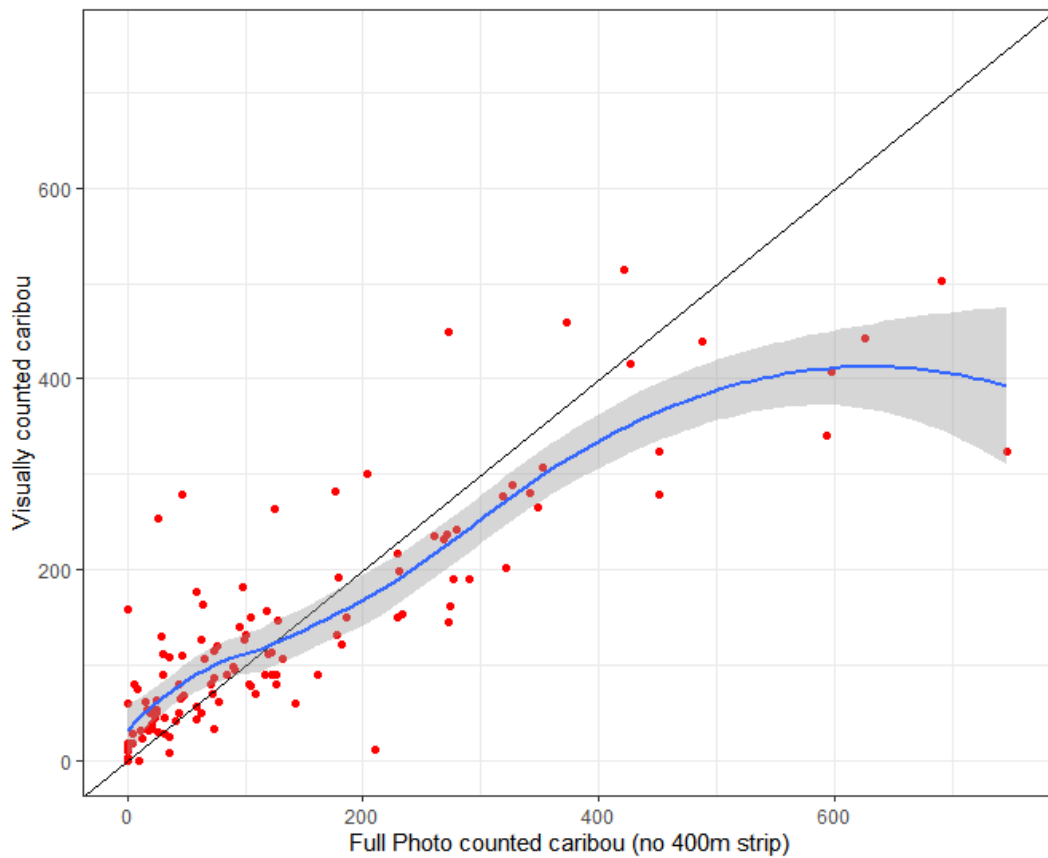


Figure 27. Relationship between caribou counted visually versus caribou counted on photos using all the caribou countable on photos with no strip width. A smoothed (blue line) is used to indicate dominant trends in the data set. Confidence limits are shown as shaded areas around the smoothed line.

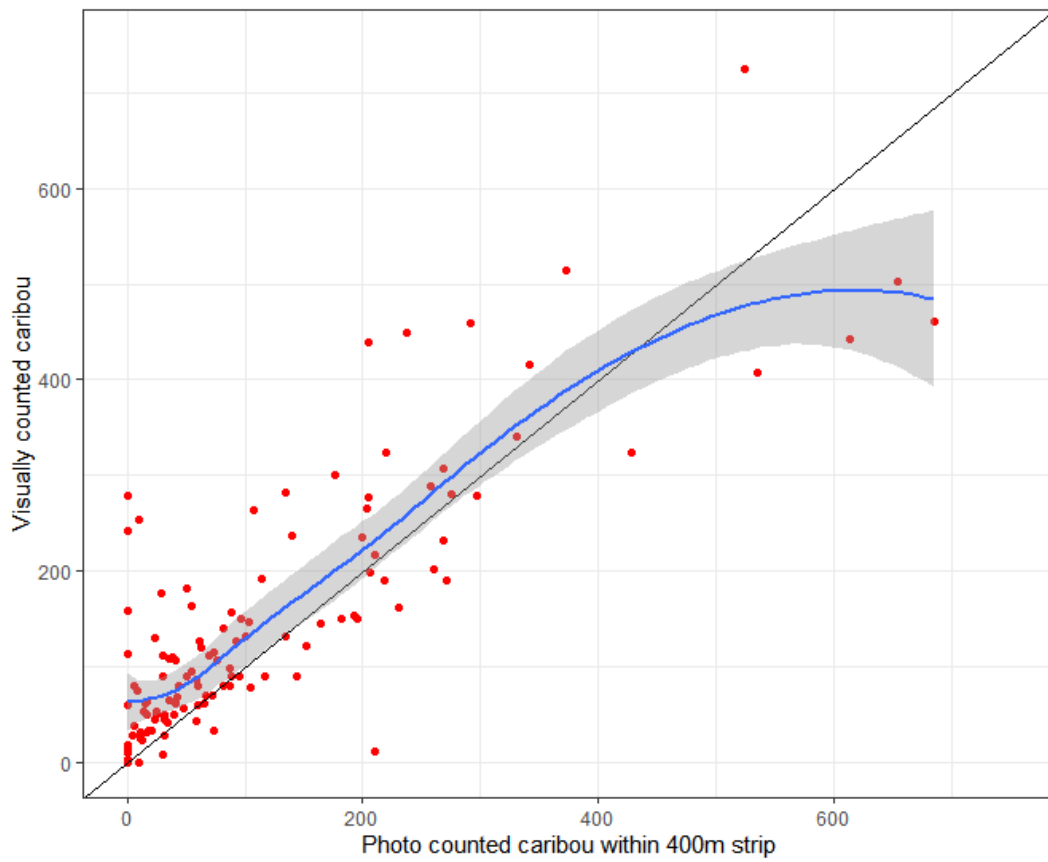


Figure 28. Relationship between caribou counted visually versus caribou counted on photos using all the caribou on photos with a 400-meter strip width applied.

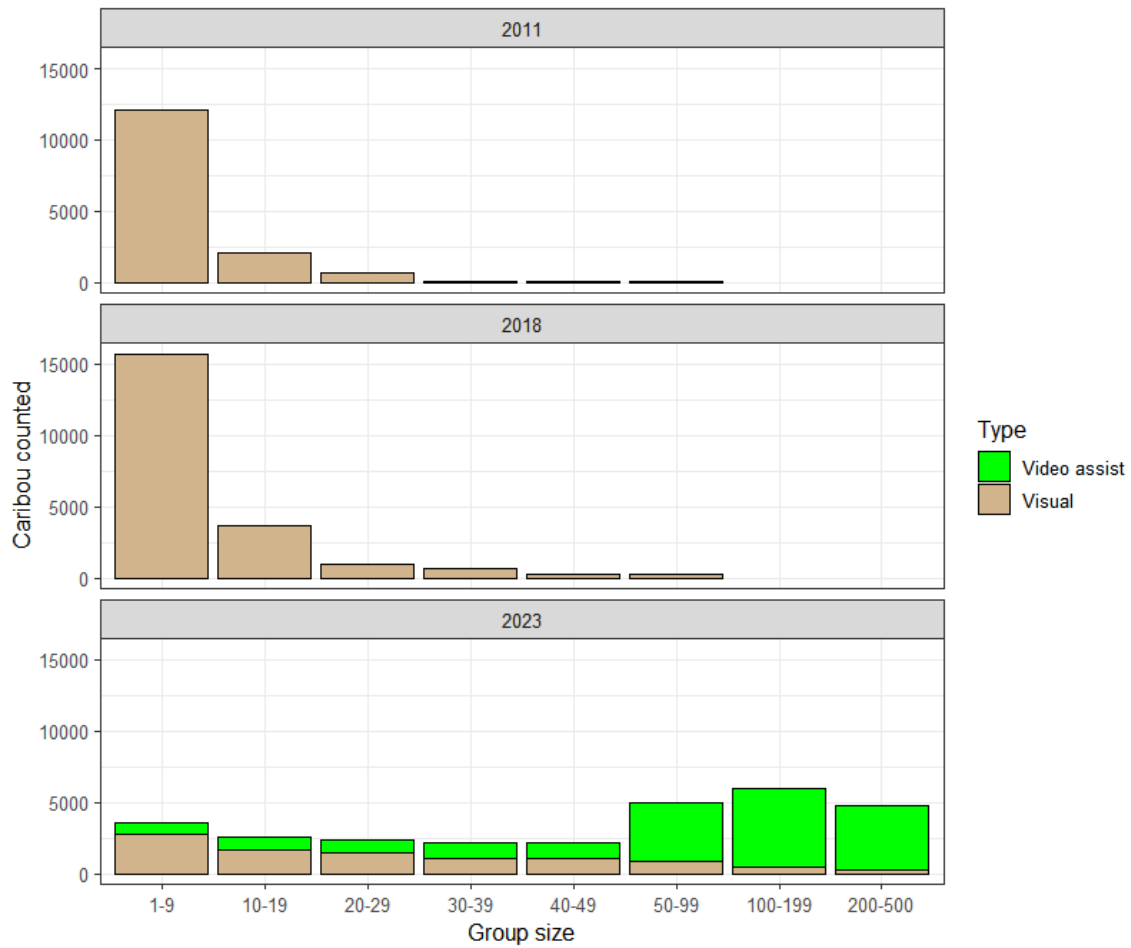


Figure 29. Comparison of contribution of group sizes observed to the total count of caribou on the 2011, 2018 and 2023 surveys. Sub-bars denote if visual counts were replaced in 2023 with video/orthomosaic counts.

4.3.3 Estimation of abundance using Jolly N with video-assisted counts

Abundance was initially estimated with the Jolly strip transect estimator. For the very-high-density strata, ortho-photo data was combined with visual counts (in areas where ortho photos were not used) to provide mutually exclusive estimates for each transect line. Transect densities were above 10 caribou per km² for many of the transect lines in the very-high-density strata. **Figure 30** shows the proportion of counts in these strata that came from photo counts versus visual counts. For most transect lines with a density above 10, the majority of caribou counted came from the photos as opposed to visual counts.

Transect densities within the remaining survey strata were below 10 caribou per km² with the exception of the High-Density-Southwest (HDSW) and Low-Density-South (LDS) strata (**Figure 31**). Higher densities in these strata were more due to bulls and non-breeders and therefore had less influence on adult female estimates. As noted earlier, higher densities in central lines of the Low-density central (LDC) were likely due to a spillover of caribou from the VHDE-1 stratum with lower densities on other survey lines. For this reason, the LDC stratum was not used in the estimate of adult females due to likely double-counting of caribou on the central lines.

Estimates of abundance and density demonstrated higher densities, in excess of approximately 20 caribou per km², in all of the very-high-density strata (**Table 6 - TBD**). In contrast, densities were 12 caribou per km² in the High Southwest strata and less than 9 caribou per km² in the rest of the strata. Of most interest were the estimates from the Very High density strata, within which, the use of video/ortho photo data reduced estimates from by approximately 14,000 caribou (17%)

compared to visual count data. Estimates from other strata were derived using double observer methods as discussed in the next section.

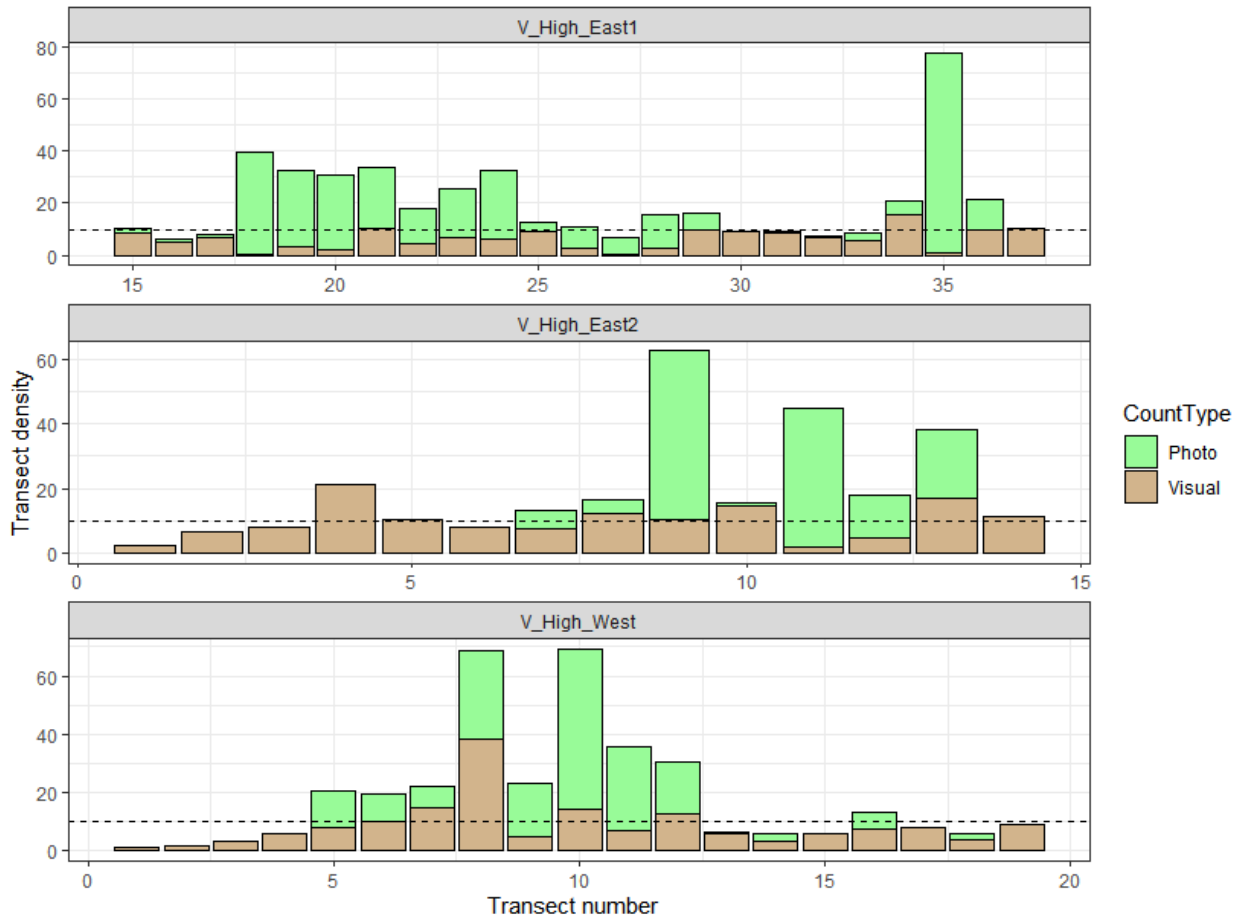


Figure 30. Transect densities for the very high strata with proportions of counts based on photo/orthomosaic's or visual source delineated for each stratum.

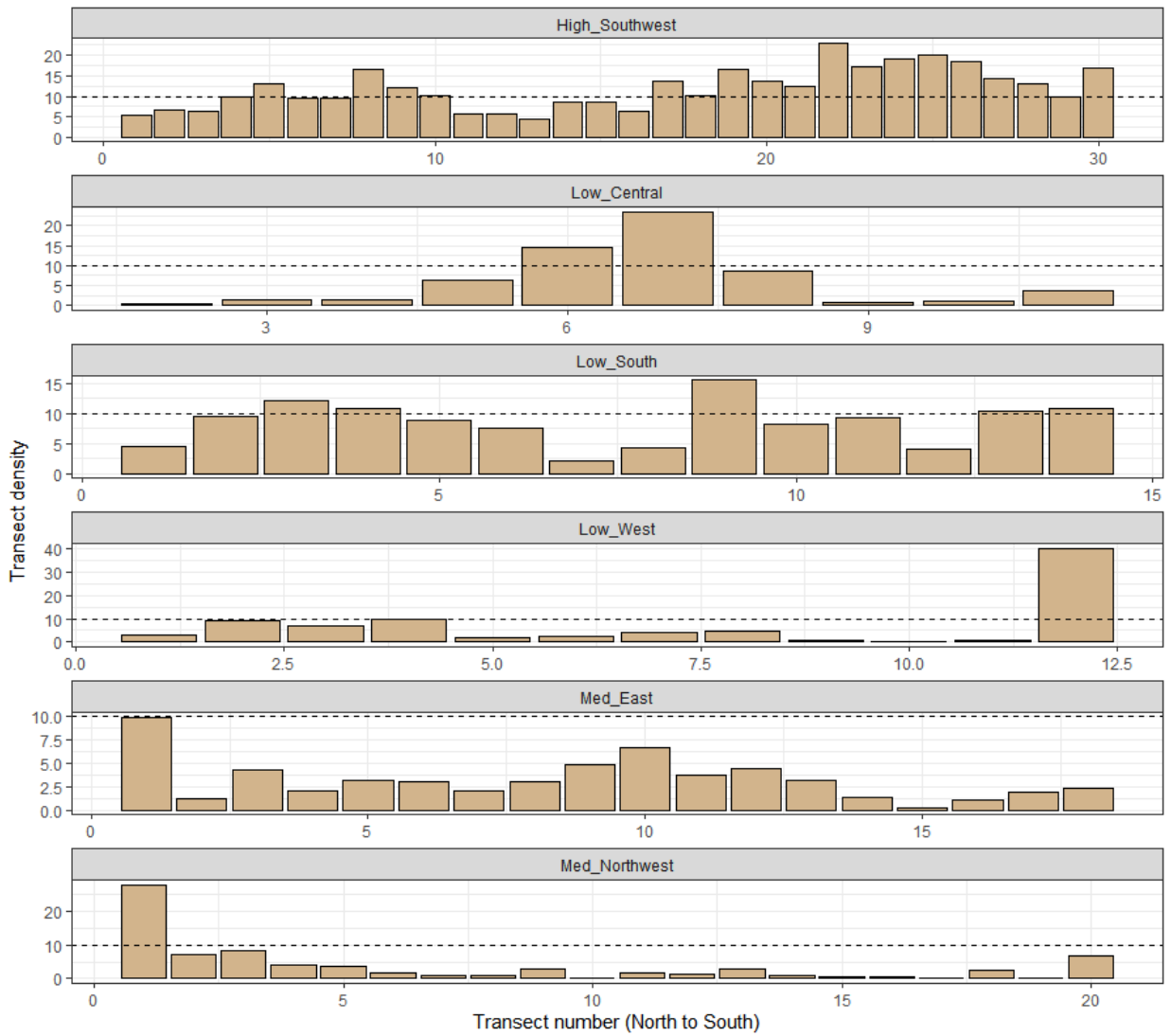


Figure 31. Transect densities for visual strata. Note that most transects were well within visual observation limits (10 to 20 caribou/km²).

4.3.4 Double observer

Double observer modelling was conducted to generate estimates of abundance for all strata except of the VHDE-1, VHDE-2, and VHDW strata where video-assisted counting was employed. It was not possible to use visual methods with video-assisted counting since video observations needed to be pooled in orthophoto areas.

Data was initially summarized based on 11 observer pairs (who switched front (primary) and rear (secondary) places intermittently during the survey). Of 5,766 observations, 5,348 were for paired observers with only 418 (7%) occurring for non-paired observers. The non-paired observers were pooled into observer pair 12. Summaries from all observer pairs suggest high detection probabilities with single observer detection probabilities greater than 0.9 and double observer probabilities approaching 1 (**Table 7** and **Figure 32**). Frequencies of observation by group size suggests most cases of single observer sightings occurred when group sizes were lower as shown in previous studies (**Figure 33**).

Summaries of snow and cloud cover indicate that the majority of observations occurred with 0 snowcover and 0 cloud cover which illustrates good sighting conditions during the survey (**Figure 34**). For model selection, cloud and snow cover were considered as categorical (i.e. one parameter (minus 1) estimated for each category) and continuous (assumes a linear relationship between cloud or snow cover and sighting probabilities). In general, the categorical form was more supported. In addition, the effect of observers and group size, whereby detectability increased with increasing group size, was also suggested as indicated by the most supported model (Model 1, **Table 8**). Another

way to view model predictions is by observer pair (**Figure 35**), which demonstrates that some observer pairs had higher sighting probabilities than others when group size was lower but, in most cases, sighting probabilities were close to 1 when groups sizes were larger.

Double observer estimates were only produced for visual strata that did not have video-assisted counts (**Table 9 -TBD**). Using these most supported models produced a total estimate of **TBD (To be determined, in preparation)** caribou with reasonable precision (CV=0.066). In contrast, estimates using just the Jolly N strip transect estimator were **TBD** (CV=0.060) which was only 415 caribou lower than the double observer estimate. The similarity in estimates was due to the high sightability conditions with most groups over five caribou being observed by both observers.

Table 7. Summary for pooled pairs given in previous table. Naïve single (p1x) and double (p2x) probabilities are given. **TBD**

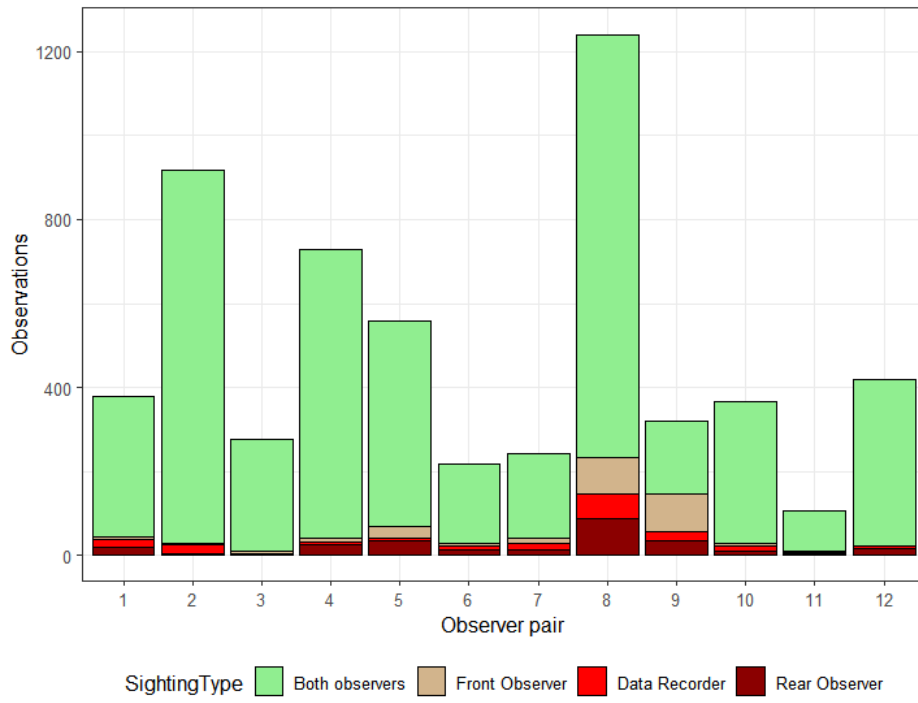


Figure 32. Sighting types by observer pair.

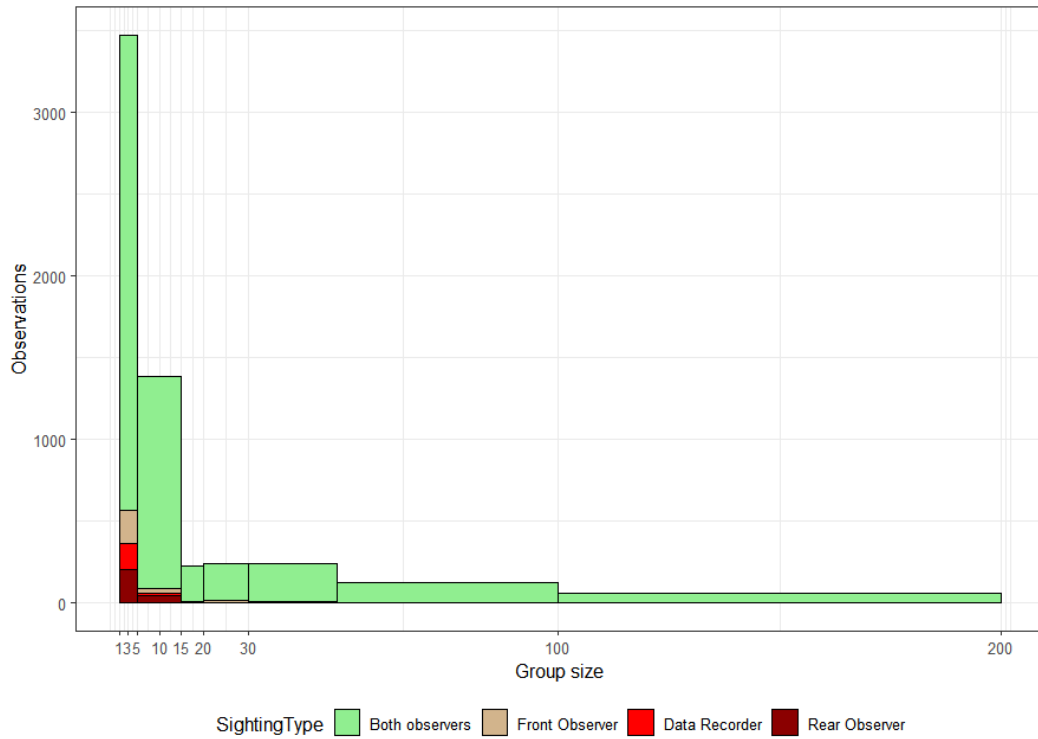


Figure 33. Frequencies of observation by group size as a function of observation type (B=Both, F=Front, R=Rear).

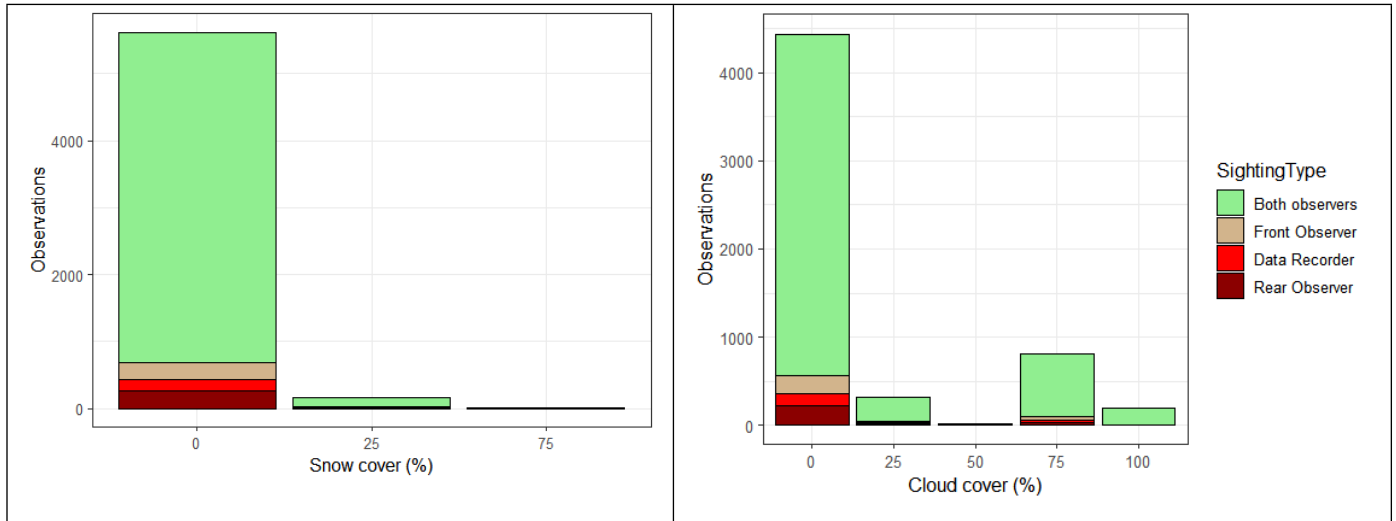


Figure 34. Observation frequencies by snow and cloud cover as a function of observation type (B=Both, F=Front, R=Rear).

Table 8. Double observer model selection results. Sample size adjusted Akaike Information Criterion (AIC_c), the difference in AIC_c between the most supported model for each model (Δ AIC_c), AIC_c weight (w_i), number of model parameters (K), and deviance is given.

No	Model	AIC _c	Δ AIC _c	w_i	K	LL
1	logsize + obs + cloudF	2877.77	0.00	0.91	17	-1420.1
2	logsize + obs	2882.48	4.72	0.09	13	-1427.2
3	logsize + cloudF	2971.64	93.88	0.00	6	-1479.6
4	logsize + snowc + cloudc	2987.39	109.62	0.00	4	-1489.6
5	logsize + cloudc	2989.05	111.28	0.00	3	-1491.5
6	logsize	2998.87	121.10	0.00	2	-1497.4
7	logsize + snowc	3000.28	122.51	0.00	3	-1497.1
8	logsize + PhaseF	3000.92	123.15	0.00	3	-1497.4
9	PhaseF * logsize	3001.88	124.11	0.00	4	-1496.8
10	obs	3027.07	149.30	0.00	12	-1500.6
11	size	3109.50	231.73	0.00	2	-1552.7
12	cloudF	3128.93	251.16	0.00	5	-1559.3
13	StrataF	3138.85	261.08	0.00	12	-1556.5
14	snowF + cloudc	3142.22	264.45	0.00	4	-1567.0

15	cloudc	3146.39	268.62	0.00	2	-
						1571.2
16	constant	3150.46	272.69	0.00	1	-
						1574.2
17	PhaseF	3150.90	273.13	0.00	2	-
						1573.4
18	snowF	3151.07	273.30	0.00	3	-
						1572.5
19	snowc	3151.37	273.61	0.00	2	-
						1573.7

Table 9. Double observer abundance estimates from Model 1 (**Table 7**) for strata excluding VHD-1, VHDE-2, and VHDW that were estimated using video counts. **TBD**

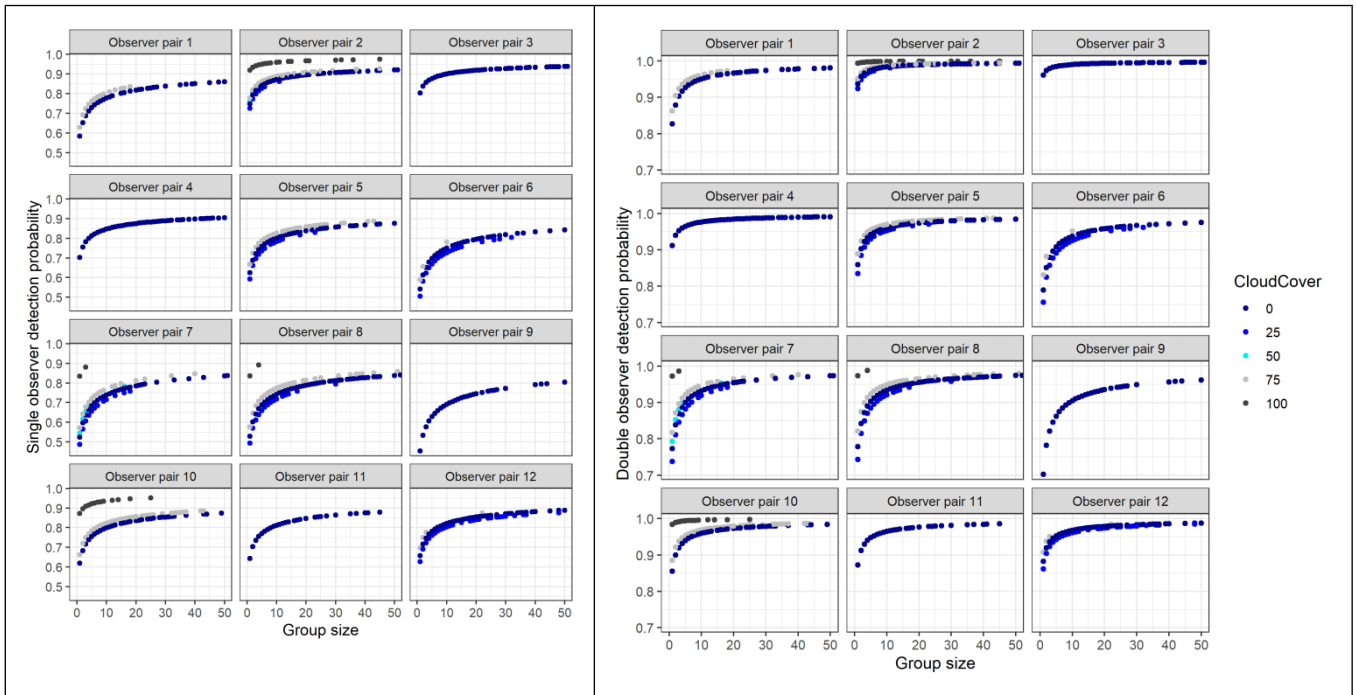


Figure 35. Predicted single and double observer sighting probability as a function of group size and observer pair.

4.3.5 Composition survey results

Composition surveys were flown from June 14th to 16th 2023 to coincide with the main visual abundance survey (**Table 2**). Results revealed expected segregation of females and bulls with the majority of females occurring in the Very High East and VHDW strata, with bulls dominating the more southern strata, a finding consistent with bull telemetry location and movement data (**Figure 36**). Of note was a sub-segregation within the VHDW stratum where considerable mixing between breeding and non-breeding females, yearlings, and young and mature bulls occurred within the southern extents of the strata, likely the result of the migratory delays and barriers imposed by the advanced melt and associated high water levels discussed earlier in this report. Overall sample sizes of groups were reasonably high in the main strata sampled yielding reliable assessments of abundance strata composition (**Table 10**). Proportions of breeding cows, bulls, and cows (breeding and non-breeding) were estimated for each survey strata (**Table 11**).

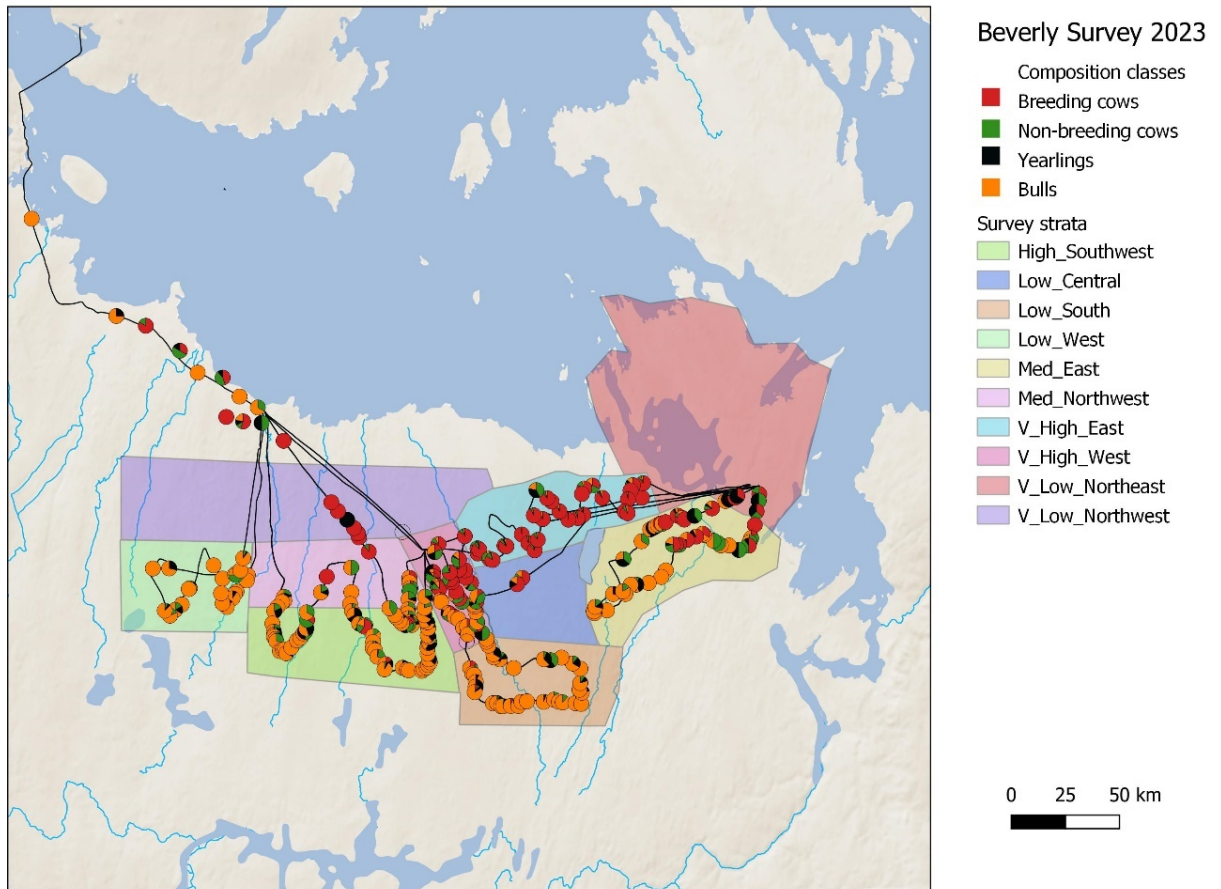


Figure 36. Composition survey flight paths with pie charts depicting each sample.

Table 10. Summary of observations during the calving-ground composition survey.

Strata	Breeding cows	Non-Breeding Cows	Calves	Bulls	Yearlings	Total 1+ Caribou	groups
V_High_East1	4510	378	4046	153	72	5113	22
V_High_East2	1178	109	1060	64	19	1370	10
V_High_West	1430	481	993	473	134	2518	38
High_Southwest	26	148	12	1078	155	1407	62
Med_East	264	71	227	145	51	531	42
Med_Northwest	13	28	7	91	9	141	18
Low_Central	32	2	28	7	3	44	2
Low_South	14	43	0	538	61	656	34
Low_West	3	18	1	292	17	330	22
V_Low_Northeast	12	6	9	3	10	31	7
V_Low_Northwest	17	0	16	0	1	18	6

Table 11. Estimated proportion of breeding females (breeding females/total) and adult females (breeding+non-breeding females)/total within calving-ground abundance strata. Standard errors and confidence limits were based on bootstrap resampling methods.

Strata	Proportion	Estimate	SE	Conf. Limit	
V_High_East1	Breeding Cows	0.882	0.012	0.858	0.905
V_High_East1	Bulls	0.030	0.004	0.021	0.037
V_High_East1	Cows	0.956	0.005	0.948	0.965
V_High_East2	Breeding Cows	0.860	0.041	0.753	0.909
V_High_East2	Bulls	0.047	0.009	0.031	0.067
V_High_East2	Cows	0.939	0.015	0.902	0.962
V_High_West	Breeding Cows	0.568	0.054	0.446	0.650
V_High_West	Bulls	0.188	0.032	0.140	0.265
V_High_West	Cows	0.759	0.037	0.674	0.815
High_Southwest	Breeding Cows	0.018	0.007	0.008	0.033
High_Southwest	Bulls	0.766	0.022	0.721	0.807
High_Southwest	Cows	0.124	0.016	0.095	0.159
Med_East	Breeding Cows	0.497	0.103	0.259	0.637
Med_East	Bulls	0.273	0.066	0.180	0.444
Med_East	Cows	0.631	0.079	0.441	0.735
Med_Northwest	Breeding Cows	0.092	0.068	0.006	0.252
Med_Northwest	Bulls	0.645	0.061	0.518	0.752
Med_Northwest	Cows	0.291	0.067	0.179	0.433
Low_Central	Breeding Cows	0.727	0.037	0.667	0.769
Low_Central	Bulls	0.159	0.005	0.154	0.167
Low_Central	Cows	0.773	0.065	0.667	0.846
Low_South	Breeding Cows	0.021	0.008	0.007	0.036
Low_South	Bulls	0.820	0.019	0.780	0.857
Low_South	Cows	0.087	0.016	0.059	0.123
Low_West	Breeding Cows	0.009	0.005	0.000	0.020
Low_West	Bulls	0.885	0.019	0.850	0.922
Low_West	Cows	0.064	0.014	0.039	0.094
V_Low_Northeast	Breeding Cows	0.387	0.125	0.125	0.618
V_Low_Northeast	Bulls	0.097	0.100	0.000	0.333
V_Low_Northeast	Cows	0.581	0.134	0.269	0.806
V_Low_Northwest	Breeding Cows	0.944	0.080	0.714	1.000
V_Low_Northwest	Bulls	0.000	0.000	0.000	0.000
V_Low_Northwest	Cows	0.944	0.080	0.714	1.000

4.3.6 Estimation of breeding females, adult females, and bulls

Results have yet to be finalized due to ongoing analysis. Final Government of Nunavut File Report will be provided upon completion of analysis.

4.3.7 Extrapolated herd estimates

Results have yet to be finalized due to ongoing analysis. Final Government of Nunavut File Report will be provided upon completion of analysis.

4.4 ABUNDANCE TRENDS

Results have yet to be finalized due to ongoing analysis. Final Government of Nunavut File Report will be provided upon completion of analysis.

4.5 COLLAR ANALYSIS

Collar data was used to estimate movement between calving grounds and derive survival rate estimates for Beverly cows and bulls. All collar data for the Beverly herd was provided by the Government of the Northwest Territories and included both cow and bull collared caribou. During the Beverly June 2023 calving-ground survey, collared female caribou from the Lorillard, Wager Bay, Ahiak, Qamanirjuaq, Beverly, Bluenose, and Bathurst herds were monitored daily, while collared bulls from the Bathurst and Bluenose herds were monitored daily. All collared data was used primarily to help predict reconnaissance and abundance survey extents and timing. Due to the overlap between the Beverly, Bathurst and Ahiak herds observed during the calving season over the last 10 years, collar data was also used to assess the degree of overlap between the Beverly survey area and the Bathurst herd to the west, and Ahiak herd to the east. Additionally, Collar data was used to assess any irregularities in the Herds spring movements onto their annual concentrated calving areas when compared to historically documented spring migratory movements and associated distribution, throughout delineated seasonal calving extents.

4.5.1 Movements between calving grounds

From 2018 to present, late winter range (April) telemetry locations and migration paths of Nunavuts mainland migratory caribou herds, reveal recent intermixing, which may have influenced movements of adult females between calving grounds up to and including June 2023 (**Figure 42**). A challenge with assessing movements between calving grounds is

that caribou need to be monitored more than one year. Sample sizes of adult females with known herd membership based on whether they were monitored over consecutive years are presented in **Table 19**. It can be seen that sample sizes are limited, being below 20 for many of the herds which ultimately limits the power to detect movements between herds (Boulanger et al. 2024).

Observations of mean calving locations of adult female caribou monitored more than one year reveals movement between the Beverly and Ahiak annual calving-grounds in most years, as well as directional movement of caribou from the Bathurst to the Beverly annual calving-ground starting in 2018 (**Figure 43**). Within the Ahiak calving-grounds fidelity was relatively low with most caribou moving to another calving ground (Wager Bay or Beverly herds) each year. In 2022 and 2023, a small number of Ahiak cows were documented to have calved just to the East of Bathurst Inlet, but not in the proximity of the majority of calving Bathurst or Beverly caribou.

The calving extents of the Beverly or Bathurst herds were roughly based on which side of Bathurst Inlet caribou were located on June 10th. However, in some cases Bathurst caribou calved just to the east of Bathurst Inlet which was further west than the majority of Beverly caribou which typically calved in the central Queen Maud Gulf. However, those cows calving to the east of Bathurst Inlet were still atypical as they were well east of the core Bathurst calving ground located, since the late 1990's, west of Bathurst Inlet. Therefore, there is some uncertainty in classifying caribou to a calving ground in this "grey area" (**Figure 44**). Caribou that calved just to the east of Bathurst Inlet were therefore also assessed based on their post-calving movements. For example, in 2021 Bathurst collared caribou cows identified as BGCA-19370, BGCA-20105, and BGCA-21162 calved to the east of Bathurst Inlet then moved further east to join other Beverly caribou cows later

in June. These individuals were therefore classified as Beverly caribou. In contrast, Bathurst Cow number BGCA-19370 calved to the east of Bathurst Inlet in 2019 but remained in this area for the remainder of June (away from other Beverly cows) and therefore was classified as Bathurst. In reality, travel conditions and other seasonal factors likely influence where caribou calve and therefore there will be a segment of caribou that occur away from the central Bathurst and Beverly caribou calving grounds leading to inexact classifications given the relatively low sample size of collars of known herd status.

Along the western boundary of the Beverly annual calving-ground, movements in and out of each calving ground for a given year, as well as the number of caribou showing fidelity to a given calving ground in a given year, are displayed in **Figure 45**. The complexity of calving-ground use overlap was exemplified in June 2023, whereby 16 Bathurst collared caribou from June 2022 returned to the Bathurst calving ground while 4 moved to the Beverly calving ground, with 1 Bluenose-East caribou moving into the Bathurst calving ground. This figure also shows how the Ahiak herd calving-ground is a “melting-pot” with movement into and out of the calving ground each year from both Beverly caribou cows in the west, and Wager Bay caribou cows in the east. The frequencies of movement into and out of calving grounds can also be shown spatially by period (2011-2018 and 2019-2023) (**Figure 46**). It can be seen that from 2019 to 2023, 12 Bathurst, and 8 Ahiak caribou, moved onto the Beverly calving ground. At the same time two Beverly caribou moved to the Bathurst calving ground in, however, these caribou occurred east of Bathurst Inlet in the “grey area” between the two herds as shown in **Figure 44**, and therefore this movement may not add up to an actual increase in the adult cows in the Bathurst herd but rather be an extra-limital movement by a Beverly cow.

The challenge with interpreting frequency data comes when attempting to estimate a proportion or probability of switching given different sample sizes of collars for each herd. To help better inform this process a multi-state model was used to estimate switching probabilities which are displayed graphically in **Figure 47**. Period-specific (2011-2018 and 2019-2023) switching probabilities were estimated for the Bathurst, Beverly, and Ahiak herds. Sparse data precluded estimation of period-specific probabilities for the Ahiak, Lorillard, and Wager Bay herds. Using When using Beverly, Bathurst, and the limited Ahiak telemetry data, estimates suggest directional movement from the Bathurst calving-ground to the Beverly, and from the Ahiak calving-ground to the Beverly in the 2019 to 2023 period. Estimates were run using Markov Chain Monte Carlo methods to ensure robust estimates. The resulting estimates suggested that fidelity for the Beverly herd was relatively high (0.90 and 0.96) for both periods while fidelity for the Ahiak herd was relatively low over the same period (0.42 and 0.62). The general conclusion from the collar analysis is that there has been net movement of caribou into the Beverly from both the Bathurst and the Ahiak calving grounds. This topic is explored further using an Integrated Population Model.

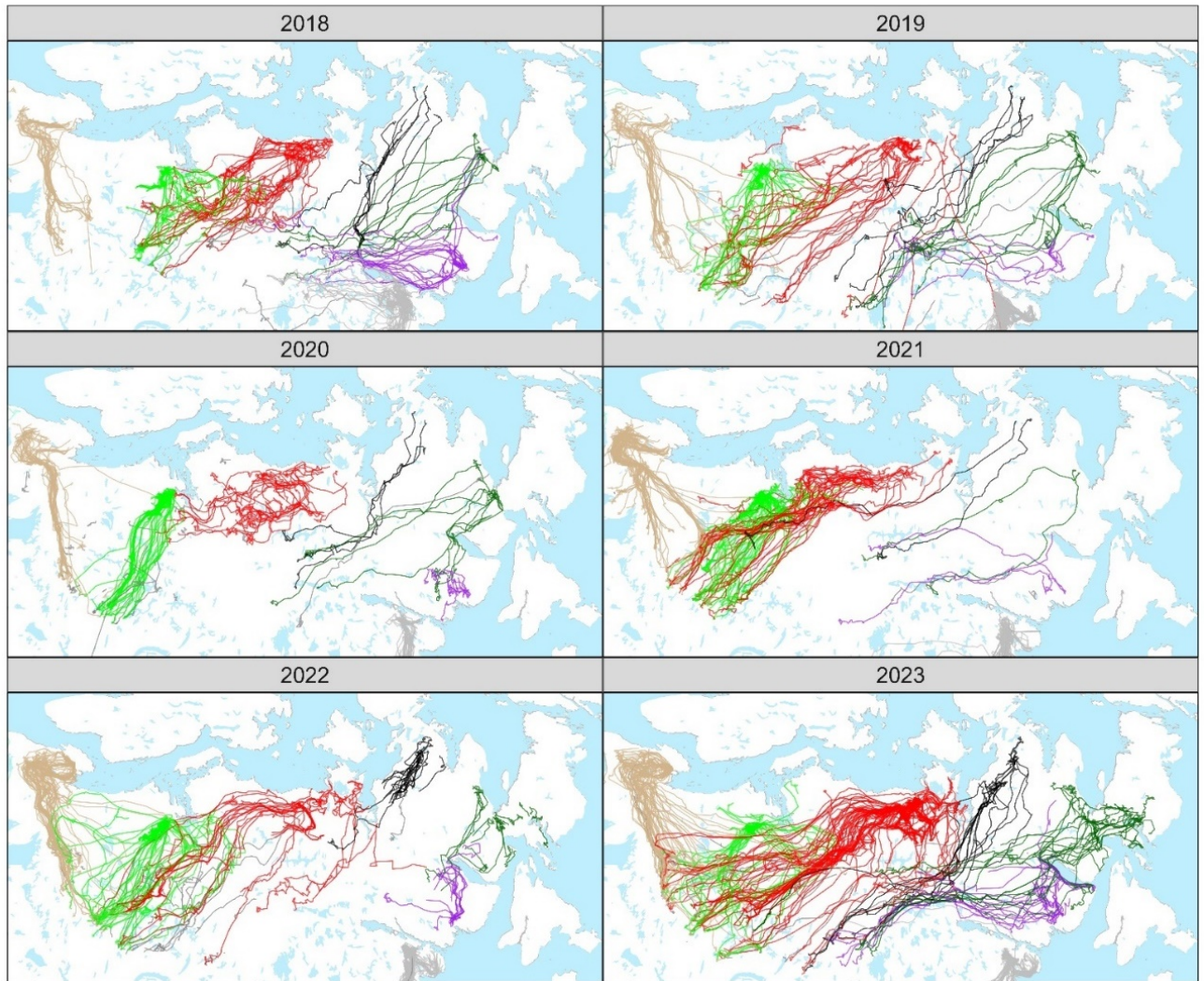


Figure 42. Migration paths (March to June 15) for the Bluenose-East (brown), Bathurst, (green), Beverly (red), Ahlak (black) Wager Bay (dark green), and Lorrillard herds (purple). Collars were classified based on the calving ground that they calved in during 2022 and 2023.

Table 19. Sample sizes of adult female caribou that were monitored more than 1 year to determine known calving ground locations between 2 years.

Year	Bathurst	Beverly	Ahiak	Wager Bay	Lorrillard
2011	10	7	7	0	6
2012	15	16	6	0	5
2013	10	11	4	1	4
2014	14	28	1	1	3
2015	22	29	1	4	5
2016	26	27	3	6	9
2017	28	26	2	5	8
2018	18	30	7	8	13
2019	22	29	5	10	5
2020	36	16	3	7	3
2021	37	29	2	2	3
2022	37	18	13	15	7
2023	16	22	9	11	9
Totals	291	288	63	70	80

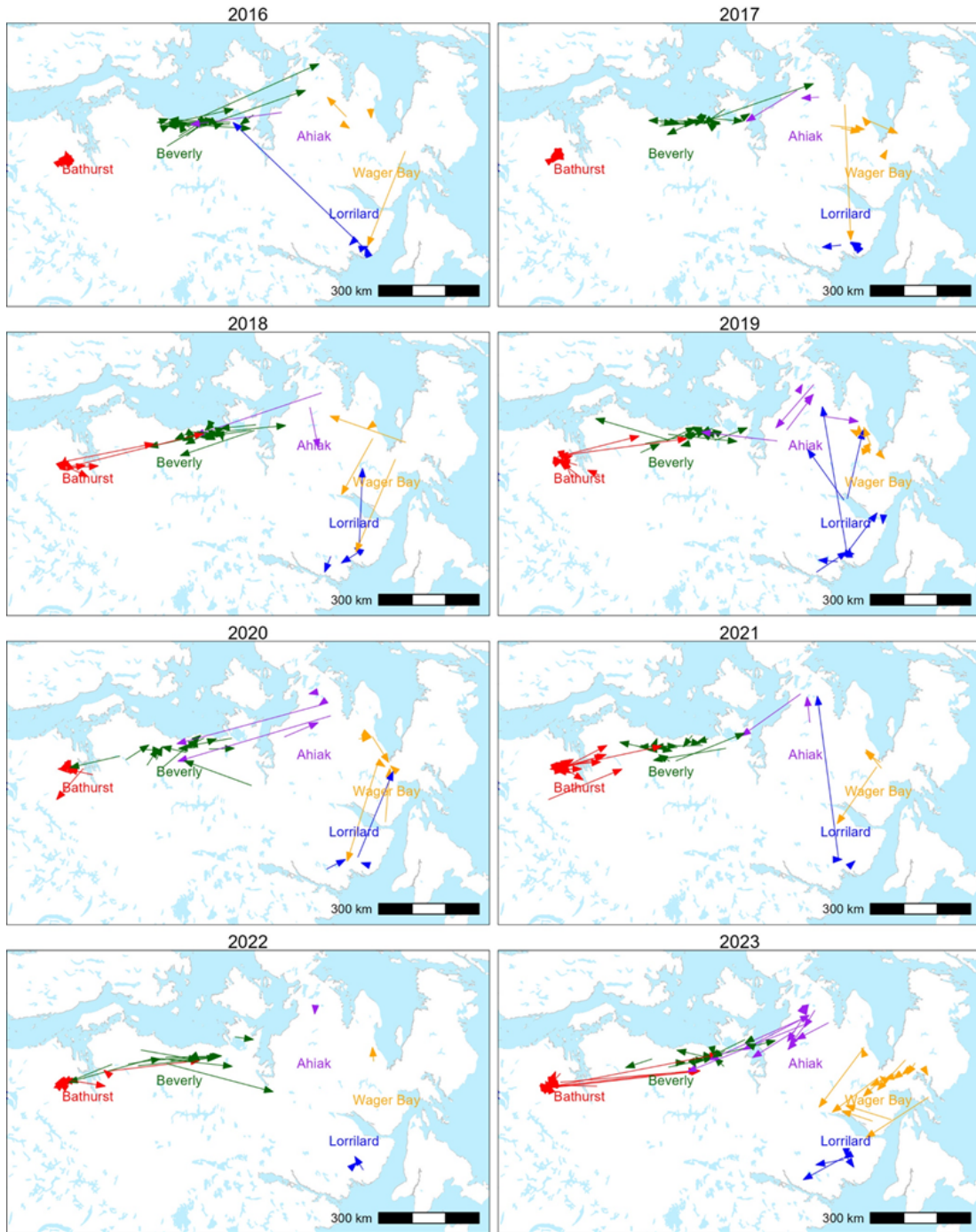
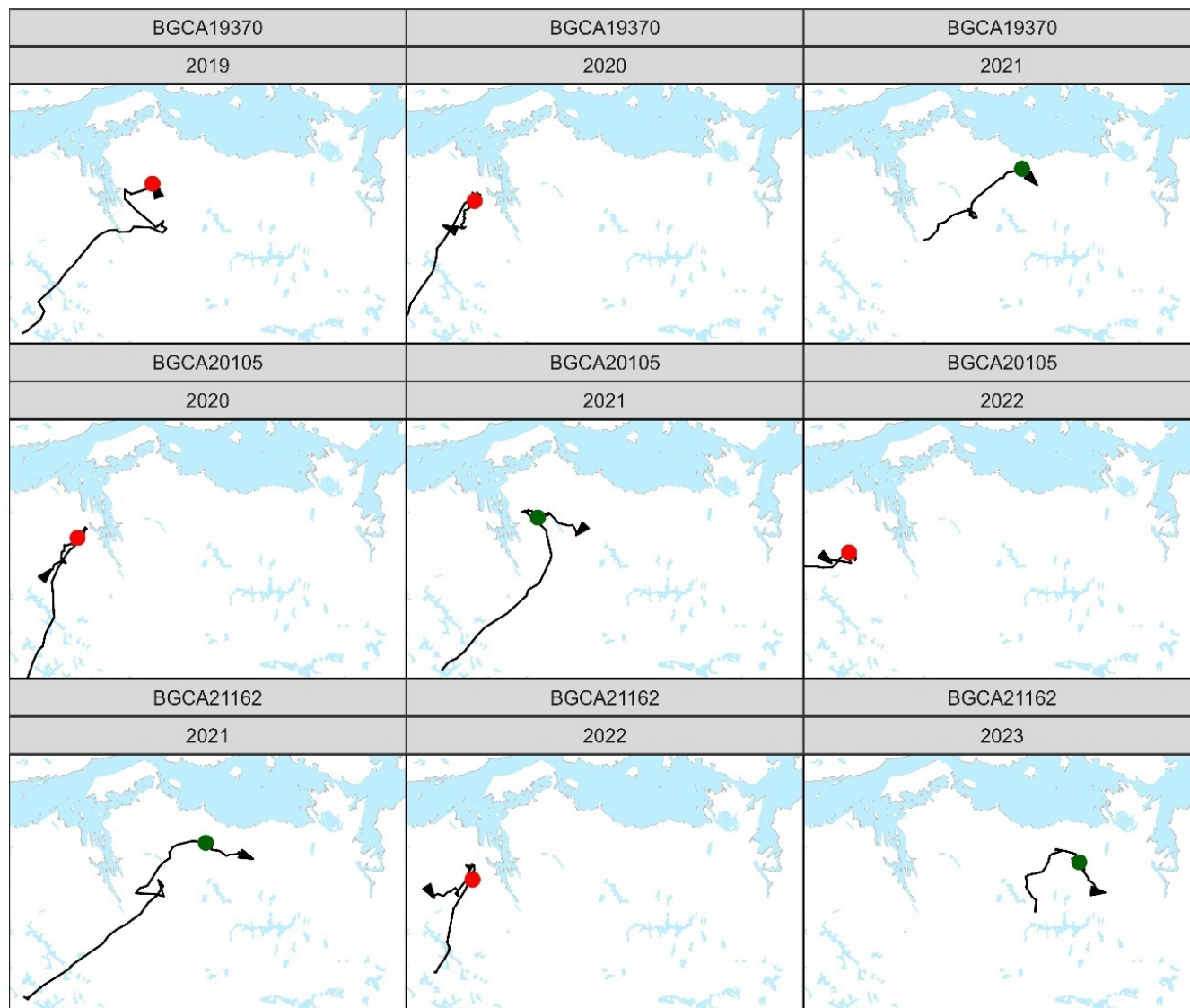


Figure 43. Mean calving ground locations for caribou in the previous year (tail of arrow) and current year (head of arrow) with the arrow colored according to the previous year calving ground.



CalvingGround ● Bathurst ● Beverly

Figure 44. Calving locations (on approximately June 10th) and paths (May 1-June 30) for 3 collars that calved inbetween the core Bathurst and Beverly calving grounds.

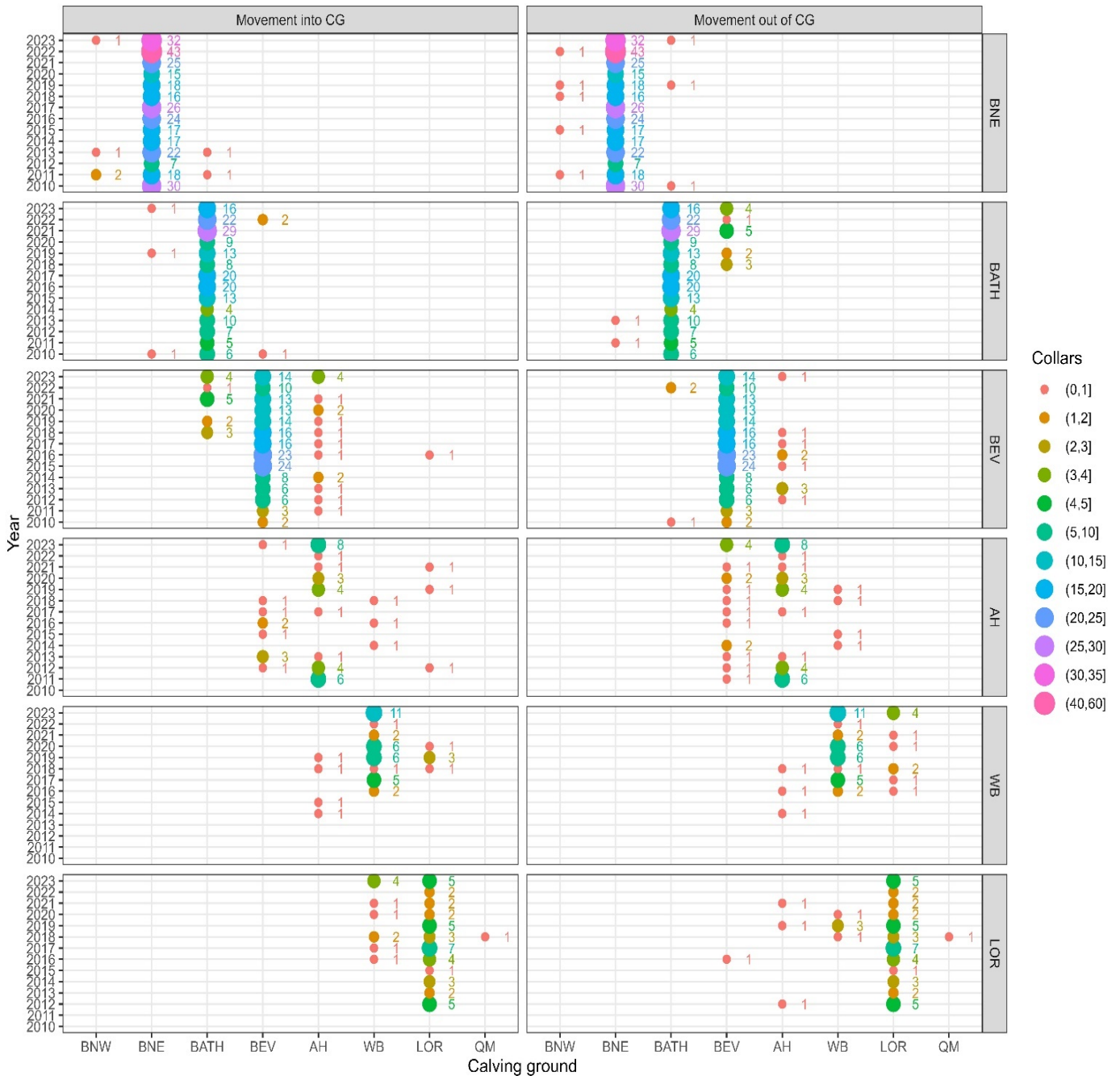


Figure 45. Graphical summary of movement events in and out of calving grounds. The left plot displays movements into the cg each year and the right are movements out, with columns indicating the herd. If a column is the same as the herd (i.e. LOR column in LOR herd plot) then sample sizes indicate caribou returning to the calving ground from the previous year (fidelity). This column is repeated for movements into and out of calving grounds.

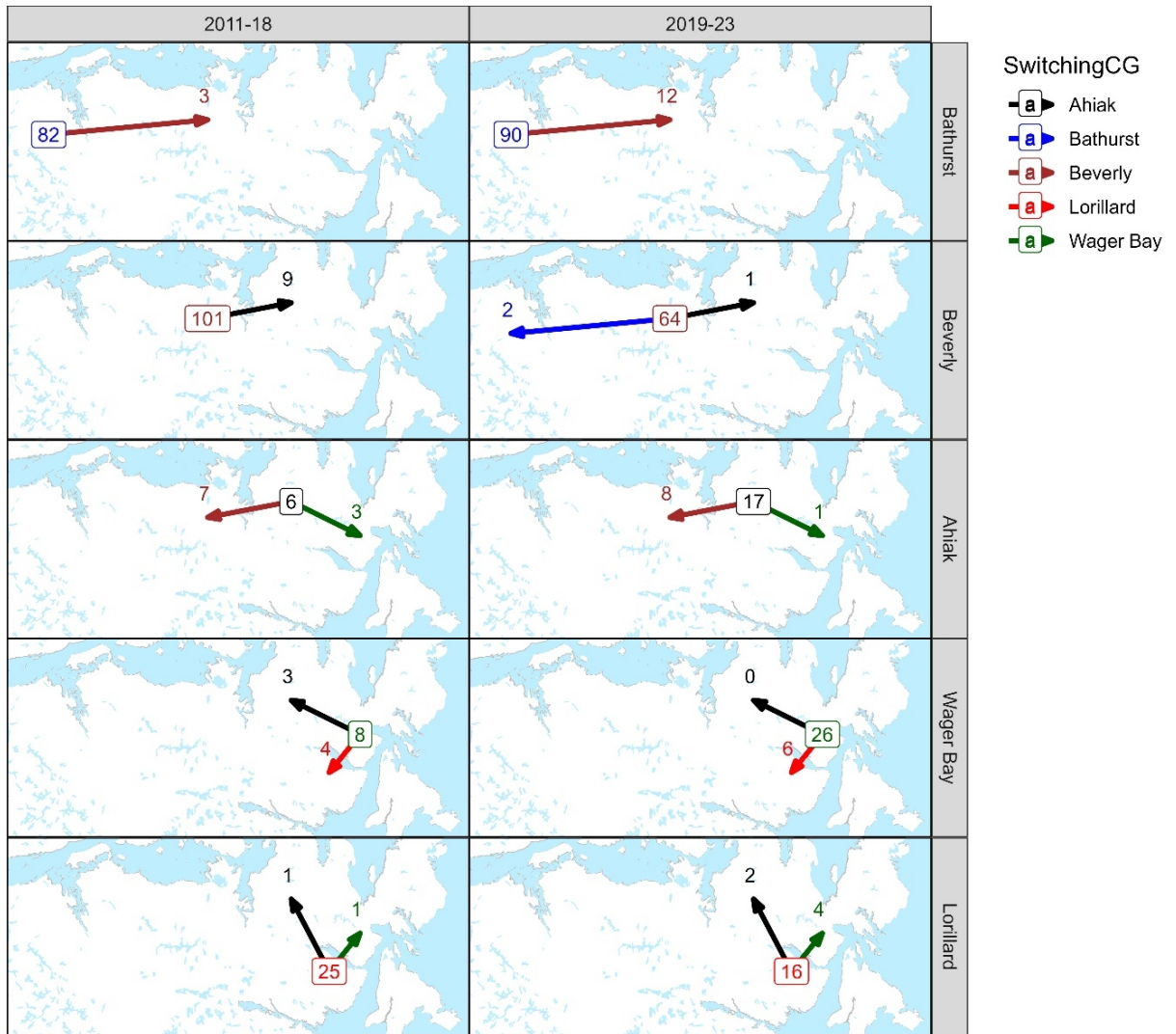


Figure 46. Frequencies of fidelity (numbers in boxes) and switching events of adult females from 2011-2018 and 2019-2023 for the Beverly and surrounding caribou herds.

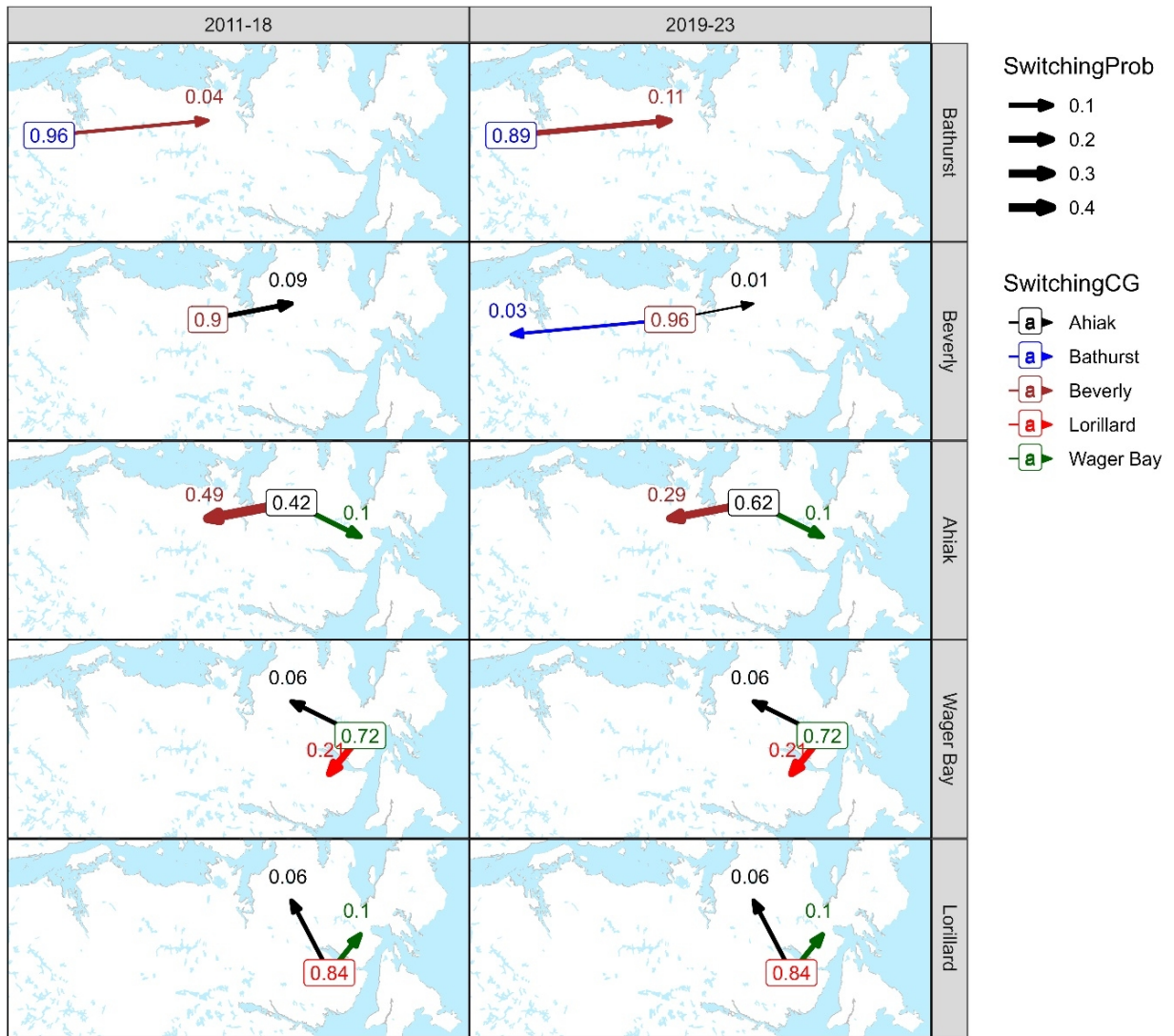


Figure 47. Estimates of fidelity (numbers in boxes) and switching probabilities (arrows) of adult females from 2011-8 and 2019-23 for the Beverly and surrounding caribou herds.

4.6 SURVIVAL ANALYSIS

One of the key demographic parameters that can be used to help understand changing barren-ground caribou abundance is adult female survival. We utilized data sets of collared adult female caribou maintained by the government of NWT to estimate survival. Caribou collar histories were constructed using location data and collar fate data. In addition, caribou were classified by the calving ground that they calved upon in a given year. A caribou that calved on the Beverly or Adelaide Peninsula area was considered a Beverly cow for this analysis (**Figure 48**). The resulting collection of associated data was then used to estimate monthly mortality rates of caribou based on the number of collar mortalities divided by the total collars monitored for a given month (**Figure 49**). Yearly survival rates were then estimated based on the product of 1-monthly mortality rate for a given caribou year, which is the Kaplan-Meier survival rate estimator (Pollock et al. 1989). Estimates, however, were of lower precision due to lower collar sample sizes (**Figure 50**). The survival rates were used as an input into the Integrated Population Model (IPM) which also utilized other data sources to refine survival rate estimates. The results of the survival analysis and the IPM within which it was used are discussed in the following section.

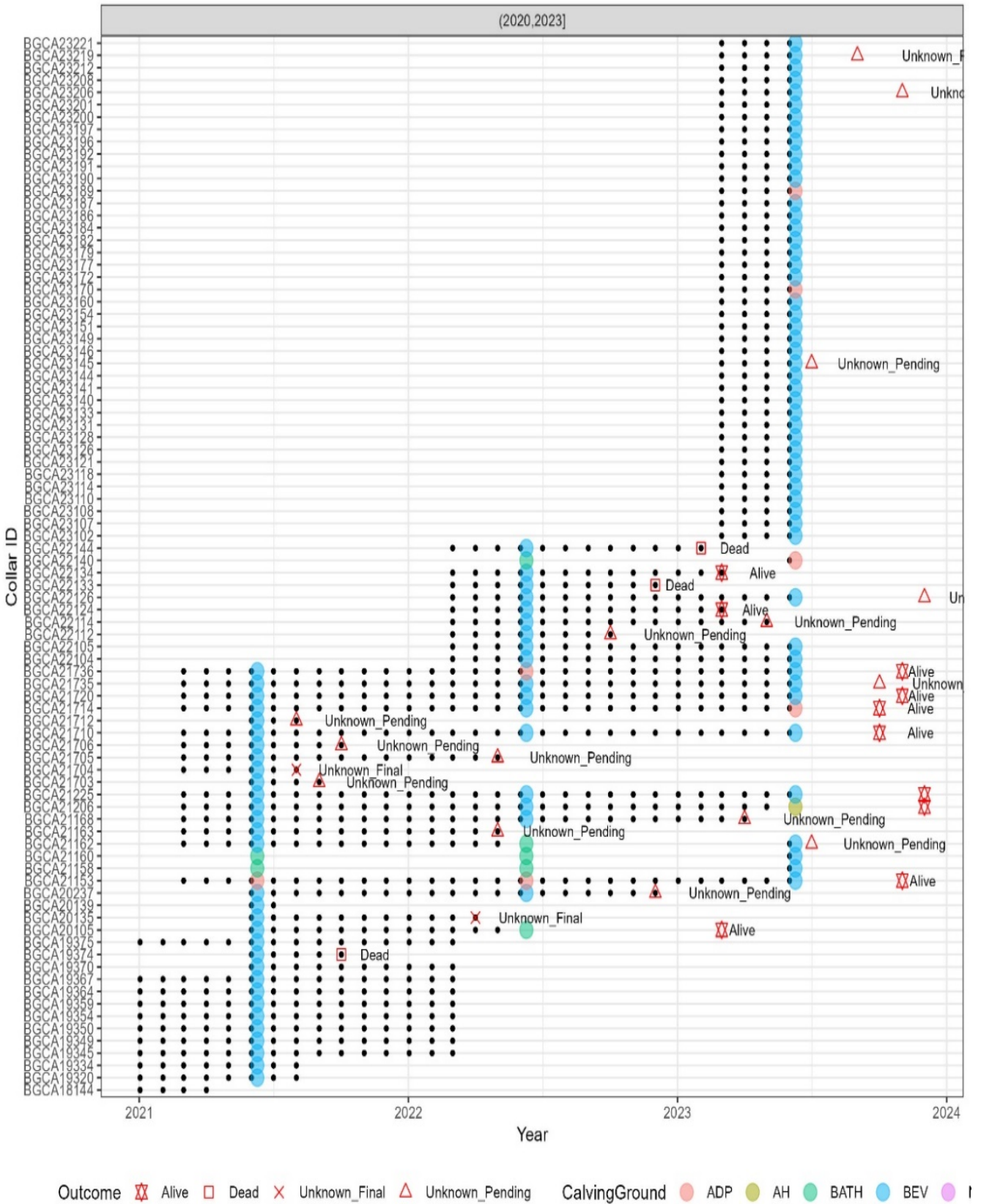


Figure 48. Collar histories of Beverly cows. Included is fate of each collar and the calving ground (colored dot) it utilized each June.

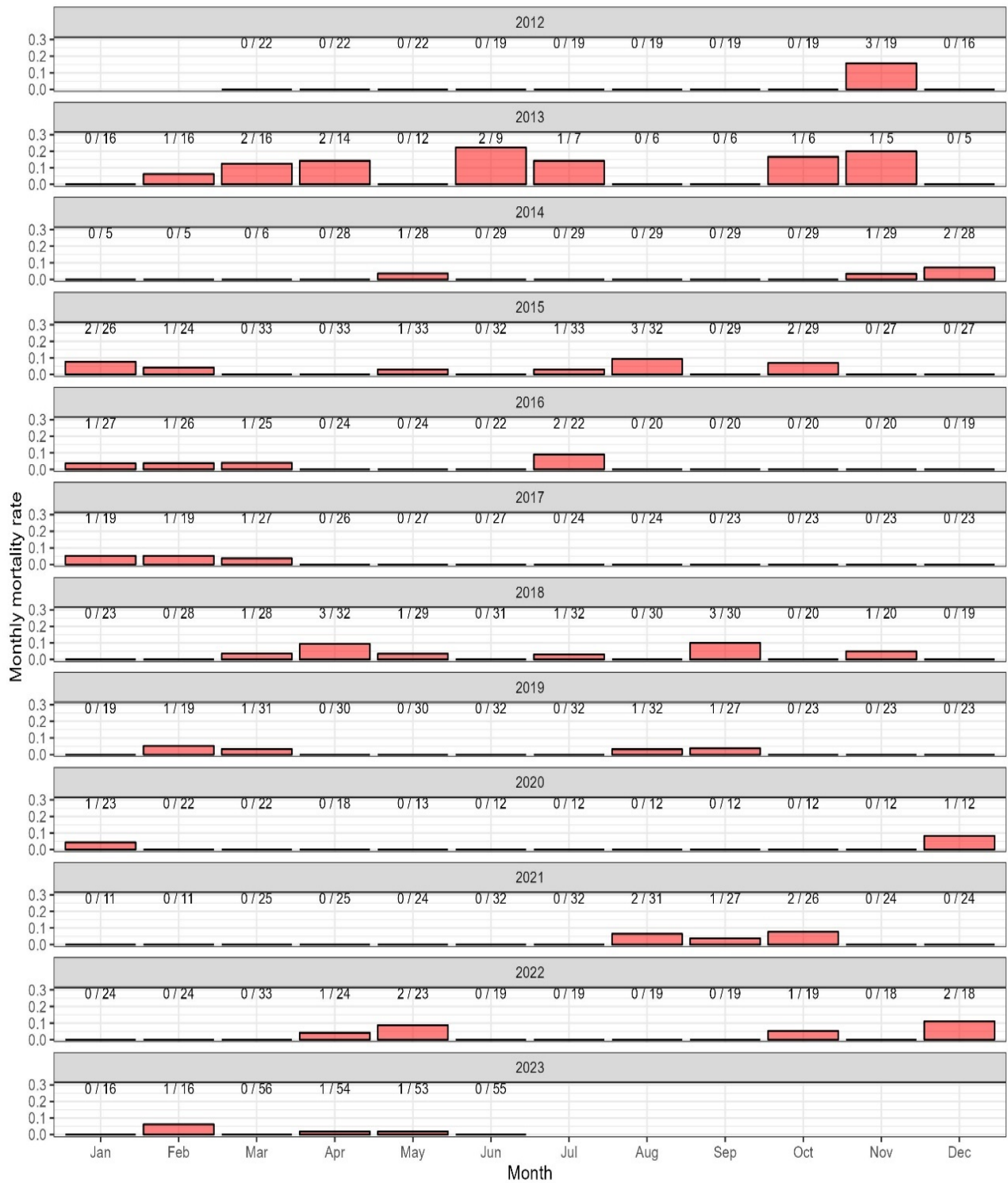


Figure 49. Monthly mortality rates for collared caribou from 2012 to 2023. Sample sizes of mortalities and collars monitored is given above each bar.

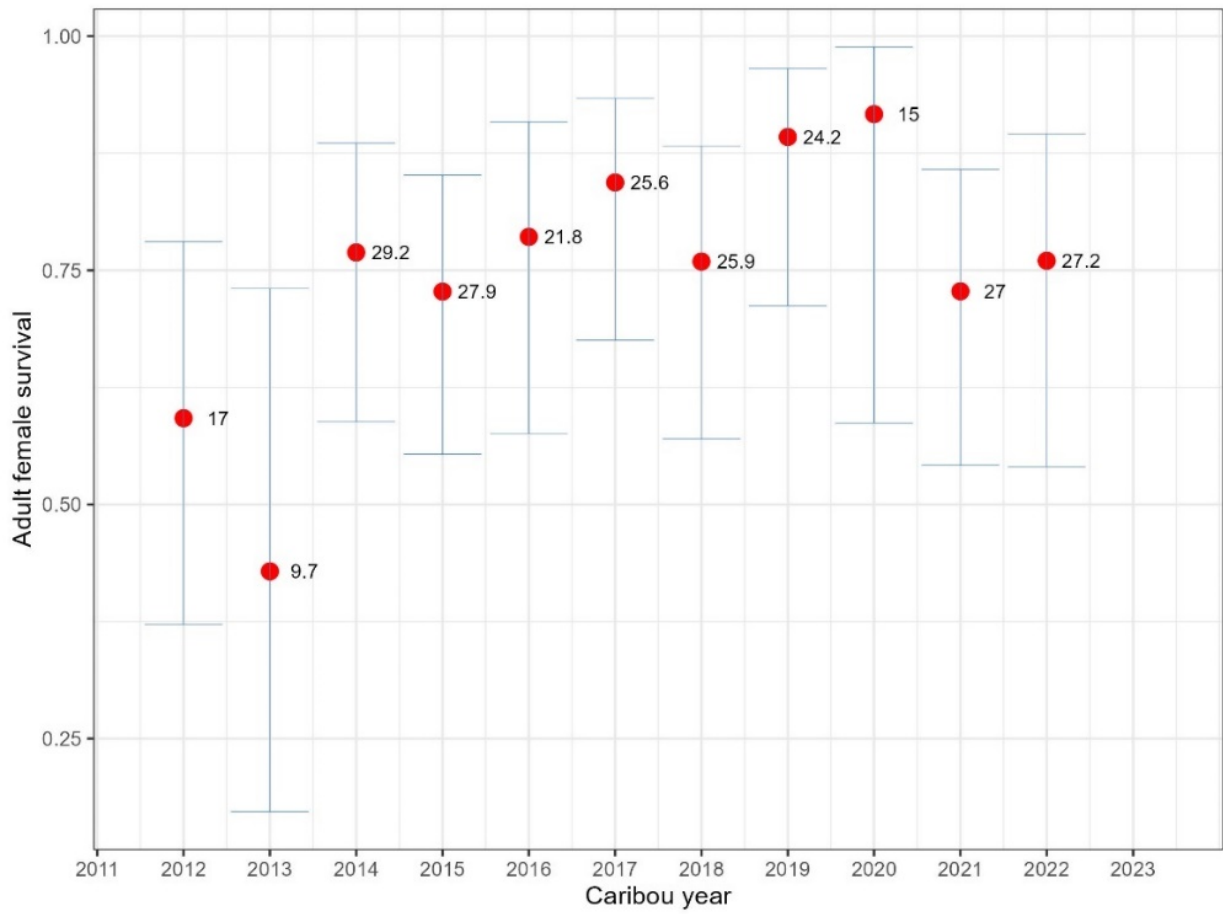


Figure 50. Yearly survival rates for collared adult females. The mean number of collars monitored is given next to each estimate.

4.7 INTEGRATED POPULATION MODEL DEMOGRAPHIC ANALYSIS.

4.7.1 Data sources

Results have yet to be finalized due to ongoing analysis. Final Government of Nunavut File Report will be provided upon completion of analysis.

5.0 CONCLUSIONS

Results have yet to be finalized due to ongoing analysis. Final Government of Nunavut File Report will be provided upon completion of analysis.

6.0 ACKNOWLEDGEMENTS.

The success of any largescale wildlife survey initiative is completely dependant on the quality of the team assembled to complete the task. Our team was made up of 24 individuals of whom 12 were observers from communities on the Beverly range. We wish to extend our most sincere thanks to Cory Barker, David Kavanna, Dennis Larocque, Gary Maksajak, Issac Kaotalok, Jimmy Evalik, John Avalak, Junior Tikhak, Justin Evalik, Mabel Angohiatok, Martina Kapolak, Peter Kapolak, and Rebecca Analok, for their patience through weather and rerouting during the survey, and for their excellent observation skills. We would also like to thank the community HTOs from Baker Lake, Kugluktuk, Cambridge Bay, Kugaaruk, and Gjoa Haven, and AANDC for their help in survey preperations and support in selecting observers. We would like to thank Terry Milton, Leana Davies and Monica Angohiatok from the GN ENV for their excellent observation and data recording skills, and their hard work and commitment to making this survey a success. A special thanks to Joel Consaul with Kenn Borek Air Ltd. for his coordination of fixed winged support and aid in logistic challenges, and to our fixedwing captains Russell Hepburn and Kyle Mclenaghan, and their first officers Jackson Bernard, Griffen Kelly, and Marie-France Lavalle for their exceptional flying skills, and commitment to excellence during the long repetitive days of transect flying, keeping us all safe through often challengeing weather and flying conditions. We would also like to extend a



sincere thanks to Canadian Helicopters pilot Rob Ohalloran and engineer Bryce Zacharias whom both did an exceptional job working remotely in, at times, extremely challenging conditions while maintain high quality operations during the critical composition phase of this survey effort. We would also like to extend a thanks to Jason Shaw with Caslys consulting for their behind the scenes support of the many twists and turns in this survey, and for keeping us updated on collared caribou movements. Finally, we would like to extend a most sincere thanks to our Director Drikus Gissing whom provided unwavering support for this challenging, seemingly on again and off again survey. Simple thanks cannot adequately express our immense appreciation to all those involved in this survey from the observers to the charter companies, organizations, and hotel staff that safely and comfortably, carried, and accommodated our team. Thank you all!

7.0 LITERATURE CITED

Adamczewski, J., A. Gunn, K.G. Poole, A. Hall, J. Nishi, and J. Boulanger. 2015. What happened to the Beverly Caribou Herd after 1994? *Arctic*. Vol.68, No. 4. Pp. 407-421.

Adamczewski, J., J. Boulanger, B. Croft, T. Davison, H. Sayine-Crawford, and B. Tracz. 2017. A comparison of calving and post-calving photo-surveys for the Bluenose-East herd of barren-ground caribou in northern Canada in 2010. *Canadian Wildlife Biology and Management* 6:4-30.

Adamczewski, J., J. Boulanger, H. Sayine-Crawford, J. Nishi, D. Cluff, J. Williams, and L. M. LeClerc. 2019. Estimates of breeding females & adult herd size and analyses of demographics for the Bathurst herd of barren-ground caribou: 2018 calving ground photographic survey. ENR Draft manuscript report No (Draft). Environment and Natural Resources, Government of Northwest Territories.

Adamczewski, J., J. Boulanger, J. Williams, D. Cluff, K. Clark, S. Goodman, K.-S. Chan, R. Abernathy, and J. Nishi. 2022. Estimates of Breeding Females & Adult Herd Size and Analyses of Demographics for The Bathurst Herd of Barren-Ground Caribou: 2021 Calving Ground Photographic Survey Environment and Natural Resources.

Adamczewski, J., J. Williams, and J. Boulanger. 2020. Unusual fall 2020 movements of Bathurst and Beverly caribou, assignment



- of bull collars to herd, and bull fidelity to herds: a summary. Environment and Natural Resources, Govt. of NWT.
- Adamczewski, J., J. Williams, and J. Boulanger. 2023a. March 2023 late-winter composition surveys of Bathurst, Bluenose-East and Beverly barren-ground caribou herds. Environment and Natural Resources, Govt of NWT.
- Adamczewski, J., J. Williams, D. Cluff, and C. Modeste-Burgin. 2023b. Fall 2022 Composition Surveys of Bathurst, Bluenose-East and Beverly Barren-ground Caribou Herds. Environment and Natural Resources Government of the Northwest Territories.
- Banfield, A.W.F. 1951. The Barren-ground Caribou. Canadian Wildlife Service Unpublished Report. 56 pp.
- Boulanger, J., J. Adamczewski, J. Nishi, D. Cluff, J. Williams, H. Sayine-Crawford, and L. LeClerc. 2019. Estimates of breeding females & adult herd size and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2018 calving ground photographic survey, Environment and Natural Resource Manuscript Report No. 278. Government of Northwest Territories, .
- Boulanger, J., J. Adamczewski, J. Williams, D. Cluff, K. Clark, S. Goodman, K.-S. Chan, and R. Abernathy. 2022. Estimates of Breeding Females & Adult Herd Size and Analyses of Demographics for the Bluenose-East Herd of Barren-Ground Caribou: 2021 Calving Ground Photographic Survey Environment and Natural Resources.
- Boulanger, J., J. Adamczewski, J. Williams, S. Goodman, K. Clark, R. Abernathy, and L. LeClerc. 2024. June 2023 Calving Ground

- Surveys: Bluenose-East and Bathurst Barren-Ground Caribou Herds Environment and Climate Change, Govt of Northwest Territories.
- Boulanger, J., M. Campbell, D. Lee, M. Dumond, and J. Nishi. 2014. A double observer method to model variation in sightability of caribou in calving ground surveys. Unpublished manuscript
- Boulanger, J., A. Gunn, J. Adamczewski, and B. Croft. 2011. A data-driven demographic model to explore the decline of the Bathurst caribou herd. *Journal of Wildlife Management* 75:883-896.
- Brownie, C., J. E. Hines, J. D. Nichols, K. H. Pollock, and J. B. Hestbeck. 1993. Capture-recapture studies for multiple strata including non-markovian transitions. *Biometrics* 49:1173-1187.
- Buckland, S., K. Newman, L. Thomas, and N. Koesters. 2004. State-space models for the dynamics of wild animal populations. *Ecological Modelling* 171:157-175.
- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: A practical information theoretic approach. Springer, New York, New York, USA.
- Calef, G.W. 1979. The Population Status of Caribou in the Northwest Territories. NWT Wildlife Service. Progress Report No. 1:30 pp.
- Campbell, M., J. Boulanger, and D. Lee. 2016. Interim report: Estimating abundance of the Qamanirjuaq mainland migratory barren ground sub-population; June 2014. Government of Nunavut, Department of Environment, Arviat, Nunavut.

- Campbell, M., J. Boulanger, D. Lee, M. Dumond, and J. McPhearson. 2012. Calving Ground Abundance Estimates of the Beverly and Ahiak Subpopulations of Barren-Ground Caribou (*Rangifer tarandus groenlandicus*) – June 2011, Technical Summary. Department of Environment, Government of Nunavut.
- Campbell, M., J. Boulanger, J. Ringrose, A. Roberto-Charron, and C. Mutch. 2022. Abundance Estimates of the Northeastern Mainland Tundra Wintering Subpopulations of Barren-Ground Caribou (*Rangifer tarandus groenlandicus*) on the Nunavut Eastern Mainland – June 2021: EXECUTIVE SUMMARY DRAFT REPORT TO THE NUNAVUT DEPARTMENT OF ENVIRONMENT & CO-MANAGEMENT PARTNERS. Department of Environment, Govt. of Nunavut.
- Campbell, M.W., A. Kelly, B. Croft, J.G. Shaw, C.A. Blyth. 2014. Barren-ground Caribou in Nunavut and Northwest Territories – Map Atlas. Government of Nunavut, Department of Environment. Government of Northwest Territories, Department of Environment and Natural Resources. Map series.
- Dauphine, T. C. 1976. Biology of the Kaminuriak population of barren ground caribou, Part 4: Growth, reproduction and energy reserves. Canadian Wildlife Service Report No. 38, Canadian Wildlife Service, Ottawa, Canada.
- GNWT Environment and Natural Resources. 2018. Beverly, Ahiak and Bathurst caribou telemetry, 2008-2018. NWT Wildlife Management Information System. Government of the NWT, Yellowknife.
- Gunn, A. 1984. A Review of Research on the Effects of Human Activities on Barren-Ground Caribou of the Beverly and

Kaminuriak Herds, Northwest Territories.

- Gunn, A. 1996. Caribou Distribution on The Bathurst Calving Grounds, NWT, June 1995. Department of Renewable Resources. Government of the Northwest Territories. Manuscript Report No. 87. 16 pp.
- Gunn, A., and A. D'Hont. 2008. Extent of Calving for the Bathurst and Ahiak Caribou Herds. June 2002. Department of Resources, Wildlife and Economic Development. Government of the NWT. Manuscript Report No. 149. 35pp.
- Gunn, A. and M. Sutherland. 1997. Surveys of the Beverly Caribou Calving Grounds 1957-1994. Dept. of Resources, Wildlife and Economic Development. Government of the Northwest Territories. Yellowknife, NWT. File Report No. 120. 119 pp.
- Gunn, A., Poole, K.G., and J.S. Nishi. 2012. A conceptual model for migratory tundra caribou to explain and predict why shifts in spatial fidelity of breeding cows to their calving grounds are infrequent. Rangifer Special Issue 20: pp. 259-267.
- Gunn, A. and R. Decker. 1982. Survey of the Calving Grounds of the Beverly Caribou Herd, 1980. Northwest Territories Wildlife Service. Government of the Northwest Territories. File Report No. 20. 27 pp.
- Gunn, A., B. Fournier, and R. Morrison. 2000. Seasonal Movements and Distribution of Satellite-Collared Caribou Cows on the Boothia and Simpson Peninsula Areas, NWT, 1991-1993. Department of Resources, Wildlife and Economic Development. Government of the NWT. Manuscript Report No. 126. 77 pp.



- Gunn, A., K. G. Poole, and J.S. Nishi. 2010. A Conceptual Model for Migratory Tundra Caribou to Explain and Predict Why Shifts in Spatial Fidelity of Breeding Cows to Their Calving Grounds Are Infrequent. *Rangifer*, Special Issue No. 20: 259-267.
- Heard, D. 1985. Caribou Census Methods Used in the Northwest Territories. *In* Proceedings of the 2nd North American Caribou Workshop. McGill Subarctic Research Paper 40: 229-238.
- Heard, D. C. 1987. Allocation of effort in a stratified survey design. Department of Renewable Resources, Government of Northwest Territories.
- Heard, D.C., and F.J. Jackson. 1990. Beverly Calving Ground Survey June 2-14, 1988. Dept. of Ren. Res. Government of the NWT. Yellowknife. File Report No. 86. 27 pp.
- Heard, D. C., and J. Williams. 1991. Bathurst calving ground survey, June 1986. Government of Northwest Territories, Yellowknife, NWT.
- Hestbeck, J. B., J. D. Nichols, and R. A. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. *Ecology* 72:523-533.
- Innes, S., M. P. Heidi-Jorgensen, J. L. Laake, K. L. Laidre, H. J. Cleator, P. Richard, and R. E. A. Stewart. 2002. Surveys of belugas and narwhals in the Canadian High Arctic. NAMMMCO Scientific Publications No. 3.
- InterGroup Consultants Ltd. 2008. Economic Valuation and Socio-Cultural Perspectives of the Estimated Harvest of the Beverly and Qamanirjuaq Caribou Herds. Prepared for the Beverly and Qamanirjuaq Caribou Management Board By; InterGroup

- Consultants Ltd. Winnipeg, Manitoba. Contractual Report submitted May 1st, 2008. 52 pp.
- Johnson, D. and R. Mulders. 2002. Beverly Calving Ground Survey, June 2002. Department of Resources, Wildlife and Economic Development. Government of the Northwest Territories. Yellowknife, NWT. Manuscript Report No. 188. 63pp.
- Johnson, D. and J. Williams. 2008. Beverly Herd Barren-Ground Caribou: Calving Ground Survey, June 2008. Department of Environment and Natural Resources. Government of the NWT. Unpublished Manuscript Report. 63 pp.
- Johnson, D., J. Nagy and J. Williams. 2008. Calving Ground Surveys of the Ahiak Herd of Barren Ground Caribou June 2006-2008. Department of Environment and Natural Resources. Government of the NWT. Manuscript Report No. XX. 34 pp.
- Jolly, G. M. 1969. Sampling methods for aerial censuses of wildlife populations. *East African Agricultural and Forestry Journal* 34:46-49.
- Kery, M., and M. Schaub. 2012. Bayesian population analyses using WinBugs: A hierarchical perspective. Volume 1. Academic Press, Watham, Massachussets, USA.
- Krebs, C. J. 1998. *Ecological Methodology* (Second edition). Benjamin Cummins, Menlo Park, California.
- Laake, J., D. L. Borchers, L. Thomas, D. Miller, and J. Bishop. 2012. Mark-recapture distance sampling (MRDS) 2.1.0. R statistical package program.

- Laake, J., M. J. Dawson, and J. Hone. 2008a. Visibility bias in aerial survey: mark-recapture, line-transect or both? *Wildlife Research* 35:299-309.
- Laake, J., R. J. Guenzel, J. L. Bengtson, P. Boveng, M. Cameron, and M. B. Hanson. 2008b. Coping with variation in aerial survey protocol for line-transect sampling. *Wildlife Research* 35:289-298.
- Manly, B. F. J. 1997. *Randomization and Monte Carlo Methods in Biology*. 2nd edition. Chapman and Hall, New York.
- Marshall, L. 2021. Distance Sampling Survey Design: dssd R package.
- Moshenko, D.J. 1974. Beverly Lake Caribou Calving Ground Survey. NWT Game Manage. Div. Report. 17pp.
- Nagy, J. and M.W. Campbell. 2012. Herd Structure, Movements, Calving Grounds, Activity Periods, Home Range Similarity, and Behaviours of Migratory and Tundra-Wintering Barren-Ground Caribou on Mainland Nunavut and Eastern Mainland Northwest Territories, Canada. Nunavut Department of Environment. Wildlife Research Section. Technical Report Series. No. 01-12. 152 pp.
- Nagy, J.A.S. 2011. Use of Space by Caribou in Northern Canada. Department of Biological Sciences. University of Alberta. Edmonton Alberta. PhD Thesis. 164 pp.
- Nagy, J.A., D.L. Johnson, N.C. Larter, M.W. Campbell, A.E. Derocher, A. Kelly, M. Dumond, D. Allaire, and B. Croft. 2011. Subpopulation Structure of Caribou (*Rangifer tarandus L.*) in Arctic and Subarctic Canada. *Ecological Applications*. 21(6): 2334-2348.

- Norton-Griffiths, M. 1978. Counting Animals. Serengeti Ecological Monitoring Programme Handbook No. 1. Afropress Ltd., Nairobi Kenya. 139 pp.
- Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53:7-15.
- QGIS Foundation. 2020. QGIS Geographic Information System. QGIS Association. <http://www.qgis.org>.
- R Development Core Team. 2009. R Foundation for Statistical Computing, Vienna, Austria.
- Ramey, R. R., J. L. Thorley, and A. S. Ivey. 2018. Local and population-level responses of Greater sage-grouse to oil and gas development and climatic variation in Wyoming. *Peer J.* 6: doi:10.7717/peerj.5417.
- Rippin, B. 1971. Beverly Lake Caribou Calving Ground Survey. NWT Game Manage. Division Report.
- Schaub, M., and M. Kery. 2022. *Integrated Population Models*. Academic Press, London, UK.
- Seber, G. A. F. 1982. *The Estimation of Animal Abundance*. 2nd edition. Charles Griffin and Company, London.
- Stephenson, B., R. Decker, and A. Gunn. 1984. Calving Ground Survey of the Beverly Caribou Herd, 1982. Dept. of Renewable Resources. Government of the Northwest Territories. Yellowknife, NWT. File Report No. 28. 34 pp.

- Sutherland, M., and A. Gunn. 1996. Bathurst Calving Ground Surveys 1965-1996. Department of Resources Wildlife and Economic Development. Government of the Northwest Territories. File Report No. 118. 97 pp.
- Thomas, D.C. 1969. Population Estimates of Barren-Ground Caribou March to May, 1967. Can. Wildl. Serv. Report Series No. 9. 44pp.
- Thomas, D.C. and S.J Barry. 1990. Age-Specific Fecundity of the Beverly Herd of Barren-Ground Caribou. Rangifer, Special Issue. No. 3. 257-263.
- Thomas, D.C. and H.P.L. Kiliaan. 1985. Movements and Physical Condition of the Beverly Herd of Caribou in Early Winter 1984-85. Canadian Wildlife Service Report. 24 pp.
- Thompson, S. K. 1992. Sampling. John Wiley and Sons, New York.
- Thorley, J. L., and J. Boulanger. 2019. Bluenose-East Caribou Herd Population Analysis 2018. *in* J. Boulanger, J. Adamczewski, J. Nishi, D. Cluff, J. Williams, L. M. LeClerc, and B. Croft, editors. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2018 calving ground photographic survey. Environment and Natural Resource, Government of Northwest Territories, Yellowknife, NWT.
- Thorley, J. L. A., G.F. 2017. The fishing and natural mortality of large, piscivorous Bull Trout and Rainbow Trout in Kootenay Lake, British Columbia (2008–2013). . Peer J. 5:doi 10.7717/peerj.2874.

- White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study Supplement* 46:120-138.
- White, G. C., and B. Lubow. 2002. Fitting population models to multiple sources of observed data. *Journal of Wildlife Management* 66:300-309.
- White, G. C., W. L. Kendall, and R. Barker. 2006. Multistate models and their extensions in program MARK. *Journal of Wildlife Management* 70:1521-1529.
- Wickham, H. 2009. *ggplot2: Elegant graphics for data analysis*. Springer, New York.
- Wiken, E. 1986. *Terrestrial Ecozones of Canada*. Ecological Land Classification Series, No. 19. Environment Canada. Ottawa, Ont. ISBN 0-662-14761-8.
- Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. *Analysis and management of animal populations*. Academic Press, San Diego.
- Williams, M.T. and D.C. Heard. 1990. Bathurst and Beverly Caribou Herd Spring Classification Counts, February and March 1984. Dept. of Renewable Resources. Government of the Northwest Territories. Yellowknife, NWT. File Report No. 83. 28 pp.
- Williams M., D. Heard and F. Jackson. 1989. Spring Composition Summaries for the Kaminuriak, Beverly, Bathurst and Bluenose Caribou Herds, 1986 - 1989. Department of Renewable Resources. Government of The Northwest Territories. Unpublished Report. 28 pp.

Williams, T. M. 1995. Beverly Calving Ground Surveys June 1993 and 1994. Department of Renewable Resources GNWT, Yellowknife. File report No. 114:

Worton, B. 1989. Kernel methods for estimating the utilization distribution in home range studies. *Ecology*. 70: pp. 164-168.