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

FILE REPORT

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ABSTRACT

The Beverly 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). The ACCA has historically been concentrated in the vicinity of Beverly Lake but in more recent years has shifted to the vicinity of the Queen Maud Gulf and Adelaide Peninsula, Nunavut. Abundance estimates developed over the last three decades suggested 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 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 an Integrated Population Model (IPM).

Similar to 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 inform the stratification of the survey area by caribou density. Following reconnaissance, we flew a combination of a stratified systematic aerial transect visual and video surveys to estimate the number of adult and yearling female and breeding female caribou within the Beverly ACCA. Our survey protocol employed a dependent double observer pair method, 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 female 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 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 using composition survey results. Finally, whole herd estimates were extrapolated using sex ratios quantified during fall composition studies.

The June 2023 abundance survey yielded a breeding female estimate of 69,900 (95% CI = 59,135-82,837; CV = 9.2%) and a total adult female estimate of 88,236, (95% CI = 75,564-103,033; CV = 8.3%). The resulting estimate documents a significant increase in Beverly caribou breeding female and female abundance and reversal in the previously observed declining trend documented during June 2011 survey estimating 67,414 (95% CI = 61,257-74,190; CV = 4.8%) breeding females and 80,705 (95% CI = 73,636-88,452; CV = 4.6%) females, and June 2018 survey estimating 48,977 (95% CI = 44,056-54,448; CV = 5.3%) breeding females and 61,070 (95% CI = 55,583-67,099; CV = 4.7%) females.

The 2023 extrapolated whole herd estimate for the Beverly herd was 152,131 (95% CI = 124,704-179,558; CV = 8.5%) adults. This estimate was significantly larger than the 2018 whole herd estimate of 103,372 (95% CI = 93,684-114,061; CV = 4.9%) documenting a yearly 8% increase for both female and whole herd estimates. The increase from 2018 to 2023 reverses a yearly 4-5% decline based on the 2018 and 2011 whole herd estimates of 136,608 and 103,372, respectively.

Analysis of cow collar locations document directional movement of caribou from the Bathurst herd to the Beverly and multi-directional movement between the Beverly herd and Ahiak herds calving ground. An integrated population model (IPM), which considers all data sources (collars, calving ground surveys, and compositions surveys) was applied to explore demographic factors as well as the relative influence on movements, herd status, and trend. Combinations of Ahiak and Beverly movements suggest that movements were relatively balanced between the two calving ground areas with only a slight net movement into the Beverly calving-ground. However, the ability of the IPM to detect annual variation in movements was limited due to sparse data. Bathurst directional movement into the Beverly did occur in many years however the overall impact to Beverly herd size was relatively low given the reduced size of the Bathurst herd. High productivity levels were estimated for the Beverly which was one of the main drivers of demographic increase given that estimated collar-based survival levels were moderate. When movement and demography was modeled, estimates from the IPM were within the confidence limits of the 2023 adult female herd estimate suggesting that movement and demography could explain the increase in magnitude of the 2023 abundance estimate when compared to the 2018 abundance estimate.

We make recommendations for the enhancement of future calving ground surveys including the use of video assisted counts, focused IPM analyses that consider neighboring herds in the same analysis, and a hybrid distance sampling visual survey method to improve robustness of estimates to sight ability bias.

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 Penninsula, Nunavut, *Rangifer tarandus groenlandicus*, abundance, population survey, decline, Integrated Population Model.

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1.0 INTRODUCTION

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). Samuel 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)**.

It wasn't until the mid-1900's that that an increase in demographic studies of the barren-ground caribou herds east of the Hudson Bay was realized (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). The most prominent mainland migratory herds during this period included the Bathurst, Beverly, and Porcupine herds (then thought to be stable), and the Qamanirjuaq herd (then thought to be declining). It was during this period of heightened research that more poorly understood subpopulations including the Melville Peninsula, Wager Bay, Cape Bathurst, and Bluenose herds (then thought to be increasing) were being more thoroughly defined (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. 2019). Since 2011, reconnaissance surveys conducted in 2013, 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/km^2) to conduct a photo-survey (Johnson et al., 2008). In the following years, the Government of the Northwest Territories (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/km^2, unpublished GNWT data). At the time, these results suggested a severe decline in the Beverly subpopulation. 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 ACCA (also known as their traditional calving grounds), to the western Queen Maud Gulf Lowlands (QMGL) and south and western extents of Adelaide Peninsula (Nagy et al. 2011; Campbell et al., 2012; Campbell et al., 2019). The knowledge of local hunters (Baker Lake, Gjoa Haven, and Kugaaruk Hunters and Trappers Organization [HTO] meetings and pers. comm.) agreed that the Beverly herd had been calving further north from 2007 to present. 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 neighboring herds into the Beverly survey study area during a survey effort. 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 the Bathurst 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 Sutherland and Gunn, 1996). Bathurst adult cow telemetry data collected by the GNWT from 2007 to present 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 Herd (a tundra wintering caribou subpopulation which is 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., 2019, 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 analysis of Northeast Mainland (NEM) caribou telemetry suggests the main calving area for the Ahiak subpopulation extends from the Adelaide Peninsula to the west coast of Simpson Peninsula, with the majority of calving occurring east of Chantrey Inlet, suggesting considerable separation between the herds. Though variable from year to year, there has been 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. 2019).

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). 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., 2019). This survey method has been incorporated into used in all Beverly caribou surveys (both reconnaissance and abundance) to present. Where densities permit, this method employs more local survey observers, is 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 to 20 caribou/km^2 are encountered (Cook and Jacobsen 1979, Buckland et al. 2010). When caribou densities fall within the suggested limits, 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 to 20 caribou/km^2, 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 when planning an abundance survey as it can be influenced by a number factors including changes in productivity and associated abundance between surveys, changes in spring melt and runoff along migratory routes, and/or other environmental or anthropogenic changes or disturbances that can modify caribou movements and distributions. For this reason, communication with aerial photography charter companies is always developed and maintained during all planned Beverly calving-ground abundance surveys.

Reconnaissance survey observations flown by the GNWT between 2007 and 2010 all reported group sizes and associated densities below the 15-20 caribou/km^2 threshold with very rare exceptions, while Government of Nunavut (GN) reconnaissance surveys flown between June 2010 and 2018 showed similar densities with only rare groupings of greater than 15 to 20 caribou/km^2 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 recommended threshold.

Our main objective for the June 2023 survey was to obtain an estimate of adult female 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 environmental and logistic challenges 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 add to the assessment of caribou subpopulations in the region, and to inform interjurisdictional and jurisdictional co-management efforts.

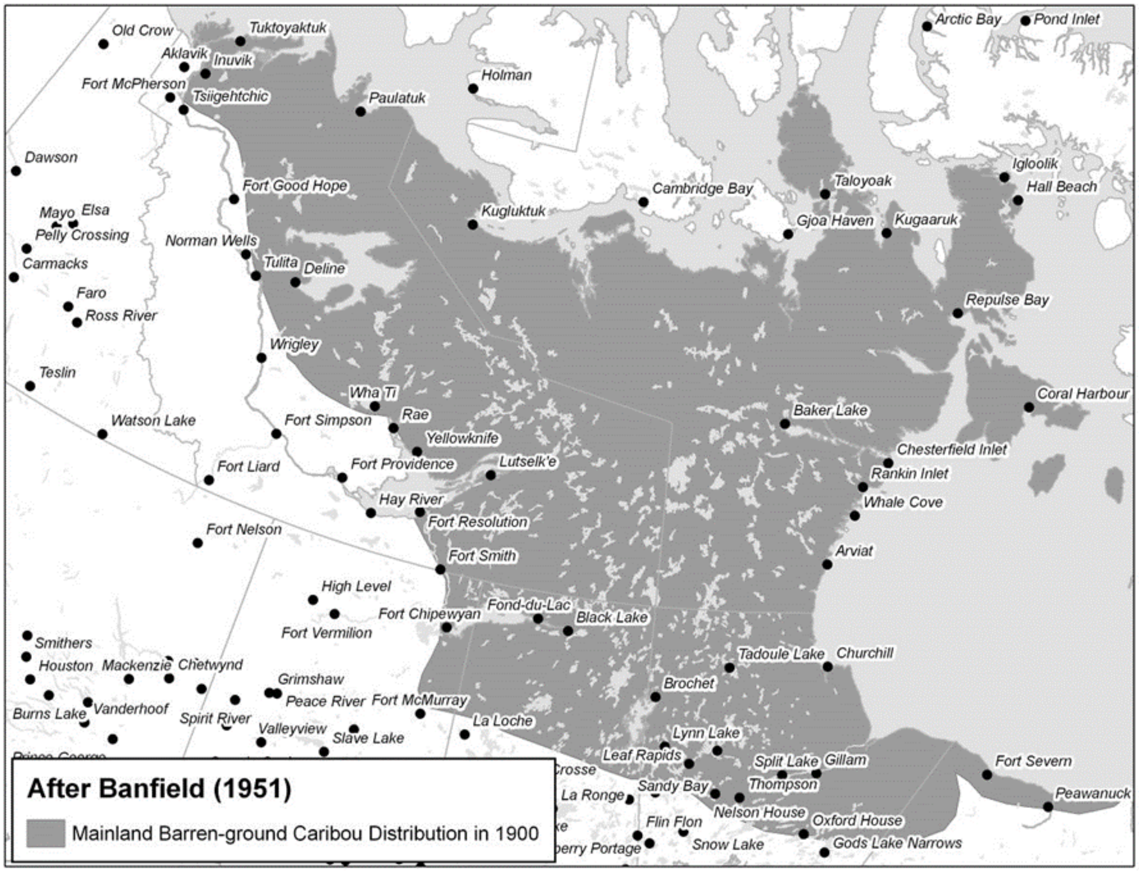


Figure 1. Mainland barren-ground caribou distribution based on local observations and studies from the early 1900s (after Banfield, 1951).

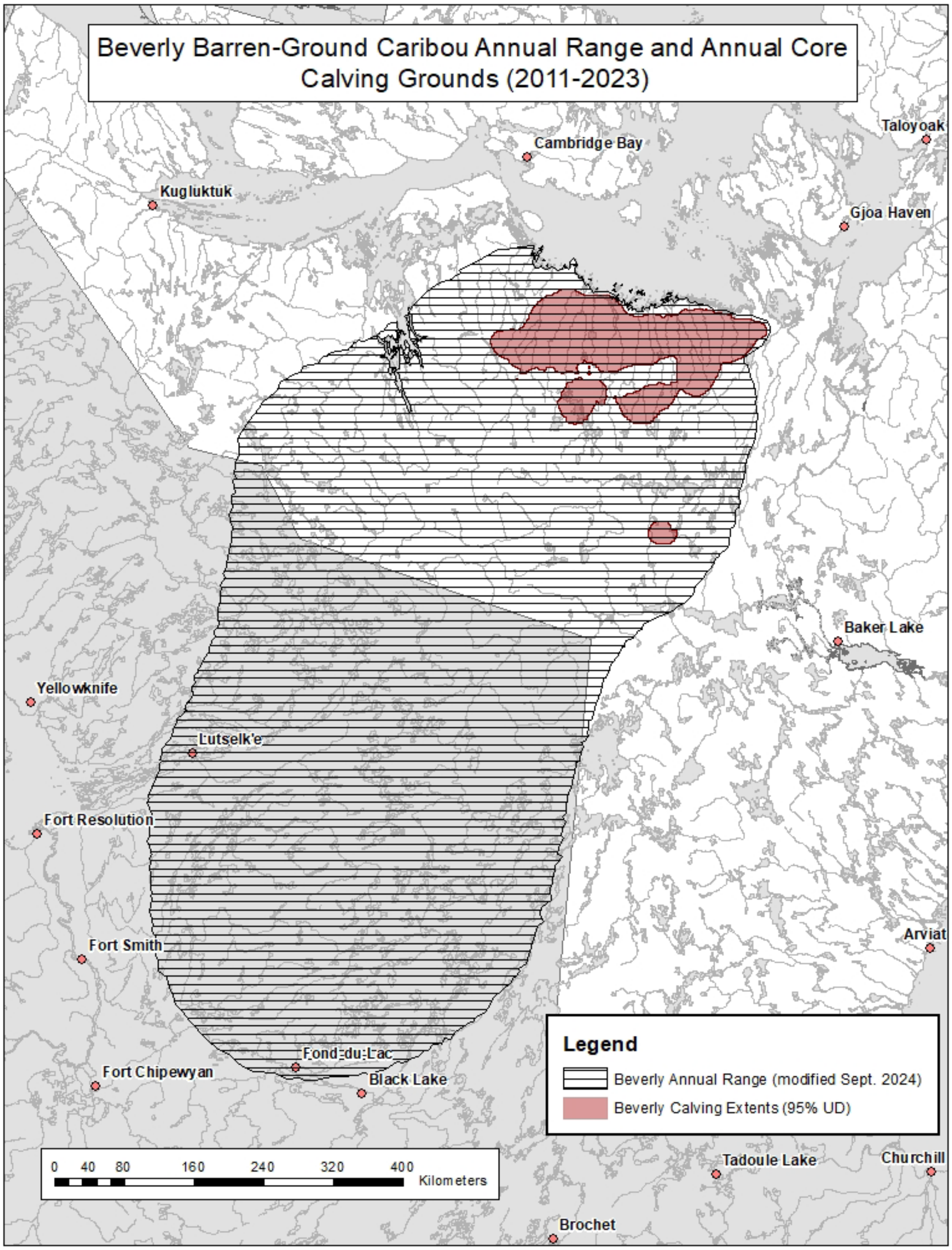


Figure 2. The annual range and concentrated calving grounds of the Beverly barren-ground caribou subpopulation. Calving polygons based on kernel analysis of all available telemetry data current to July 2023 and representing the 95% utilization distribution. Annual range extents modified from Nagy and Campbell (2012) to reflect calving data current to July 2023.

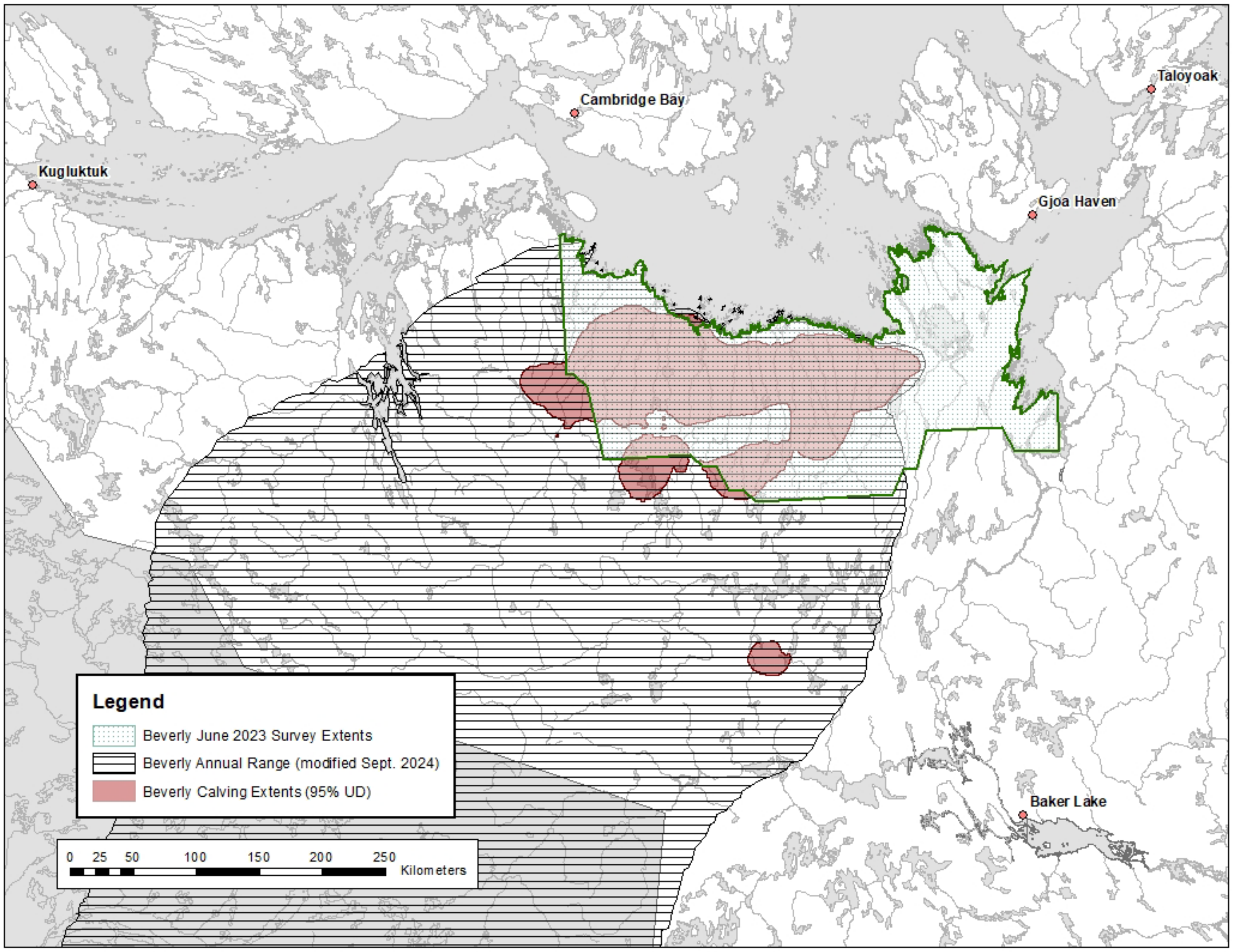


Figure 3. The June 2023 calving-ground abundance survey extents (Green) including annual core calving grounds (red) and annual range (Black). Calving polygons based on kernel analysis of all available telemetry data current to July 2023 and representing the 95% utilization distribution. Annual range 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 km^2 (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 (QMG) calving extents, was estimated using kernel analysis, and found to be 38,491 km^2. By way of comparison, the historical pre-2011 Beverly Lakes ACCA was an estimated 16,131 km^2 or 41% of post 2011 QMG extents (Nagy et al. 2011, Nagy and Campbell 2012, Campbell et al. 2014). The majority of the ACCA, 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, within the Beverly subpopulation's annual range.

The June 2023 Beverly calving ground survey area covered an estimated 73,184 km^2. It extended south from the shores of the Queen Maud Gulf and northern and eastern 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). The Beverly subpopulation's annual range extends from the Southern Arctic Ecozone south through the Taiga Shield Ecozone (Wiken, 1986) 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 (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 Ericatious 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 offering protection to much of the Beverly ACCA (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). Though the annual range of the Beverly subpopulation crosses into Saskatchewan, the combined 95% utilization distribution of all Beverly seasonal ranges do not.

Season	Total Area (km^2)	NU Area (km^2)	NWT Area (km^2)	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 Migration	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%

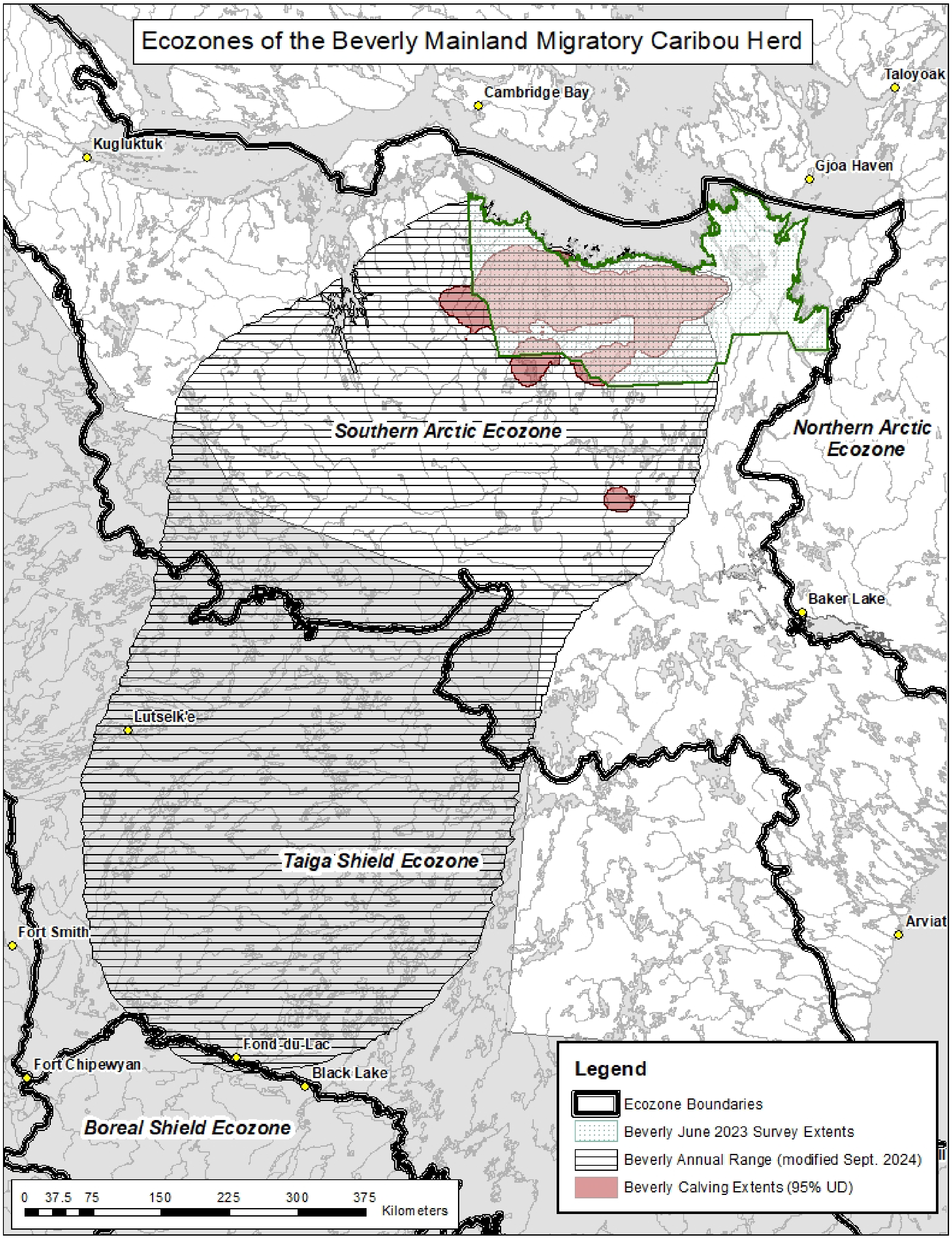


Figure 4. Ecozones of the Beverly barren-ground caribou subpopulations annual range extents and annual concentrated calving areas (ACCA) (Wiken, 1986, Ecological Stratification Working Group 1996, Campbell et al. 2014 & 2019).

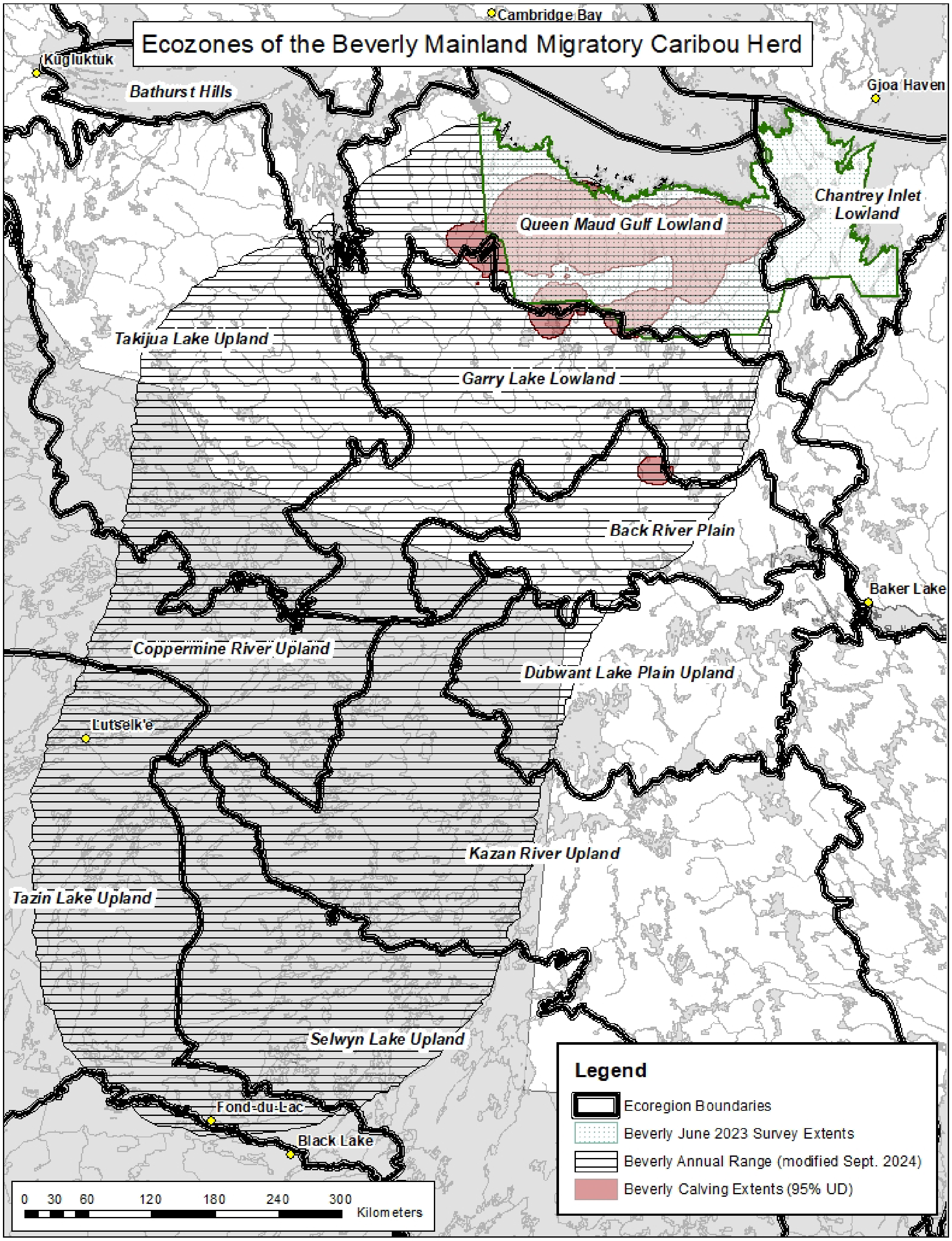


Figure 5. Ecoregions of the Beverly barren-ground caribou subpopulations annual range extents and annual concentrated calving areas (ACCA) (Wiken, 1986, Ecological Stratification Working Group 1996, Campbell et al. 2014).

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 in June 2023 necessitated a redesign of survey logistics with Cambridge Bay as the sole base of operations. This change did not impact survey quality but increased survey costs and ferrying time at the beginning and end of each flying day.

The abundance estimate used 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 a previously undocumented and uncharacteristic clumping of calving Beverly caribou observed on the 2023 calving ground. Though a contingency to use 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 used 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, reduce the probability of either double counting and/or under counting (due to movement over time) caribou within the study area, and to involve more HTO representation within survey aircraft. At the same time as the video and visual surveys, 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 used fall composition data collected during the rutting period in October 2022 by GNWT Biologists (Adamczewski et al. 2024). 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 employed 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, were comprised of 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 Twin 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 (Campbell et al. 2012) and were calculated using the formula from Norton-Griffiths (1978):

$$w = W*(h/H)$$

where W is the strip width, H is the flight height, h is the observer height when the plane is on the ground and w is measured and marked on the ground to position wing strut marks (**Figure 6**).

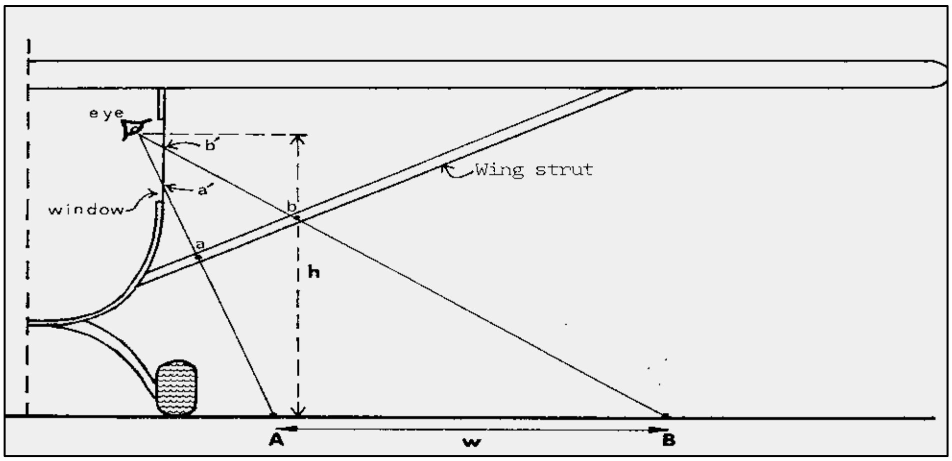


Figure 6. Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978).

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 (both reconnaissance and abundance 2008 to 2018), larger than expected group sizes (>100 caribou/km^2) of caribou were observed during the 2023 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 due to mechanical problems necessitating an alternative 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 utilizing 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 in plane 1, and two iPhone 12 smartphones in plane 2, on each on the left and right sides of each plane. The field of view of the video spanned the entire strip width and included the leading edge of the struts with associated strip width markings. This video, or secondary counting method, allowed for a simultaneous visual count of the same groupings 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 equaled or exceeded 15 percent. The reconnaissance survey is a low coverage survey (9%) used to survey known calving extents, as well as beyond known calving extents when justified, 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 geographically explicit relative densities of caribou and their general composition (such as breeding and non-breeding females). The results of the reconnaissance survey are then used to calculate and plot relative densities of females for the purposes of stratification, with areas of similar density grouped together into strata for the abundance phase of the survey. Defining strata in this way increases precision of the population estimate and informs on the counting method required to maximize accuracy.

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 Ellice River to Committee Bay **(Figure 10)** using UTM coordinates and the WGS 84 datum. Reconnaissance transects covered 7,570 linear kilometers and observed an area estimated to cover 6,056 km^2. 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 km^2 (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 (number of observations per 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 Beverly herd calving ground and assess their breeding status. To achieve this, the survey area was stratified following the results of a systematic reconnaissance survey. Survey stratification involved grouping neighboring segments with similar density into contiguous areas termed strata, so that each stratum enveloped distributions of similar caribou densities. In addition, stratification was used to determine if stratum density summaries where high enough to require the use of a photo survey plane (> 20 caribou/km^2), or if visual observation methods could be used. In this survey, two higher-density strata were identified; these strata were planned to be addressed, at least in part, using photographic methods. Other strata that had lower densities of caribou (< 20 caribou/km^2) were flown using visual survey methods alone. Given that the objective of the survey was to estimate breeding females and total females, priority, as defined by survey effort, 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 within each stratum. Within each stratum, transects were aligned at right angles to the longitudinal axis of the stratum to maximize the total number of transects (N). Transect placement for each stratum began with the initial random placement of the first transect perpendicular to a line running through the stratum parallel to its longest axis, with 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, a power analysis of previous survey data 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 (Boulanger 2020). In the context of sampling, increasing the number of lines in a stratum minimizes the influence of any one transect 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 survey and coordinated abundance strata composition surveys immediately followed the reconnaissance survey. This quick turnaround was necessary to minimize the effects of the movement of caribou between newly delineated abundance strata based on reconnaissance observations. 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 the collection of composition data from the fixed wing aircraft was optional. Both the abundance and composition surveys were completed as quickly as possible while prioritizing good sightability. 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 rotary aircraft to complete abundance strata composition. Sampling was structured to begin at a fuel cache and then proceed to a predetermined transect station within a minimum of two (2) kilometers from the strata corner/boundary. From this transect station the aircraft would proceed to the next nearest transect station to the north and/or south, prioritizing the sampling of the next nearest caribou group (including individuals) encountered on route. Transect stations (each 10 km apart) were selectively used to fly rough transects aimed to equally distribute composition effort (Campbell et al. 2012). At times, observed groups of caribou drew the aircraft away 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 between transect stations. From this point, only caribou groups observed within this five-kilometer buffer would be sampled and an attempt to rejoin the original flight path was made while sampling any groups of caribou encountered. During re-positioning flights from the stratum to the fuel caches, caribou encountered within a minimum 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 re-fueling routes.

During composition surveys caribou were classified as yearlings (≥ 1 year and < 2 years of age), bulls, cows with calves (calves < one month old), calves (< 1 year of age or short yearlings), cows with udders, udderless (udders not visible) 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, calves, yearlings, and young and mature bulls, for each stratum surveyed on the calving ground.

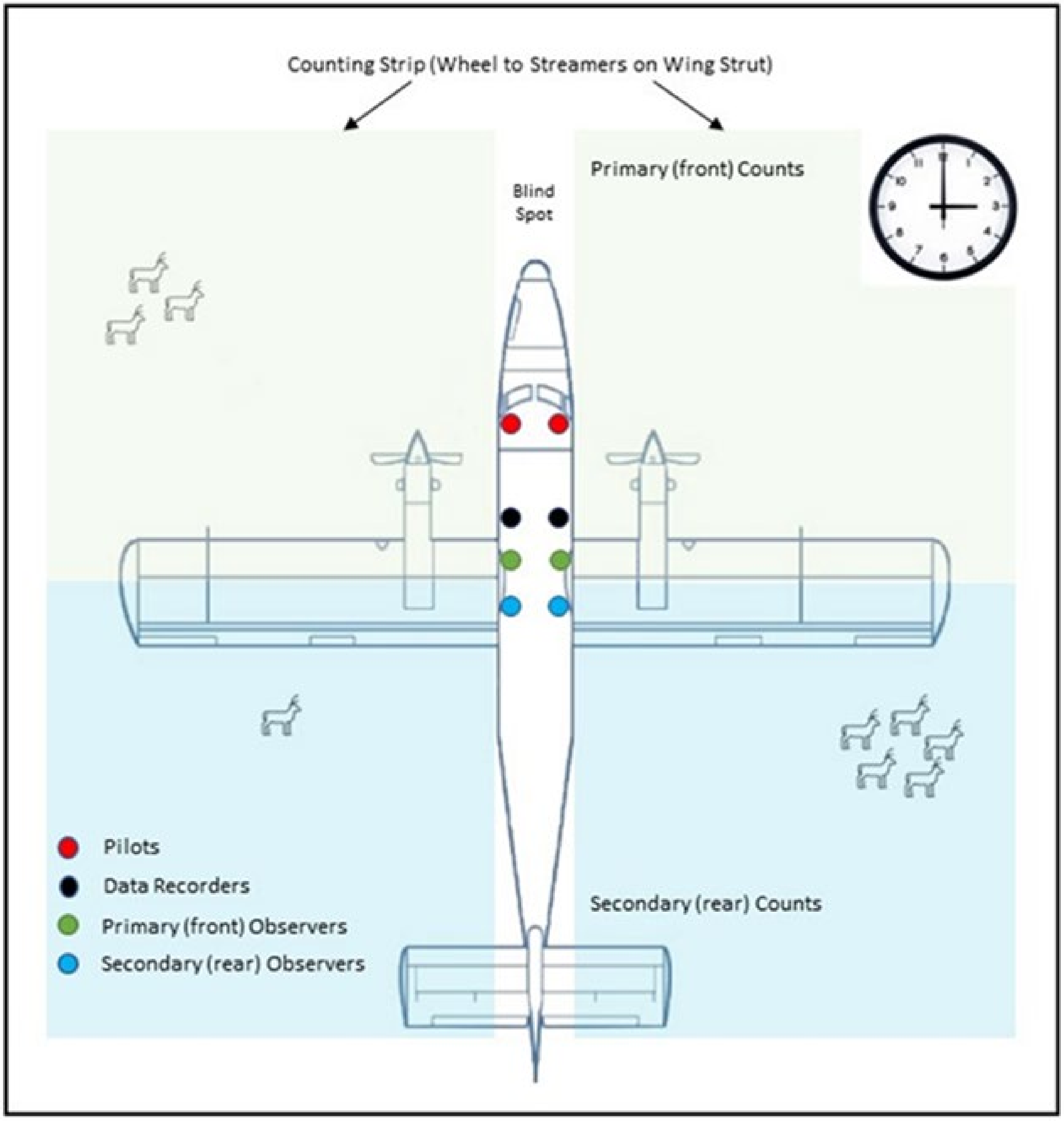


Figure 7. Observer position for double observer methods. The secondary (rear) observer calls caribou not seen by the primary (front) observer after the caribou have passed the main field of vision of the primary observer. Time on a clock is used to reference relative locations of caribou groups (e.g.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

Figure 8. A Samsung S22 smartphone mounted on the window on the right side of the aircraft at the data recorders seat.

Figure 9. Screen shot from videos used for secondary video counts of caribou (note caribou within both video frames). This image taken from the data recorders seat on the right-hand side of the aircraft (note the inclusion of the leading edge of the wing strut and transect width markers). Excellent sightability conditions are evident with clear skies and no snow cover.

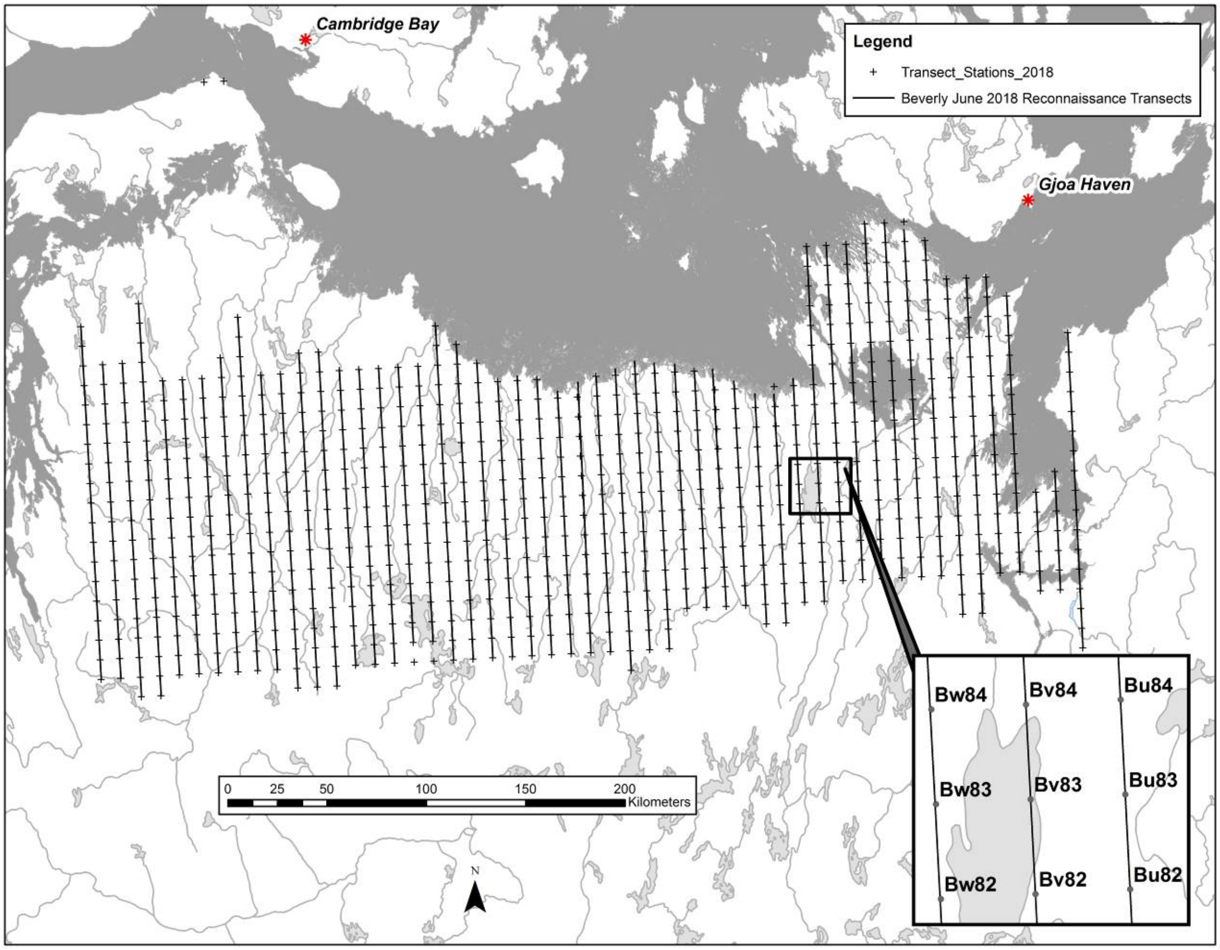


Figure 10. Reconnaissance transects and transect stations (lower right) of the Beverly 2023 calving ground abundance survey. Transects placed to cover the known extents of female caribou based on previous surveys and collar telemetry.

Table 2. A comparison between the June 2011, 2018, and 2023 Beverly mainland migratory caribou subpopulation abundance survey timing. Survey timing based on an observed reduction of daily collared caribou cow 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	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			

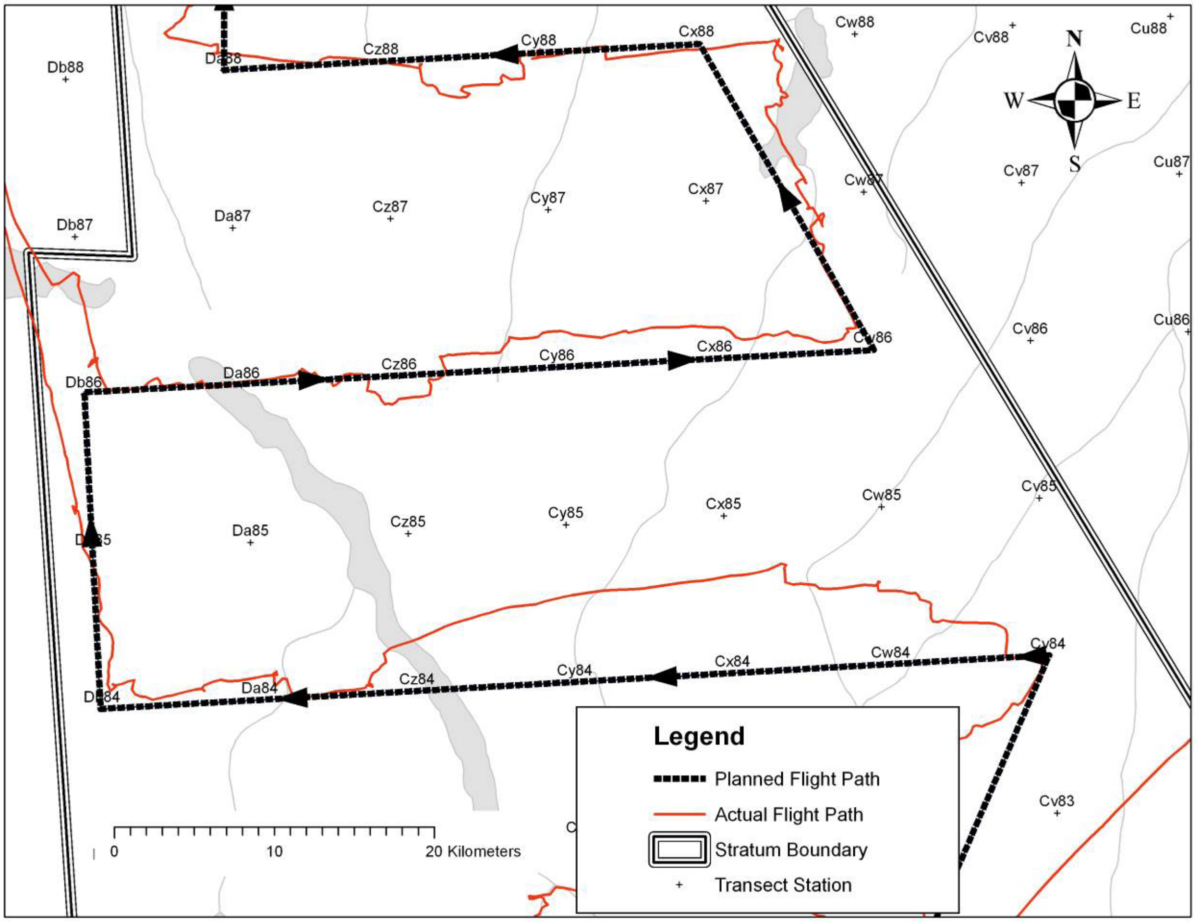


Figure 11. Stratum composition flight methods used during the 2023 Beverly calving ground survey vs. planned routes. Actual track deviations (red line) away from planned routes (black lines) were required to classify all observed caribou groups. The next nearest group would be classified up to a maximum 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 images were generated without georeferencing information due to the data capture method so manual georeferencing was achieved using landscape features from basemap imagery, and an approximate location from the video capture time and aircraft GPS data. The orthomosaic images 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, methods to increase the accuracy in caribou identification were developed. 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 image. 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 image 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 fell outside of the actual 400m survey strip or were "Off Transect". For this reason, a 400m survey strip was overlaid on the orthomosaic images 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 image (**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 image. As in the visual double observer survey method, orthomosaic images often did not overlap the actual transect line due to the blind spot 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 image. To confront this uncertainty, the distance from each tablet waypoint to the nearest orthomosaic image (on the same side of the plane of the waypoint) was estimated. Tablet waypoints were then paired with the orthomosaic image location based on a series of threshold distances of the waypoint from the polygon ranging from 200 to 1,500 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 image, 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).

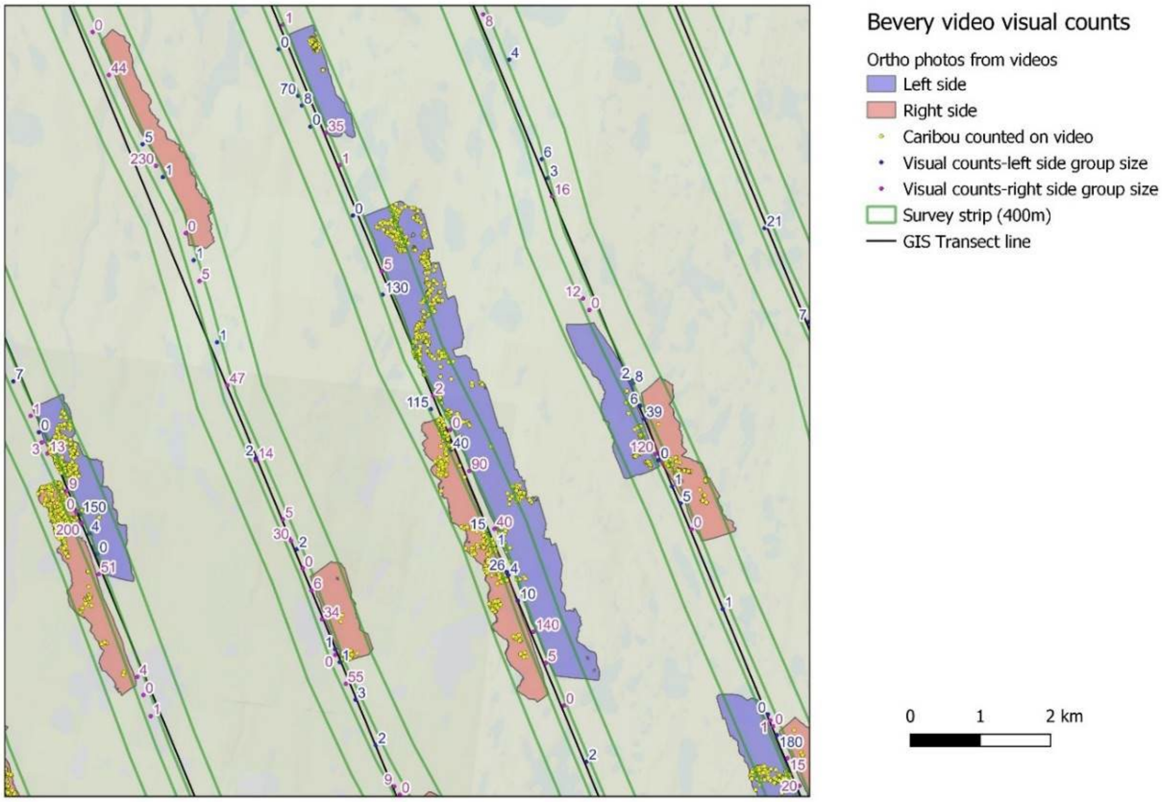


Figure 12. Example of orthomosaic polygons compared to visual observations. The 400m survey strip is outlined in green. The count of caribou groups from the survey plane is labelled next to each waypoint with caribou counted on orthophotos delineated by yellow points.

3.3 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).

3.3.1 Modelling of Visual Sighting Probability Variation

For the visual component of the survey 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 3**). 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) 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 3**). 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 3. Covariates used to model variation in sightability for double observer analysis.

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

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

Calving-ground composition surveys were conducted concurrently with visual surveys. 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 resampling's 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).

3.3.3 Analysis of Fall Composition Data

Composition surveys were conducted in the fall of 2022 by the Government of the Northwest Territories (Adamczewski et al. 2024). 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, a bootstrap process using 1,000 resamples was conducted on the original data set (Manly 1997).

3.3.4 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 conducted in October 2022 (Adamczewski et al. 2024) 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 the 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 Climate Change (ECC), Government of Northwest Territories) using bull data retrieved from the ECC database (Adamczewski et al. 2020, Adamczewski et al. 2024).

3.4 COLLAR ANALYSIS

3.4.1 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 locations of collared females were classified based on calving ground location. Using this information, movements between calving grounds as well as fidelity were assessed graphically. Multi-state models (Hestbeck et al. 1991, Brownie et al. 1993, White et al 2006) 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.

3.4.2 Survival Rate Analysis

Collar data collected for female caribou from 2011-2023 were compiled for the Beverly caribou herd by GNWT ECC staff. Fates of collared caribou were determined by assessing the movement of collared caribou cows, with mortality being assigned to collared caribou based on lack of collar movement over an extended period unrelated to 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 indicating 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. This IPM has been applied to both the Bathurst and Bluenose-East herds since 2012 (Boulanger et al 2024). A state space model allows separate modelling of field sampling estimates and demographic processes. This work was in collaboration with a Bayesian statistician/modeler (Joe Thorley-Poisson Consulting) (Thorley 2017, Ramey et al. 2018, Thorley and Boulanger 2019). Details of the IPM are given in **Appendix A**.

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 (Boulanger 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 (i.e. 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.

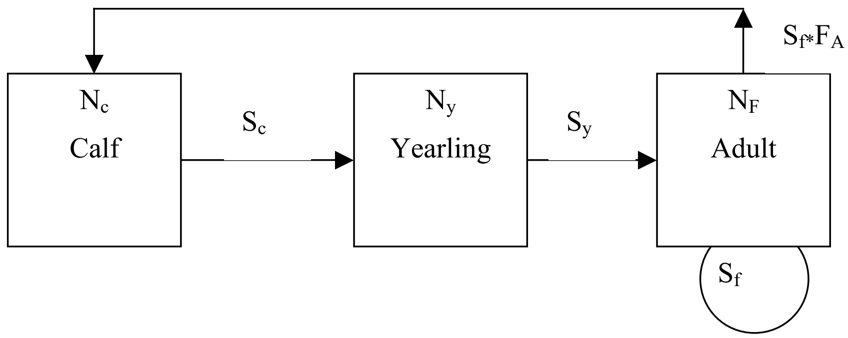


Figure 13. Underlying stage matrix life history diagram for the caribou demographic model used for Beverly caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates 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 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), developed and deployed in June 2011, was used for this survey (Campbell et. al. 2012). 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, and again in 2023 (Boulanger et al. 2018).

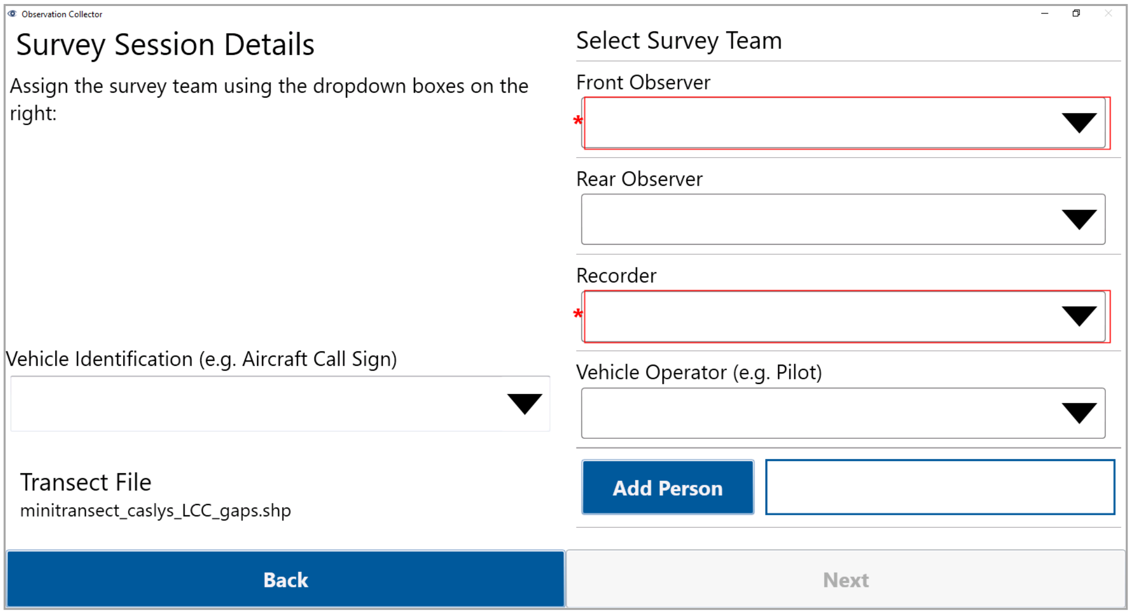
The AWS-OC software operates with Windows editions 7 through 10 and was developed specifically for use in both independent and dependent double-observer pair aerial caribou surveys, including distance-sampling applications, to facilitate the collection of field data, and the subsequent management of 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.



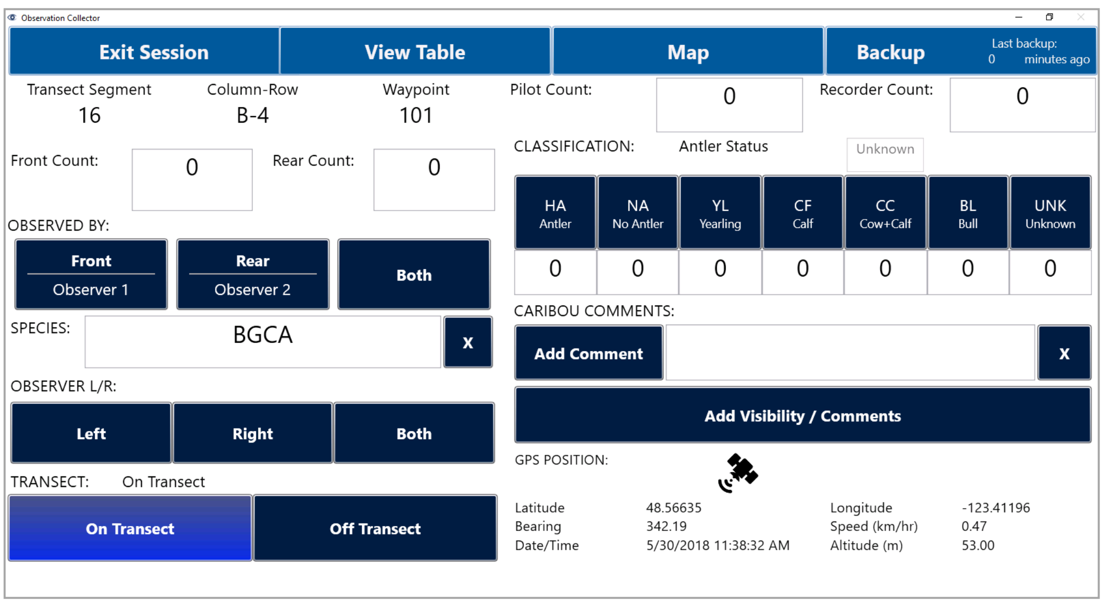


Figure 14. The data entry screens of the AWS-OC tablet interface used during the June 2023 Beverly mainland migratory barren-ground caribou abundance survey. Screen shots include the s urvey session details (Top), and primary data collection display (Bottom).

4.0 RESULTS & DISCUSSION

The geographic distribution of calving caribou observed during the June 2023 Beverly calving-ground abundance survey was atypical when compared to June reconnaissance and abundance surveys flown between 2008 and 2018. Between June 2008 and 2018, Beverly caribou cows had arrived onto the Queen Maud Gulf ACCA, between the Ellice River east to McNaughton River near Adelaide Peninsula, across a much larger geographic area (**Figure 15**). This larger area of occupation lead to much lower relative densities across the calving ground. Densities encountered over these survey years were consistently lower than the 15 to 20 caribou/km^2 threshold that would trigger the need for photographic counts. As a result, and coupled with a confirmed declining trend up to 2018, Beverly herd reconnaissance and abundance surveys have been set up as visual surveys since 2008 (Campbell et al. 2012; Campbell et al. 2019). However, in June 2023 densities of caribou were significantly higher within high density strata. During the 2023 June survey effort, unseasonably high air temperatures and an associated early spring melt of the QMG lowland snow pack and river and lake ice covers, caused Rivers and creeks within the calving grounds to surge, creating high-water volumes and dangerous currents, causing rivers and creeks to overflow their banks. These high volumes of fast-moving water created an effective barrier to the movement of migrating calving caribou cows onto their known annual core calving areas in early June, 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 and prior calving extents. This situation was moderated on or about June 14th and 15th as the water levels started to drop. This clumping posed counting problems, whereby some groups were too large and dense (in some instances in excess of 100 caribou/km^2) to accurately count using visual methods alone. Though a photo plane was kept on standby for such events, the aircraft unavailable due to mechanical issues. With a steady 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 method 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 both in the field and post-survey, 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 and 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**).

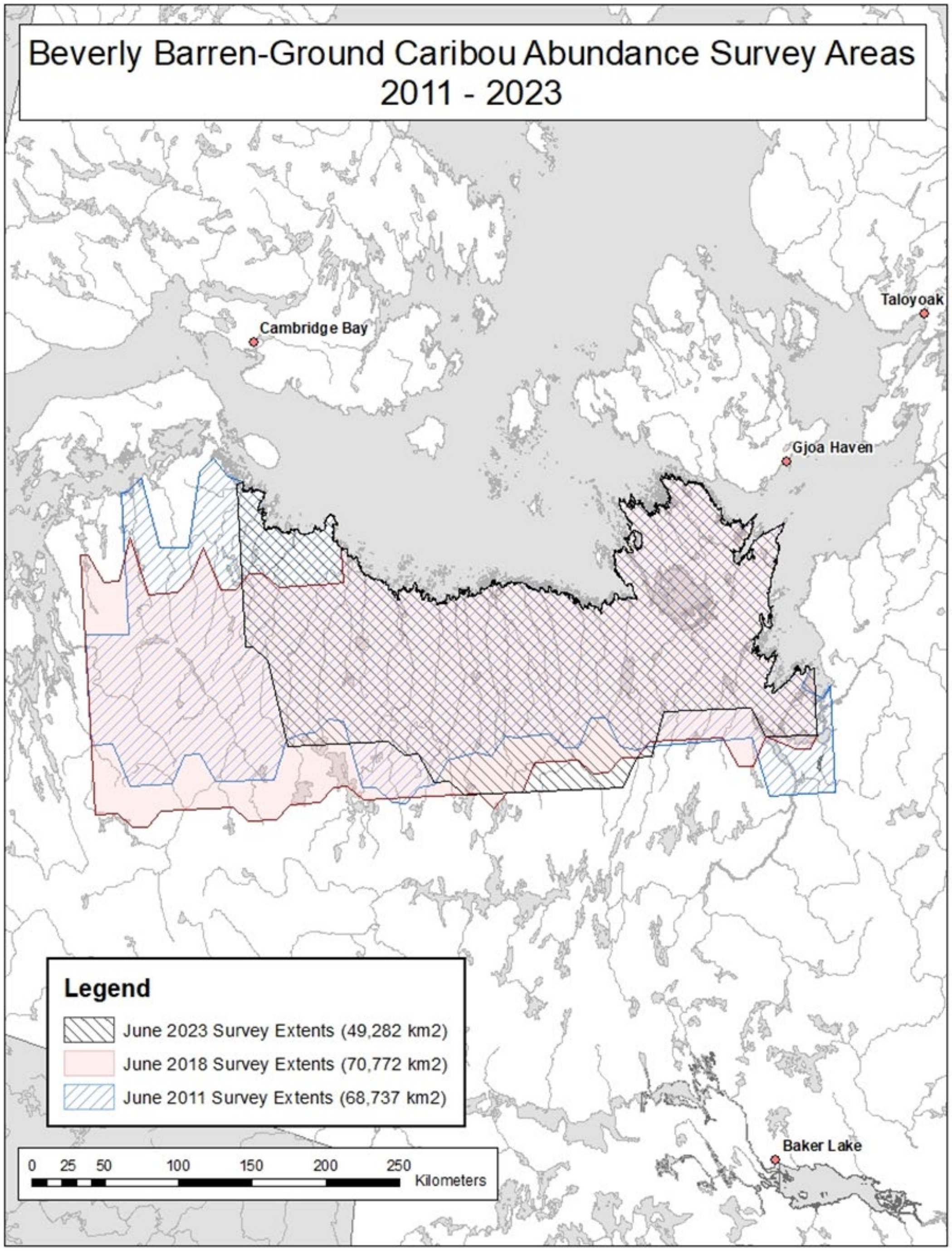


Figure 15. Beverly Herd Reconnaissance survey extents for the June 2011, 2018, and 2023 Beverly Herd calving-ground surveys (June 2023 survey extents in black).

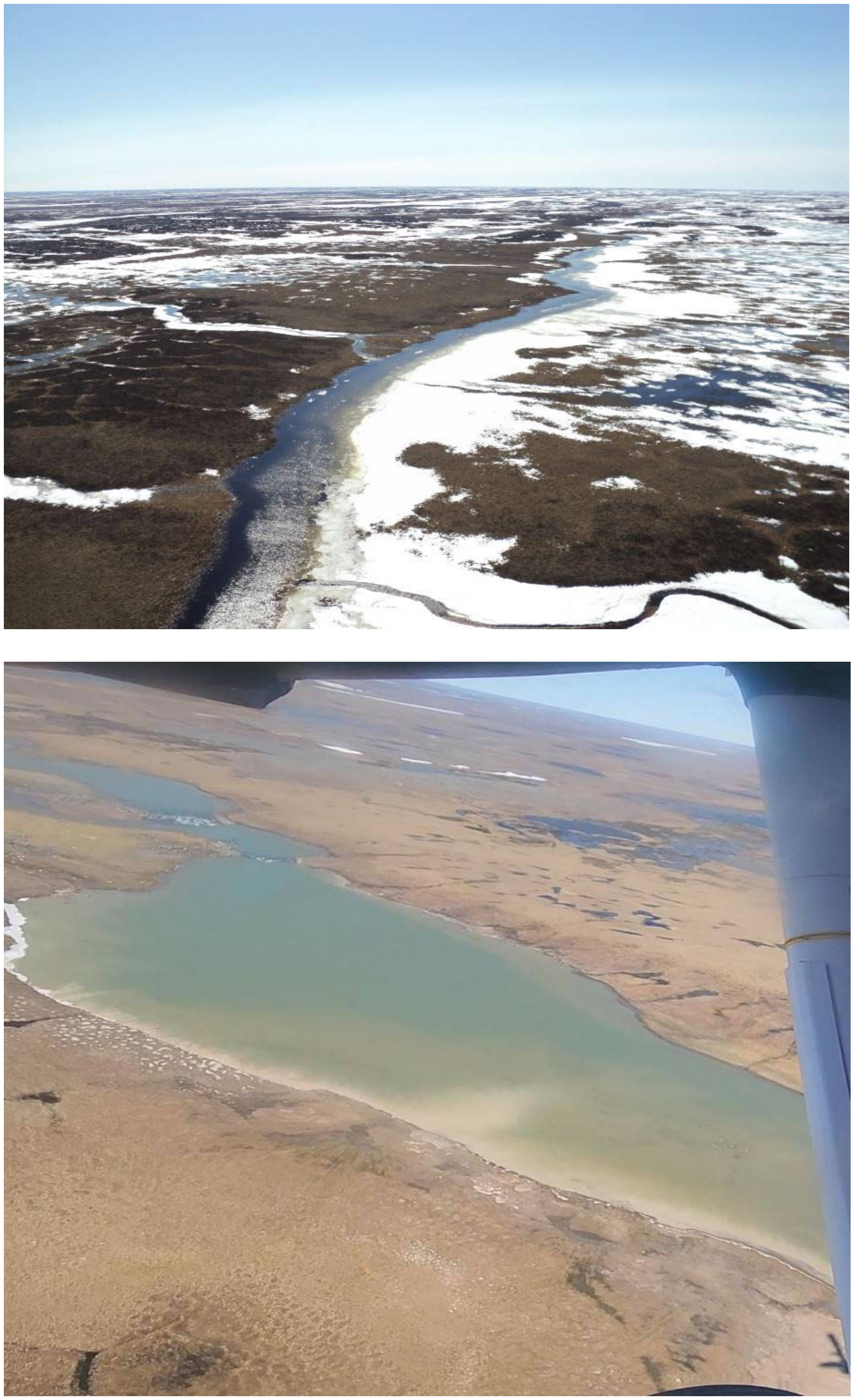


Figure 16. The Queen Maud Gulf Lowlands in the vicinity of Armark River June 12th, 2011 (Above), and in the same general vicinity June 8th, 2023 (Below).

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 early spring melt and early breakup. These high-water conditions created a barrier to the late spring migration of calving cows east of the Simpson River, funneling caribou between large river systems and restricting movement to the more northern extents of their annual calving grounds (**Figure 17**).

Reconnaissance data was summarized by 10 km segments revealing many segments with high densities and 6 segments with extremely high densities (>50 caribou/km^2) (**Figure 18**). Strata development was achieved by first overlaying strata boundaries over reconnaissance segment based relative densities, and secondly by adjusting based on recon summary composition observations (**Figure 19**). Two strata (Very-high-density-east and Very-high-density-west) had segments with densities equal to or exceeding 50 caribou/km^2 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 dominantly contained breeding females with mixed breeding females and non-breeders in most remaining medium and low-density strata.

4.2 ALLOCATION OF EFFORT

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 re-flown 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 further split into two strata, Very-high-density-east-1 and Very-high-density-east-2, 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.

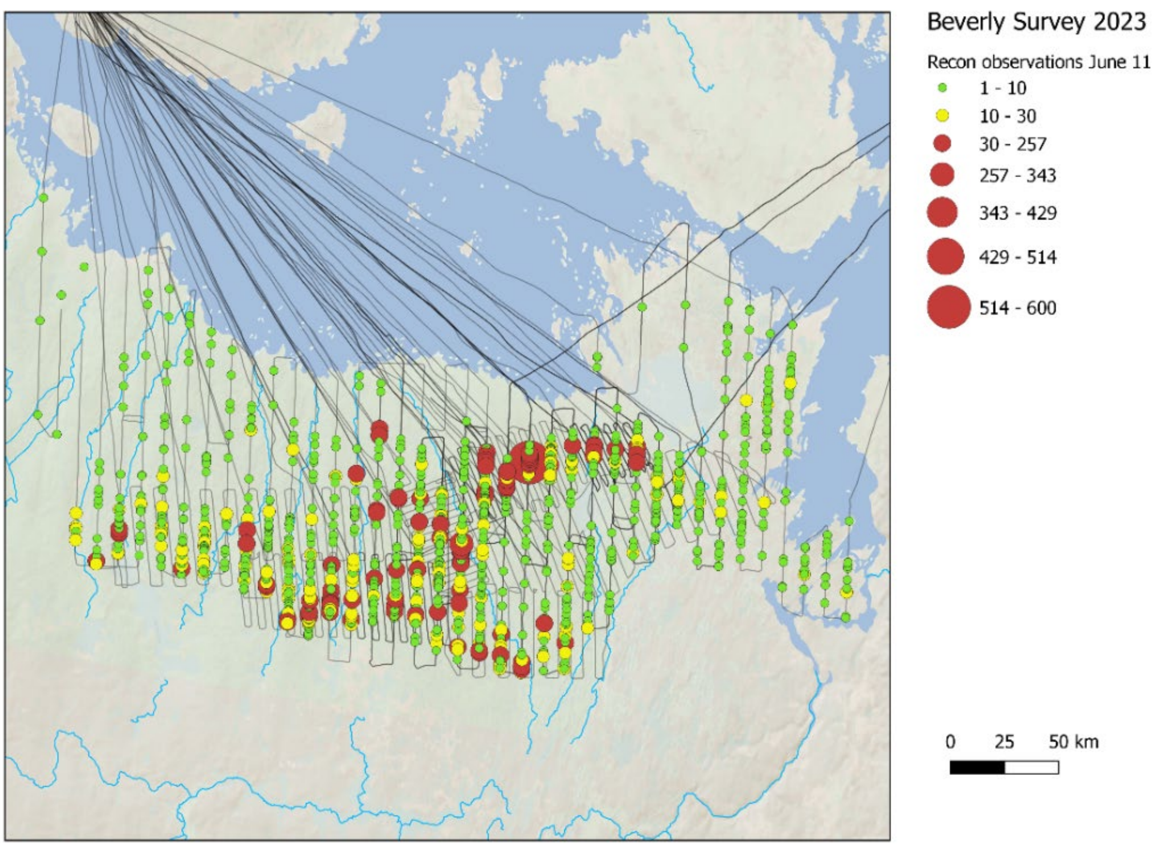


Figure 17 Flight lines and reconnaissance observations. Observations are color and size coded based on the number of caribou observed.

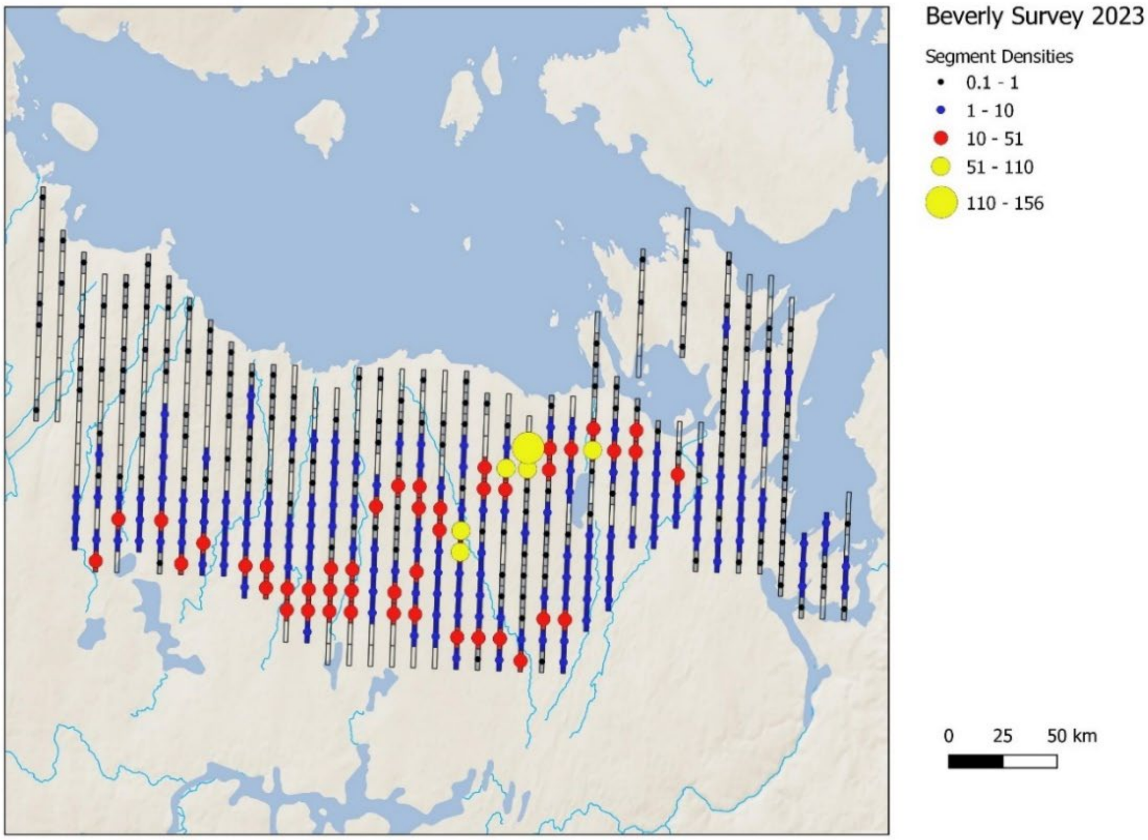


Figure 18. Summary of reconnaissance survey segments.

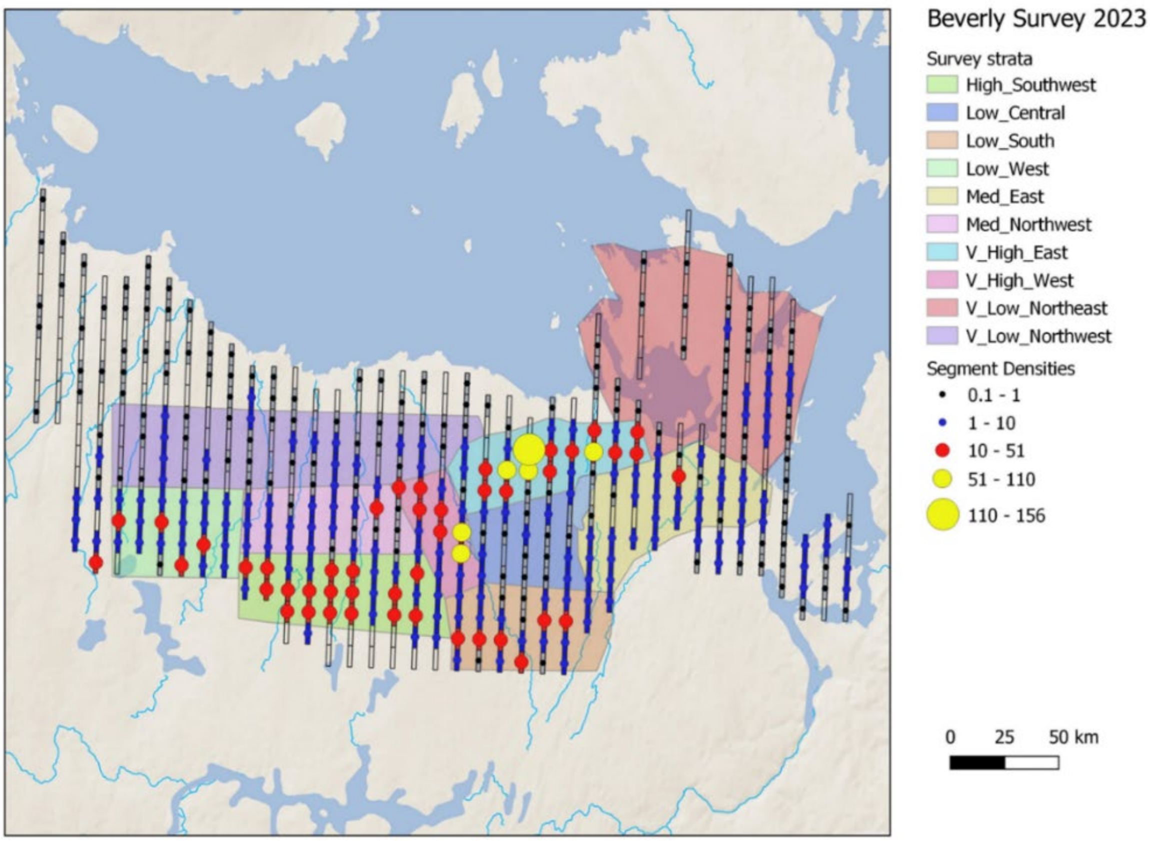


Figure 19. Summary of reconnaissance survey segment density with developed abundance strata overlaid.

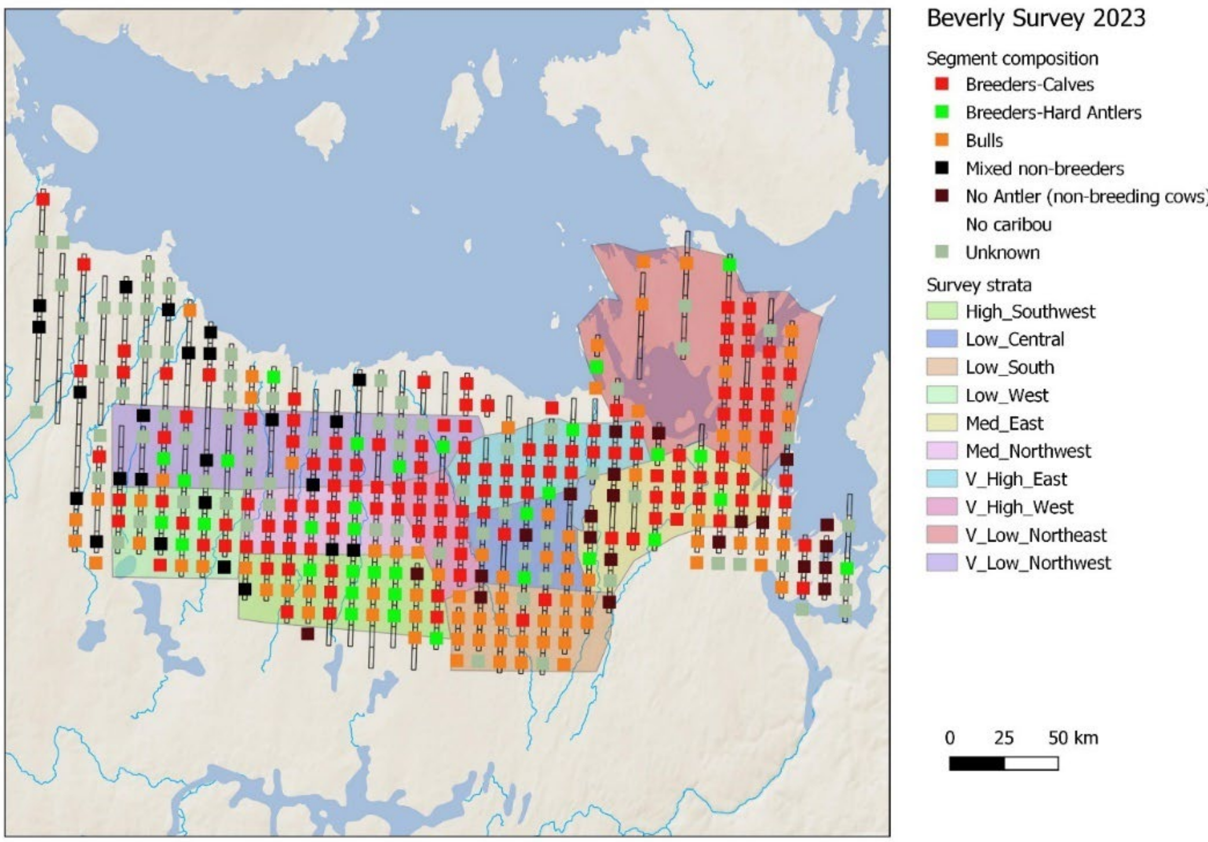


Figure 20. Summary of reconnaissance survey segment composition.

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 (km^2)	# of transects	Average transect width (wi)	Baseline length	Total transect km	Total area surveyed (km^2)	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, excluding all the Very Low-density strata and the Low-density South stratum (**Figure 21**) which used June 2023 reconnaissance data (**Figure 20**). 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 a north-eastern path for female caribou with most ending up in the two Very-high-density strata while bulls mainly occurred within southern strata (**Figure 22**). In contrast to previous abundance surveys, very little northern movement within the Beverly herds ACCA was observed in June 2023. 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, stopped at swollen rivers and creeks during their eastward migration onto the calving-ground, explains the atypical movement rates during calving and the lack of movement cues typically representative of peak calving for this herd. 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 the strata (**Figure 24**) with the exception of a burst of movement out of the Very-high-density-east strata into the Low-density-central stratum on June 15 when this area was flown. For this reason, estimates from the Low-density-central stratum were not used in estimates of adult females due to likely double counting of caribou.

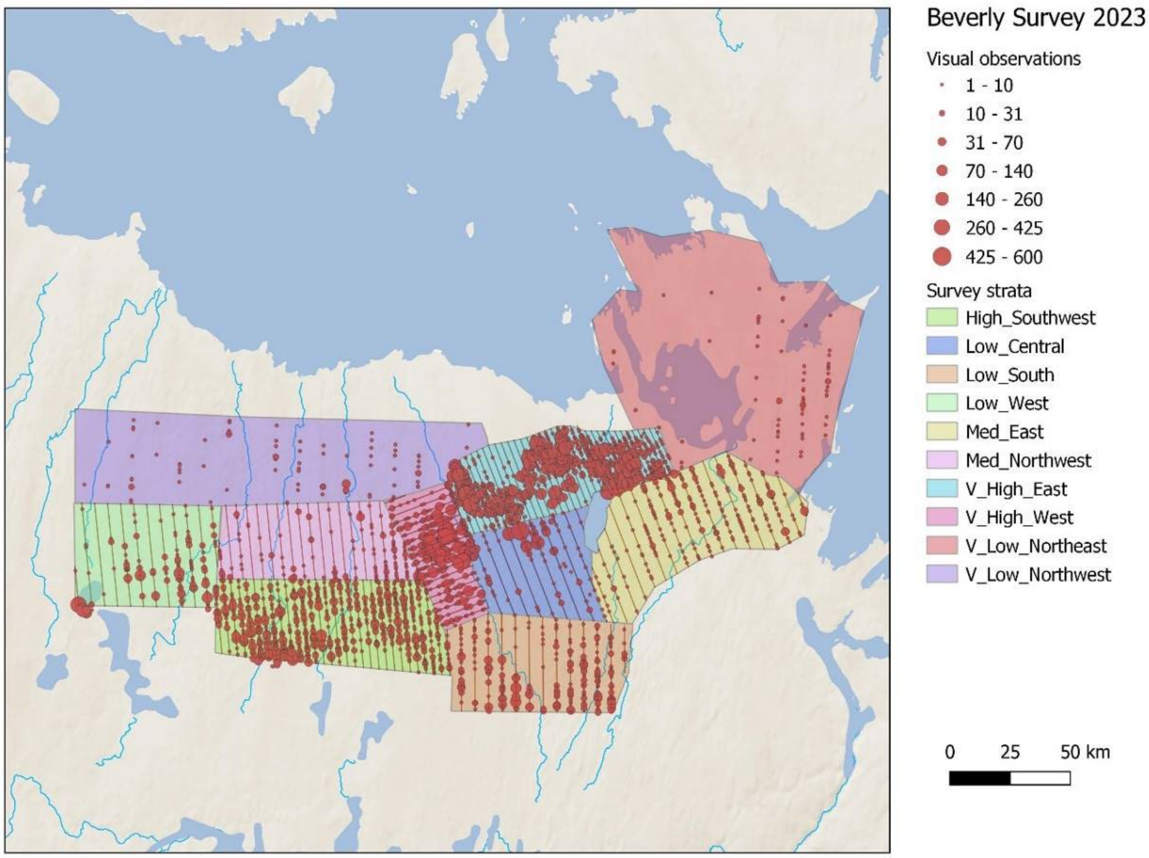


Figure 21. Visual survey transect lines and observations.

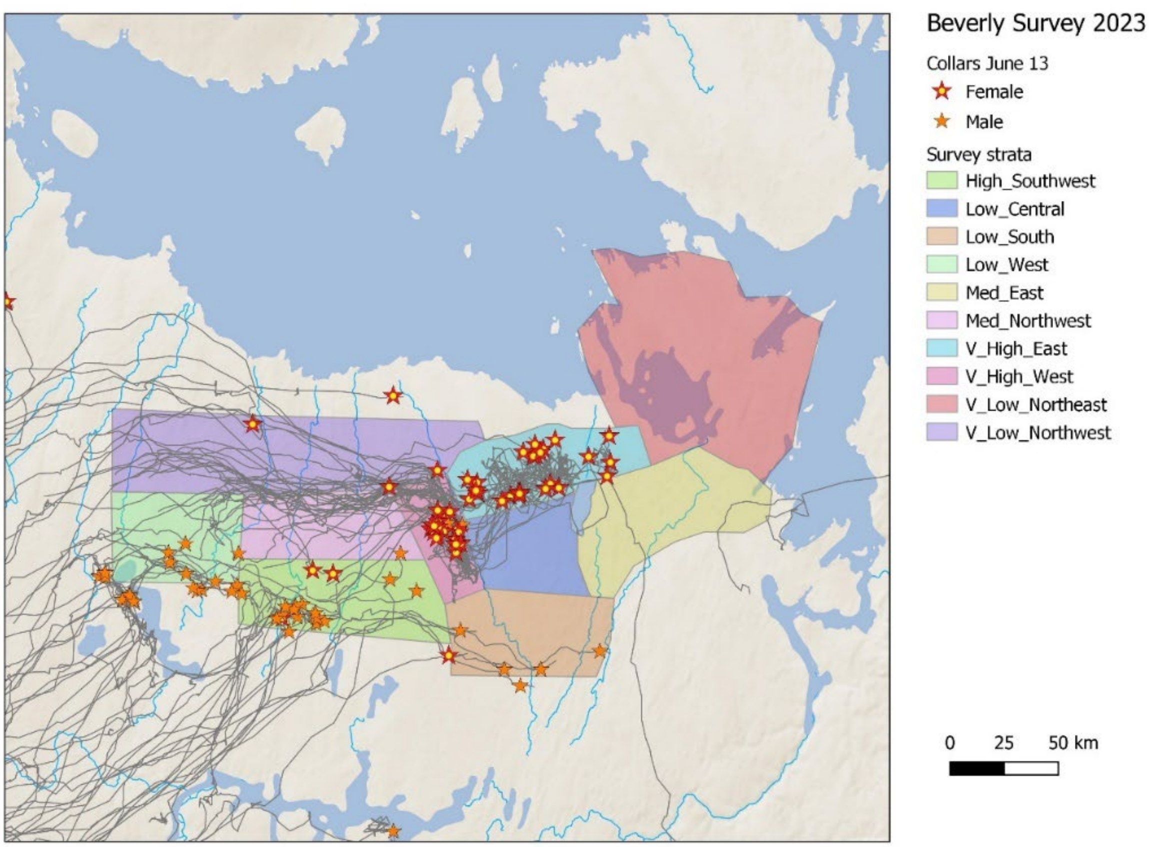


Figure 22. Collar migration paths up to June 13th when visual surveys occurred.

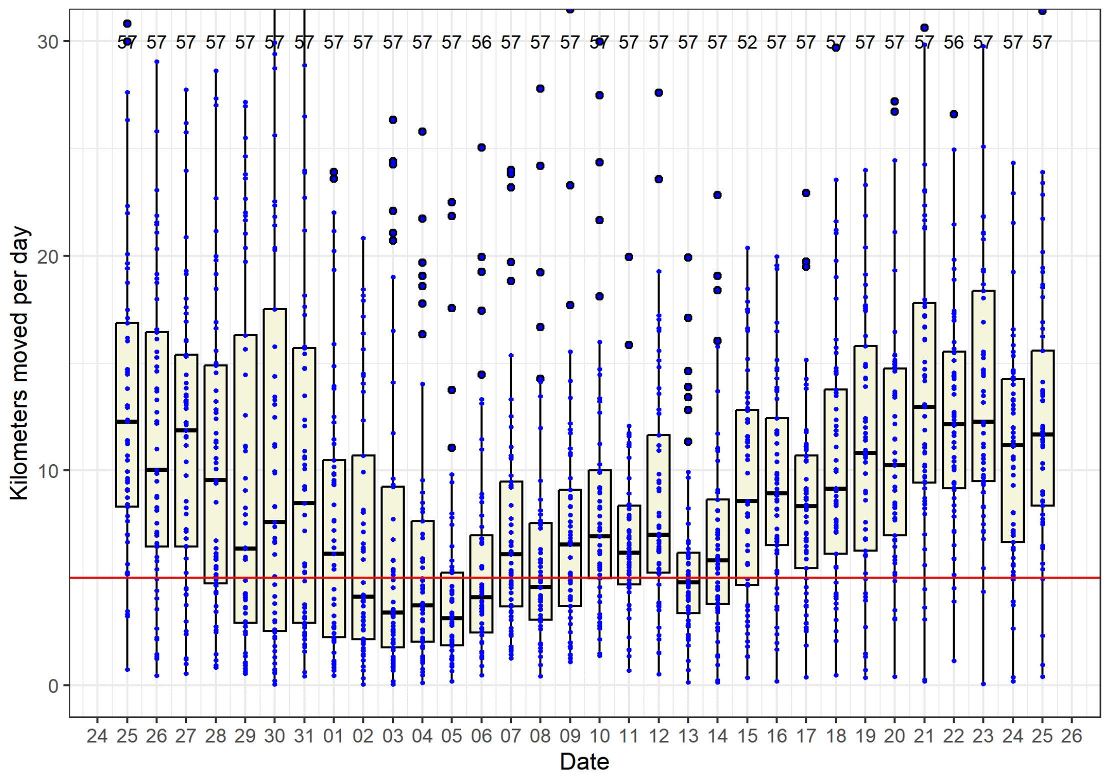


Figure 23. Movement rates of Beverly caribou during the June 2023 Beverly calving-ground survey.

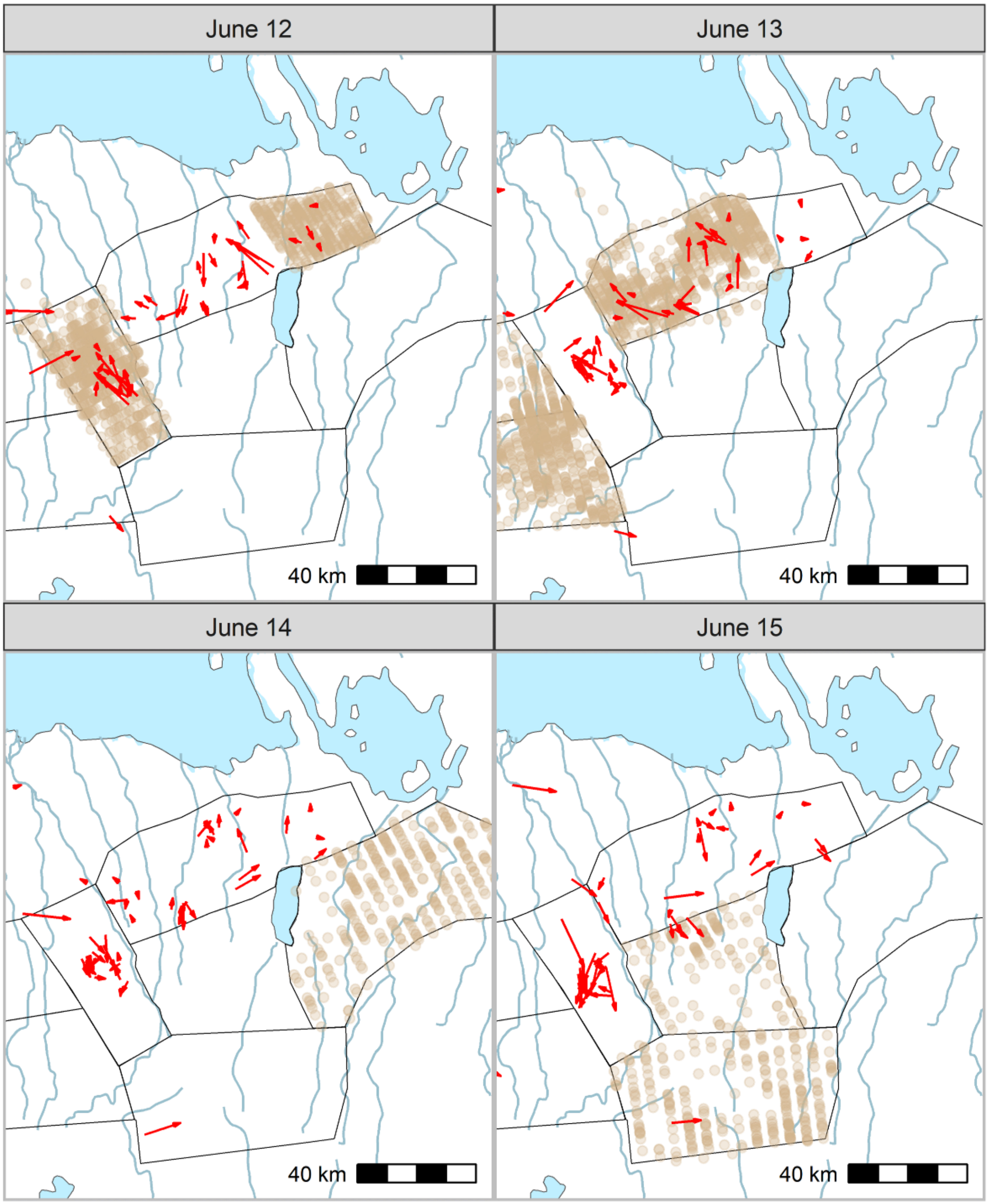


Figure 24. Directional daily movements of collared females relative to transects flown (brown circles) for the main days in which central high-density strata were flown. The direction of daily movement of caribou is indicated by arrows.

4.3.2 Video Assisted Counts in High-Density Strata

In total, 125 video/orthomosaic images of the three Very-high-density survey strata were taken during the survey (**Figure 25**). Of the 125 orthomosaics, 61, 18, and 44 occurred 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 orthomosaics.

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 caribou, 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 locations 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 photo 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 reflects 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.

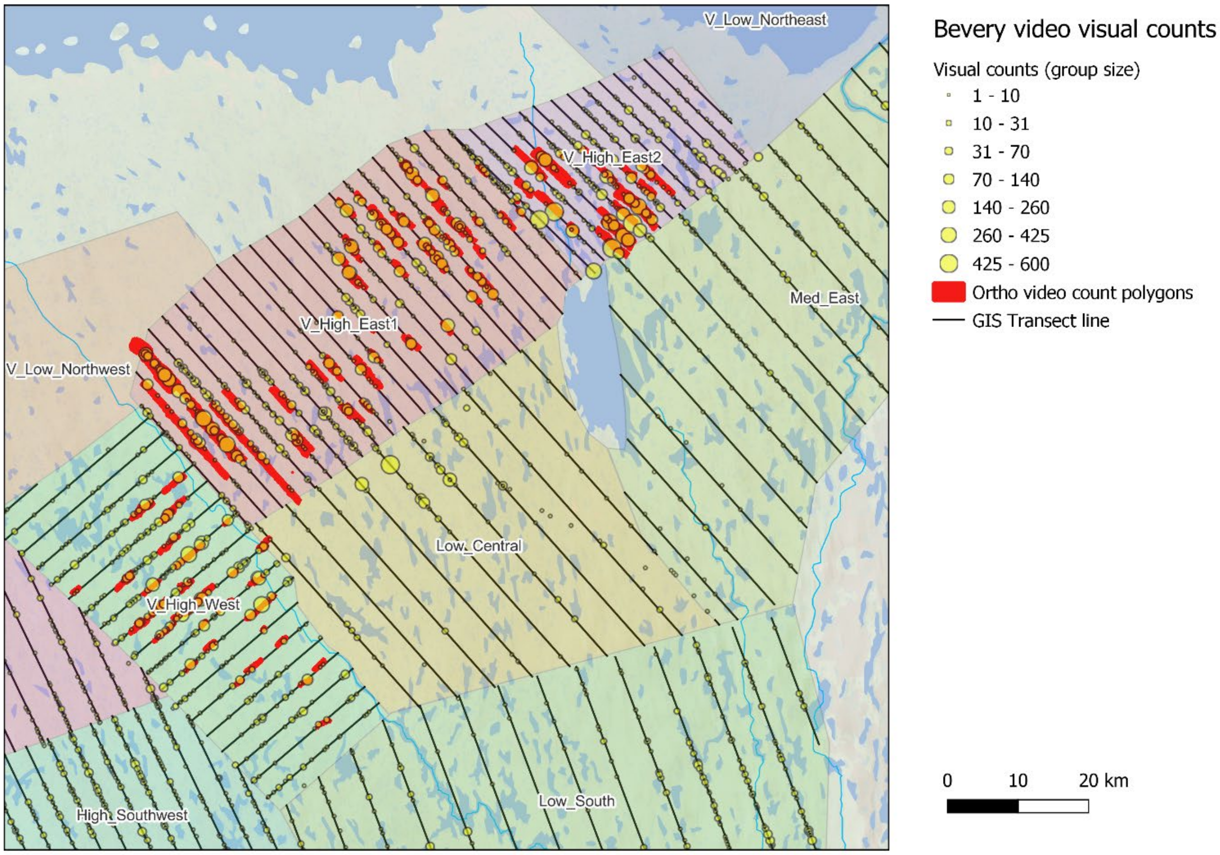


Figure 25. Coverage of ortho photos relative to visual observations in the Very-High-Density West and East strata.

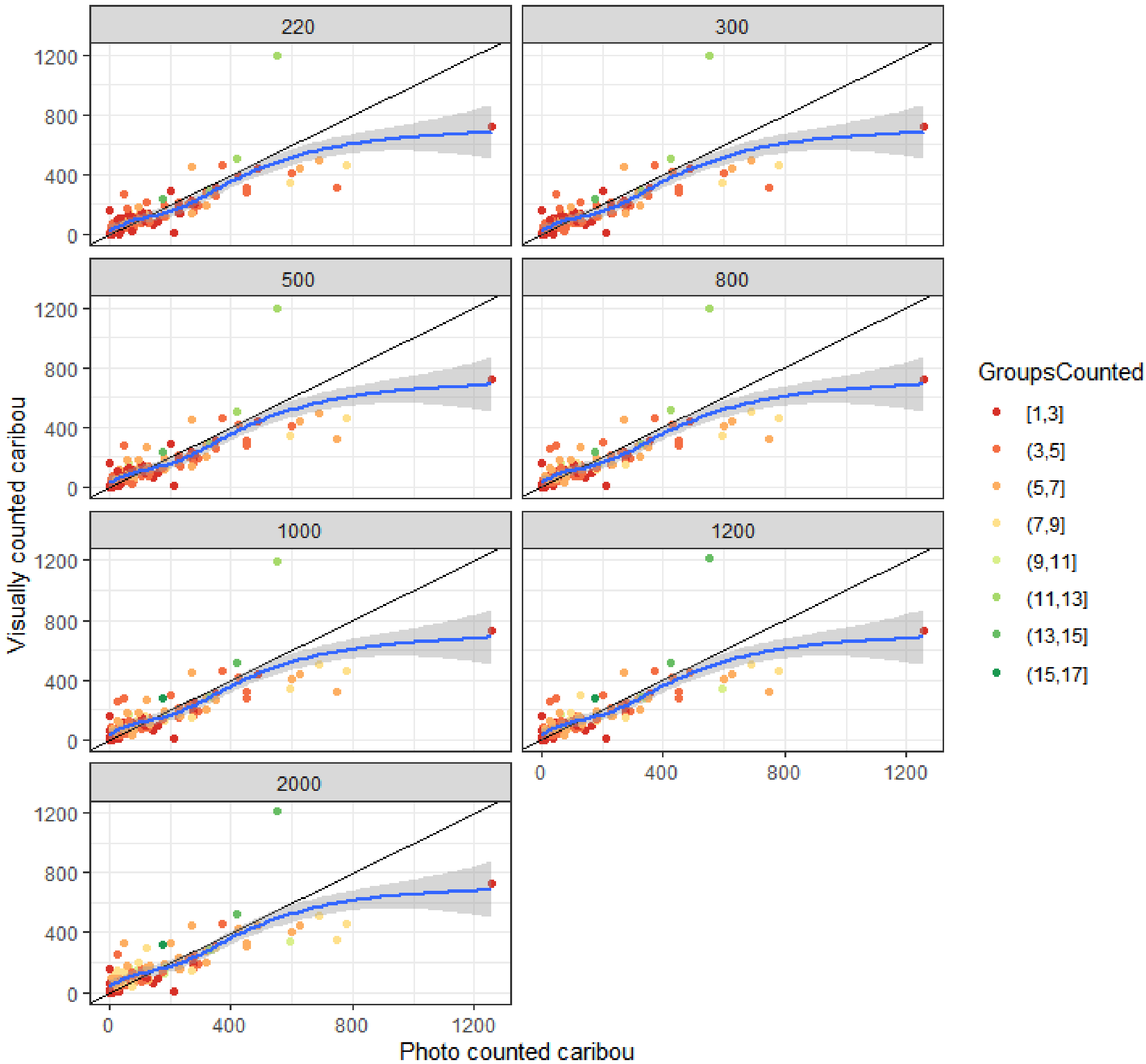


Figure 26. Relationship between visually counted caribou (assumed to be within the orthomosaics photo-video) and the number of caribou counted on each orthophoto. The number of visual group waypoints within each photo is also displayed by color of point.

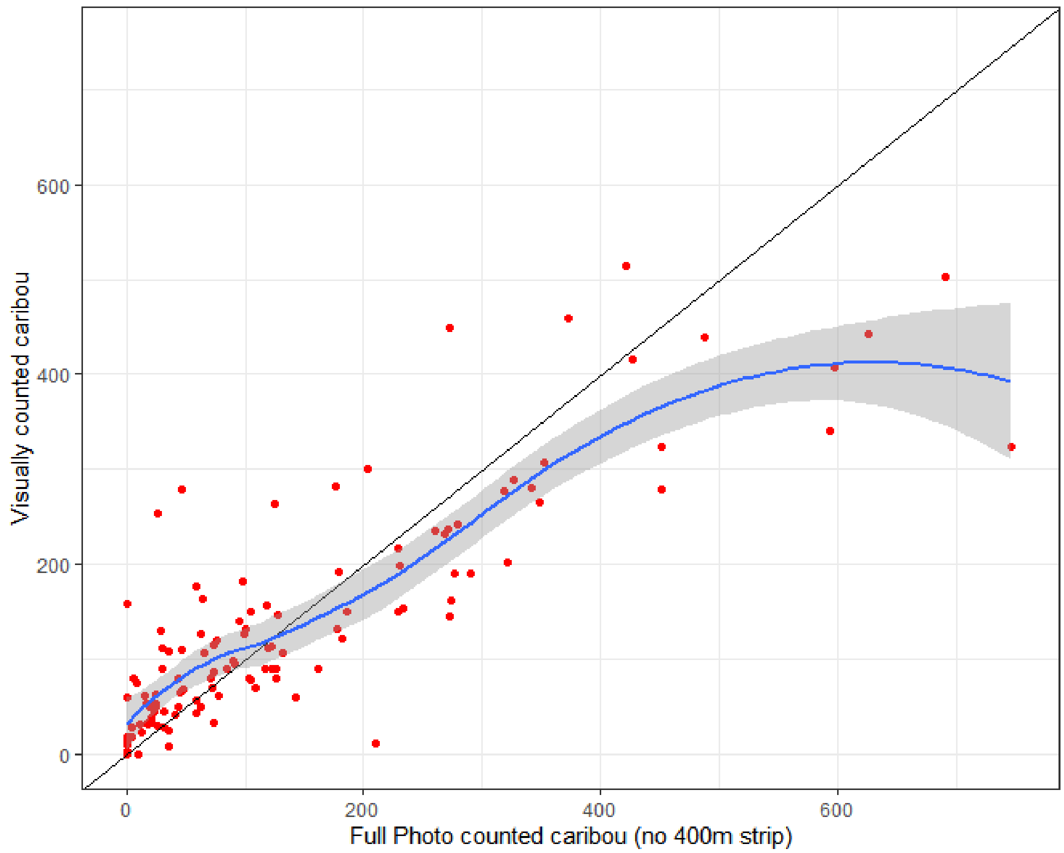


Figure 27. Relationship between caribou counted visually versus caribou counted on photos using all the caribou countable on photos with no strip width. A smoothed (blue line) is used to indicate dominant trends in the data set. Confidence limits are shown as shaded areas around the smoothed line.

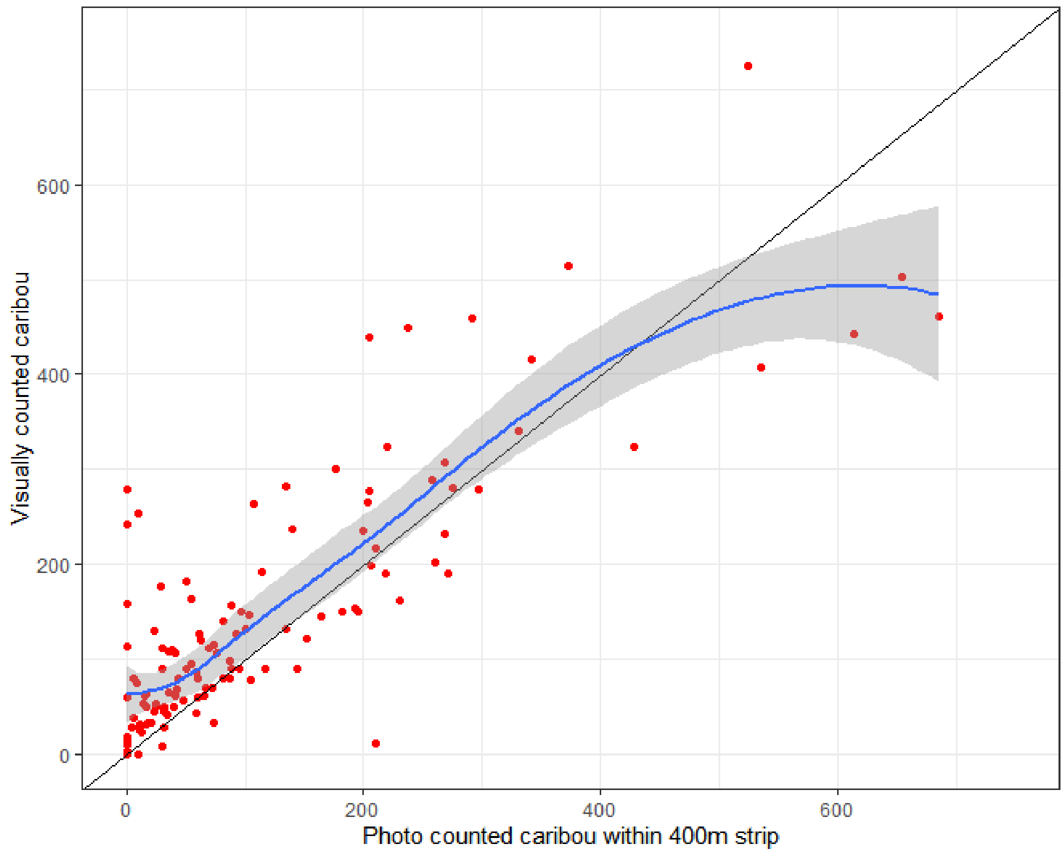


Figure 28. Relationship between caribou counted visually versus caribou counted on photos using all the caribou on photos with a 400-meter strip width applied.

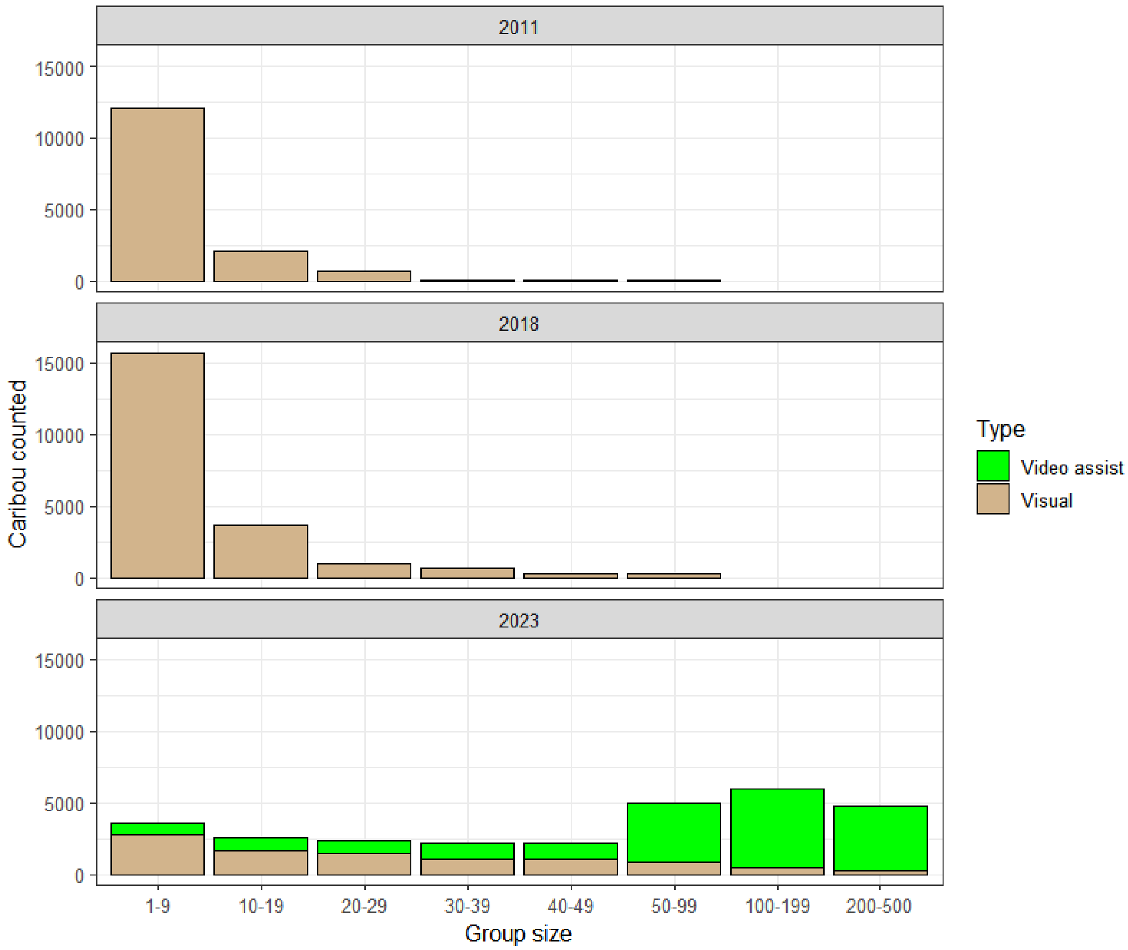


Figure 29. Comparison of contribution of group sizes observed to the total count of caribou on the 2011, 2018 and 2023 surveys. Sub-bars denote if visual counts were replaced in 2023 with video/orthomosaic counts.

4.3.3 Estimation of abundance using Jolly strip transect estimator 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 15 to 20 caribou per km^2 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 km^2 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 km^2, in all of the very-high-density strata (**Table 6**). In contrast, densities were 12 caribou per km^2 in the High-density-southwest strata and less than 9 caribou per km^2 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.

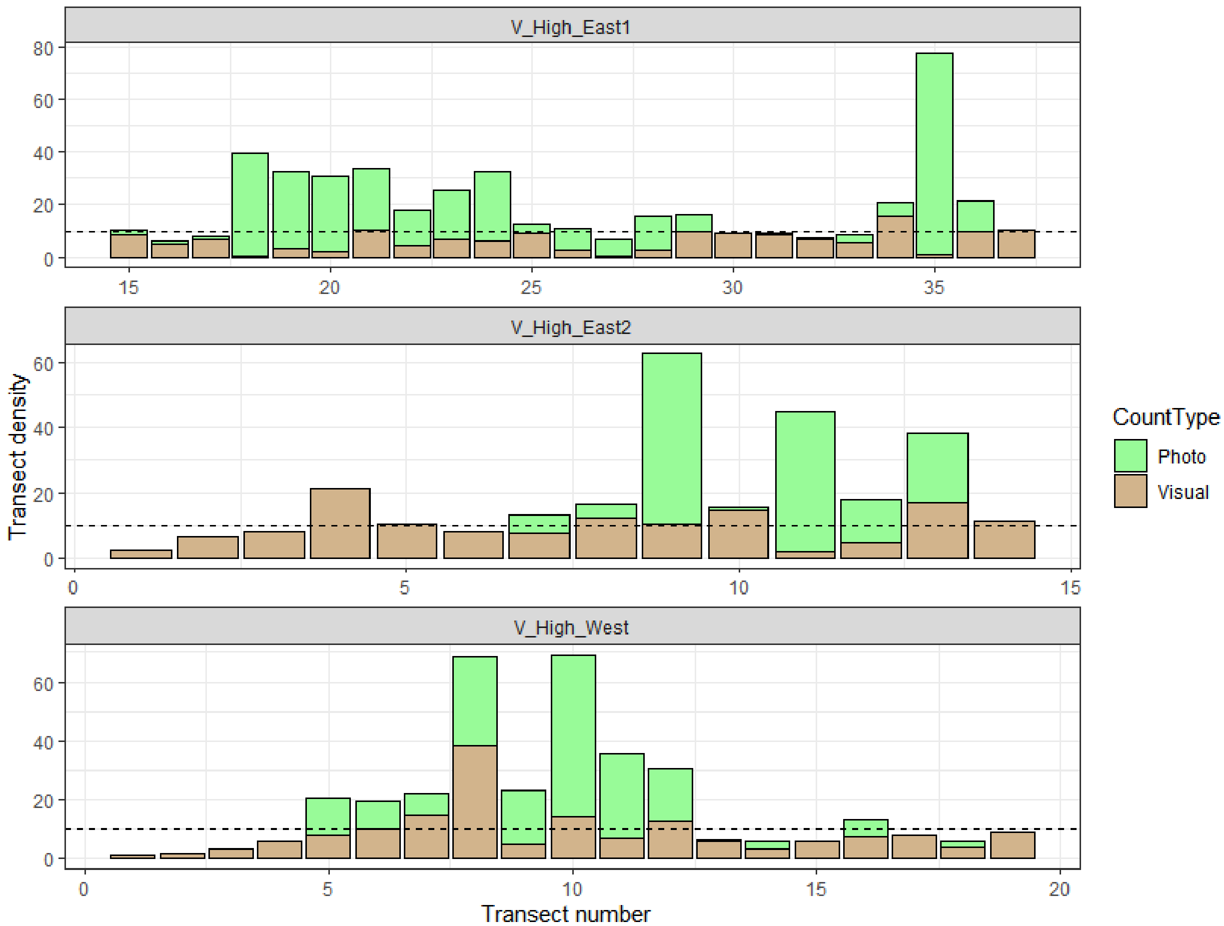


Figure 30. Transect densities for the very high strata with proportions of counts based on photo/orthomosaics or visual source delineated for each stratum.

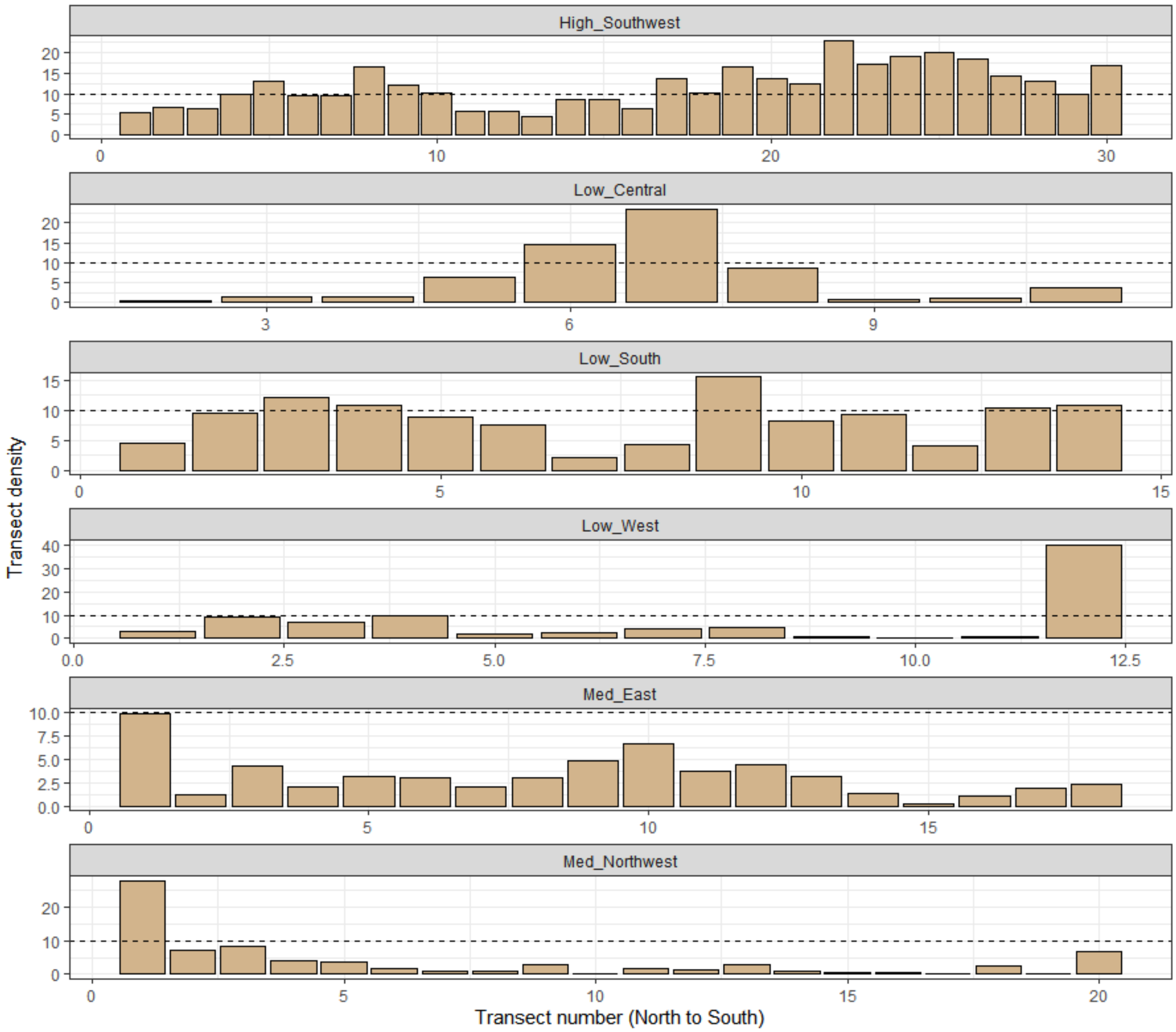


Figure 31. Transect densities (caribou/km^2) for visual strata. Note that most transects were well within visual observation limits (15 to 20 caribou/km^2).

Table 6. Estimates of density and abundance using the standard Jolly 2 strip transect estimator. Video-corrected data was used for High East1, High East2, and High West strata.

strata	Caribou counted	N	SE	Conf. Limit		CV	Density (caribou/km^2)
Video-assisted counts							
V_High_East1	12,075	39,319	5251.9	29,842	51,805	0.134	20.2
V_High_East2	5,444	14,988	2685.0	10,209	22,003	0.179	20.9
V_High_West	6,929	27,198	5758.9	17,517	42,230	0.212	19.8
Visual counts							
High_Southwest	9,596	38,645	2473.5	33,908	44,044	0.064	11.9
Med_East	1,533	10,239	1292.3	7,853	13,349	0.126	3.0
Low_South	3,272	23,847	2720.9	18,653	30,489	0.114	8.5
Med_Northwest	1,090	5,825	1161.3	3,854	8,806	0.199	2.4
Low_West	1,931	12,957	3843.4	6,838	24,552	0.297	5.2
V_Low_Northwest	483	5,828	1182.2	3,807	8,920	0.203	1.0
V_Low_Northeast	324	4,010	1323.8	1,959	8,211	0.330	0.5
Low_Central	2,045	12,917	4405.5	6,099	27,356	0.341	6.9

4.3.4 Double observer modelling of sightability

Double observer modelling was conducted to generate estimates of abundance for all strata except 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 snow cover 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**). Using these most supported models produced a total estimate of 101,767 caribou with reasonable precision (CV=6.6%). In contrast, estimates using just the Jolly N strip transect estimator were 101,352 (CV=6.0%) 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.

Observer pair	Frequencies				Single observer probabilities		Double observer Probabilities	
	Front	Rear	Both	Data recorder	No data recorder	Data recorder	No data recorder	Data recorder
1	9	20	333	17	0.94	0.90	1.00	0.99
2	5	5	887	20	0.99	0.97	1.00	1.00
3	4	4	268	1	0.99	0.98	1.00	1.00
4	12	25	683	6	0.97	0.96	1.00	1.00
5	28	34	490	7	0.94	0.93	1.00	0.99
6	4	14	190	10	0.93	0.89	1.00	0.99
7	11	15	202	14	0.93	0.88	1.00	0.99
8	86	89	1007	58	0.92	0.88	0.99	0.99
9	90	35	174	21	0.88	0.83	0.99	0.97
10	4	9	337	14	0.97	0.94	1.00	1.00
11	4	5	96	1	0.95	0.94	1.00	1.00
12	1	17	394	6	0.96	0.94	1.00	1.00

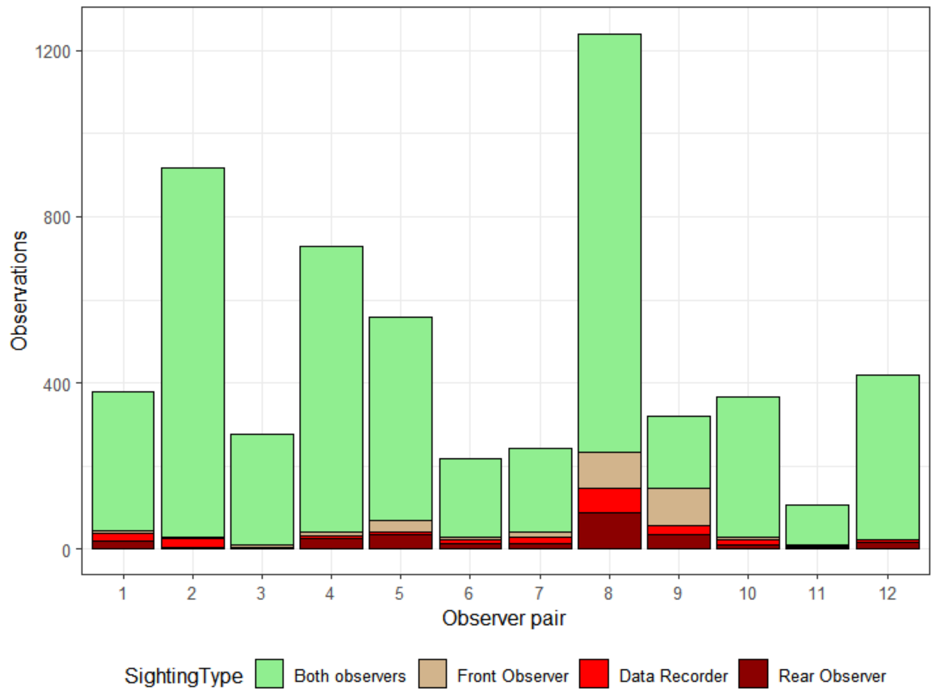


Figure 32. Sighting types by observer pair.

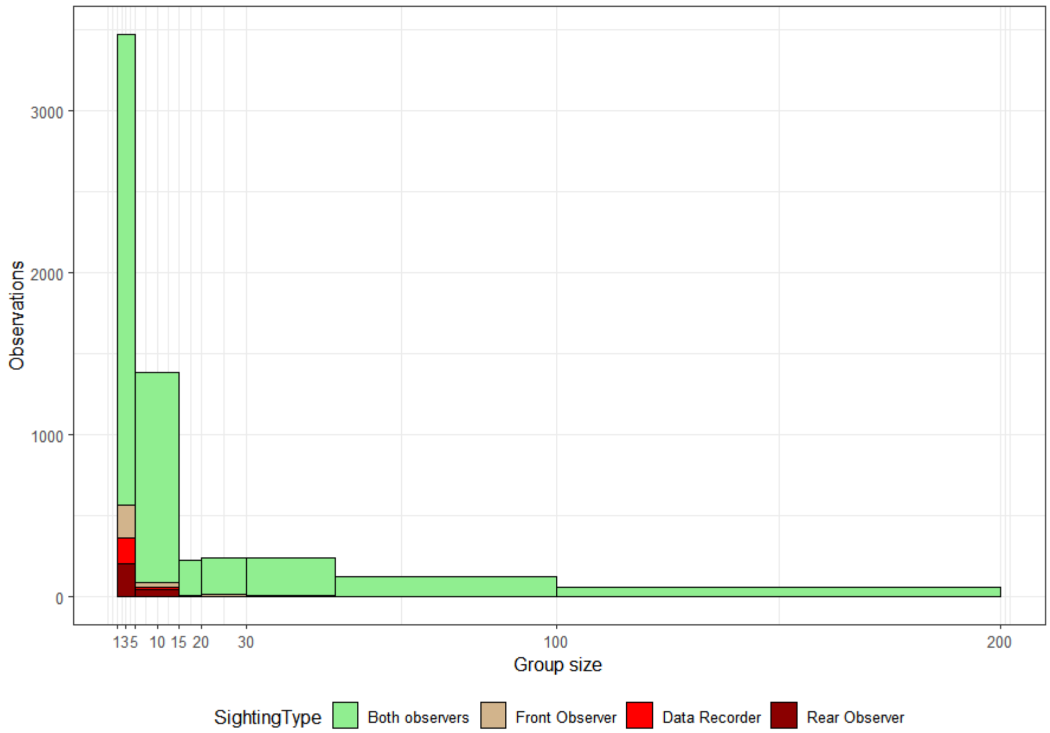


Figure 33. Frequencies of observation by group size as a function of observation type (B=Both, F=Front, R=Rear).

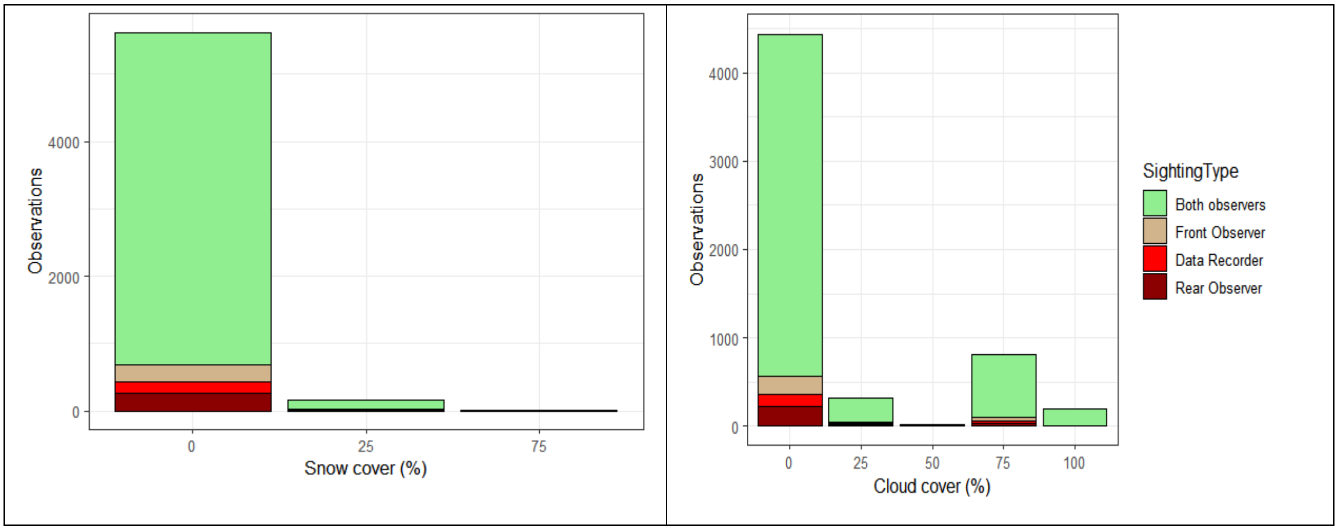


Figure 34. Observation frequencies by snow and cloud cover as a function of observation type (B=Both, F=Front, R=Rear).

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

No	Model	AIC_c	ΔAIC_c	w_i	K	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 visual abundance estimates from Model 1 (**Table 7**) for strata excluding VHD-1, VHDE-2, and VHDW that were estimated using video counts.

Strata	Counted	N	SE	Conf. Limit		CV
V_Low_Northeast	324	4,032	759.8	2,553	6,368	0.188
High_Southwest	9,616	38,825	1853.1	35,072	42,980	0.048
V_Low_Northwest	483	5,881	1372.5	3,493	9,901	0.233
Med_East	1,533	10,285	1003.9	8,252	12,819	0.098
Low_South	3,272	23,866	3269.9	17,288	32,948	0.137
Med_Northwest	1,104	5,910	1244.4	3,715	9,400	0.211
Low_West	1,931	12,968	5100.6	5,127	32,803	0.393
Total	**18,263**	**101,767**	**6720.1**	**88,461**	**117,075**	**0.066**

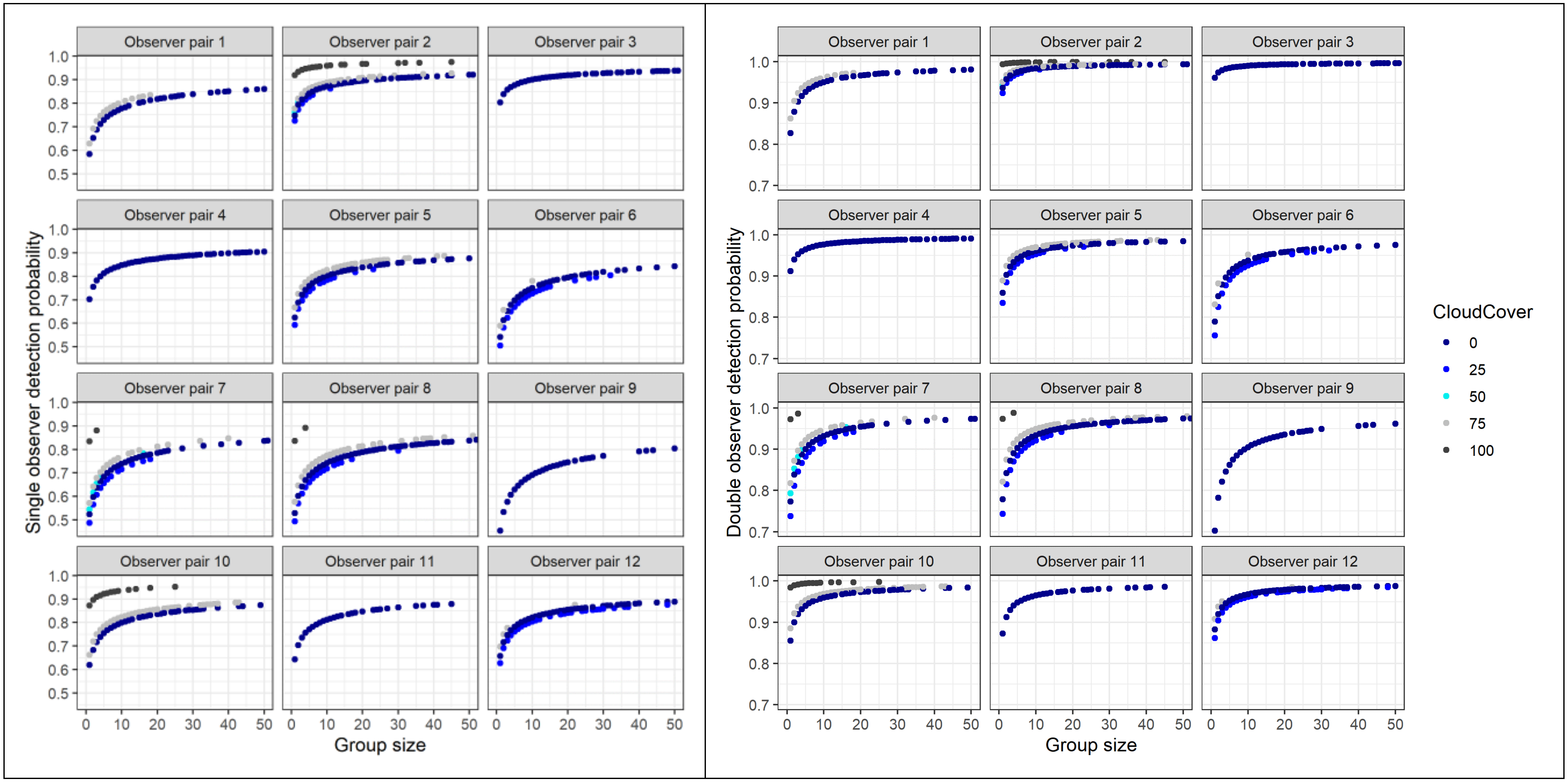


Figure 35. Predicted single and double observer sighting probability as a function of group size and observer pair.

4.3.5 Composition survey results

Calving ground 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 VHDE and VHDW(1+2) 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. 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**).

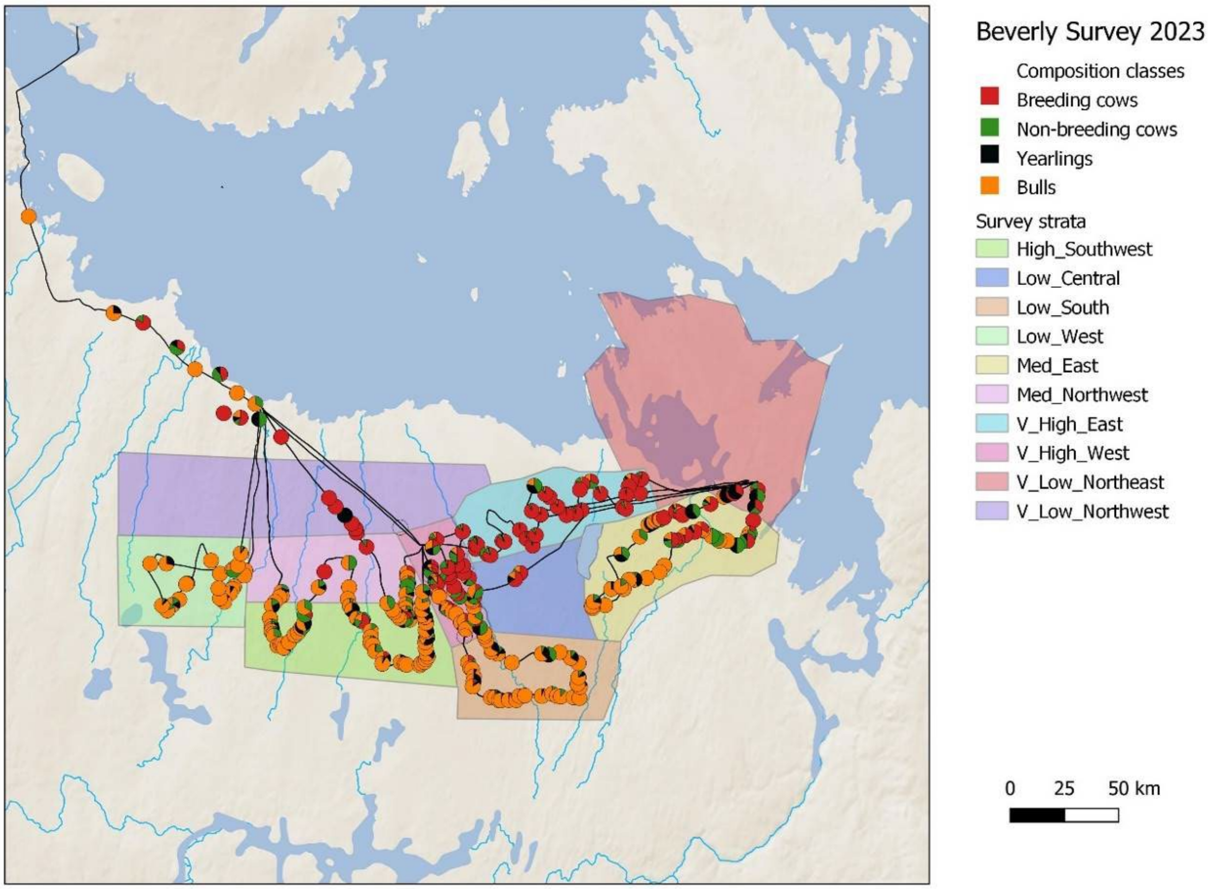


Figure 36. June 2023 composition survey flight paths with pie charts depicting each sample.

Table 10. Summary of observations during the June 2023 Beverly 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 the Beverly June 2023 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

Estimates of breeding females were derived by multiplying the overall estimates for the calving ground by the proportion breeders in each stratum (**Table 12**). Estimates of adult females were derived by multiplying total caribou by proportions of adult females (**Table 13**). Estimates of bulls were derived by multiplying the proportion bulls in each stratum by the total caribou (**Table 14**). An estimate was also derived for all caribou (bulls, cows, and yearlings) which included the very low strata (where no composition surveys were conducted) which increases the estimates by 9,913 caribou (CI = 6,046-16,270) (**Table 15**). It is assumed that the majority of these caribou were non-breeding caribou. All results were used in combination with fall composition data, data that is used to determine sex ratios as all sexes and ages gather during the fall rut, to develop a whole herd estimate.

Table 12. Estimates of breeding females in the Beverly June 2023 calving-ground core stratum.

Strata	N total caribou	CV	Prop. Breeding females	CV	N breeding females	SE	Conf. Limit		CV
V_High_East1	39,319	0.134	0.882	0.013	34,679	4655.5	26,284	45,755	0.134
V_High_East2	14,988	0.179	0.860	0.048	12,890	2390.8	8,664	19,178	0.185
V_High_West	27,198	0.212	0.568	0.095	15,448	3587.5	9,545	25,003	0.232
High_Southwest	38,825	0.048	0.018	0.363	699	255.9	328	1,488	0.366
Med_East	10,285	0.098	0.497	0.207	5,112	1168.2	3,069	8,516	0.229
Low_South	23,866	0.137	0.021	0.358	501	192.1	209	1,203	0.383
Med_Northwest	5,910	0.211	0.092	0.735	544	415.9	120	2,467	0.765
Low_West	12,968	0.393	0.009	0.573	117	81.2	25	542	0.694
Total	**173,359**	**0.061**			**69,990**	**6473.5**	**59,135**	**82,837**	**0.092**

Table 13. Estimates of adult females in the Beverly June 2023 calving-ground core stratum.

Strata	N total caribou	CV	Prop. Adult F	CV	N Adult females	SE	Conf. Limit		CV
V_High_East1	39,319	0.134	0.956	0.005	37,589	5024.0	28,524	49,535	0.134
V_High_East2	14,988	0.179	0.939	0.016	14,074	2531.8	9,571	20,695	0.180
V_High_West	27,198	0.212	0.759	0.048	20,643	4483.7	13,148	32,409	0.217
High_Southwest	38,825	0.048	0.124	0.132	4,814	674.0	3,577	6,479	0.140
Med_East	10,285	0.098	0.631	0.125	6,490	1028.1	4,545	9,266	0.158
Low_South	23,866	0.137	0.087	0.186	2,076	480.1	1,210	3,562	0.231
Med_Northwest	5,910	0.211	0.291	0.230	1,720	536.8	872	3,393	0.312
Low_West	12,968	0.393	0.064	0.220	830	373.8	290	2,376	0.450
Total	**173,359**	**0.061**			**88,236**	**7343.3**	**75,564**	**103,033**	**0.083**

Table 14. Estimates of bulls in the Beverly June 2023 calving-ground core stratum.

Strata	N total caribou	CV	Prop. Bulls	CV	N Bulls	SE	Conf. Limit		CV
V_High_East1	39,319	0.13	0.030	0.140	1,180	228.0	793	1,755	0.19
V_High_East2	14,988	0.18	0.047	0.201	704	189.7	397	1,247	0.27
V_High_West	27,198	0.21	0.188	0.170	5,113	1387.4	2,921	8,951	0.27
High_Southwest	38,825	0.05	0.766	0.029	29,740	1656.6	26,413	33,486	0.06
Med_East	10,285	0.10	0.273	0.243	2,808	735.9	1,567	5,030	0.26
Low_South	23,866	0.14	0.820	0.023	19,570	2718.2	14,113	27,136	0.14
Med_Northwest	5,910	0.21	0.645	0.095	3,812	880.6	2,294	6,336	0.23
Low_West	12,968	0.39	0.885	0.022	11,477	4520.9	4,531	29,069	0.39
Total	**173,359**	**0.61**			**74,404**	**5822.5**	**61,855**	**89,499**	**0.08**

Table 15. Estimates of total 1+ year old caribou *including* very low-density strata for the Beverly June 2023 calving-ground survey.

Strata	N	SE	Conf. Limit		CV
V_High_East1	39,319	5251.9	29,842	51,805	0.134
V_High_East2	14,988	2685.0	10,209	22,003	0.179
V_High_West	27,198	5758.9	17,517	42,230	0.212
High_Southwest	38,825	1853.1	35,072	42,980	0.048
Med_East	10,285	1003.9	8,252	12,819	0.098
Low_South	23,866	3269.9	17,288	32,948	0.137
Med_Northwest	5,910	1244.4	3,715	9,400	0.211
Low_West	12,968	5100.6	5,127	32,803	0.393
V_Low_Northwest	5,881	1372.5	3,493	9,901	0.233
V_Low_Northeast	4,032	759.8	2,553	6,368	0.188
Total	**183,272**	**10635.6**	**161,417**	**208,084**	**0.058**

4.3.7 Extrapolated herd estimates

The most recent fall composition survey for the Beverly herd occurred in October 2022 (Adamczewski et al. 2024) and was used to determine the sex ratio of the Beverly herd as typically all sexes and ages gather together in the fall during the October rut. Sampling for the survey occurred in 2 periods (**Figure 37**) with the first period (October 20-23) targeting Bathurst collars and the second period (October 24-November 3) targeting Beverly collared caribou. Further inspection of collar locations revealed that there were 3 Beverly cow collars mixed in with Bathurst cows in the first sampling period and observations around these collars were used to estimate bull cow ratios. In contrast, the second sampling period mainly targeted Beverly bulls and the remainder of the Beverly cow collars and therefore these observations were also used for estimates. The resulting data set had 251 groups (2,661 bulls:3,675 cows) classified. The resulting estimate of bull cow ratio was 0.724 (SE=0.037, CI=0.659-0.799) and the adult cow proportion was 0.580 (SE=0.012, CI=0.556-0.605). If only the October 23-November 4 data is used the bull-cow ratio was 0.628 (SE=0.042, CI=0.55-0.71), and an adult cow proportion of 0.614 (SE=0.0183, CI=0.579-0.650) which are the ratios reported in Adamczewski et al. (2024).

As the Beverly June 2023 calving-ground survey was designed to assess the abundance of adult female caribou, the total or “extrapolated” herd size was estimated using the estimated number of adult females developed during the abundance phase, divided by the proportion of cows in the herd using 2022 fall composition results (herd size = $N_{adult\ females}$ / proportion females in herd (fall)) (**Table 16**).

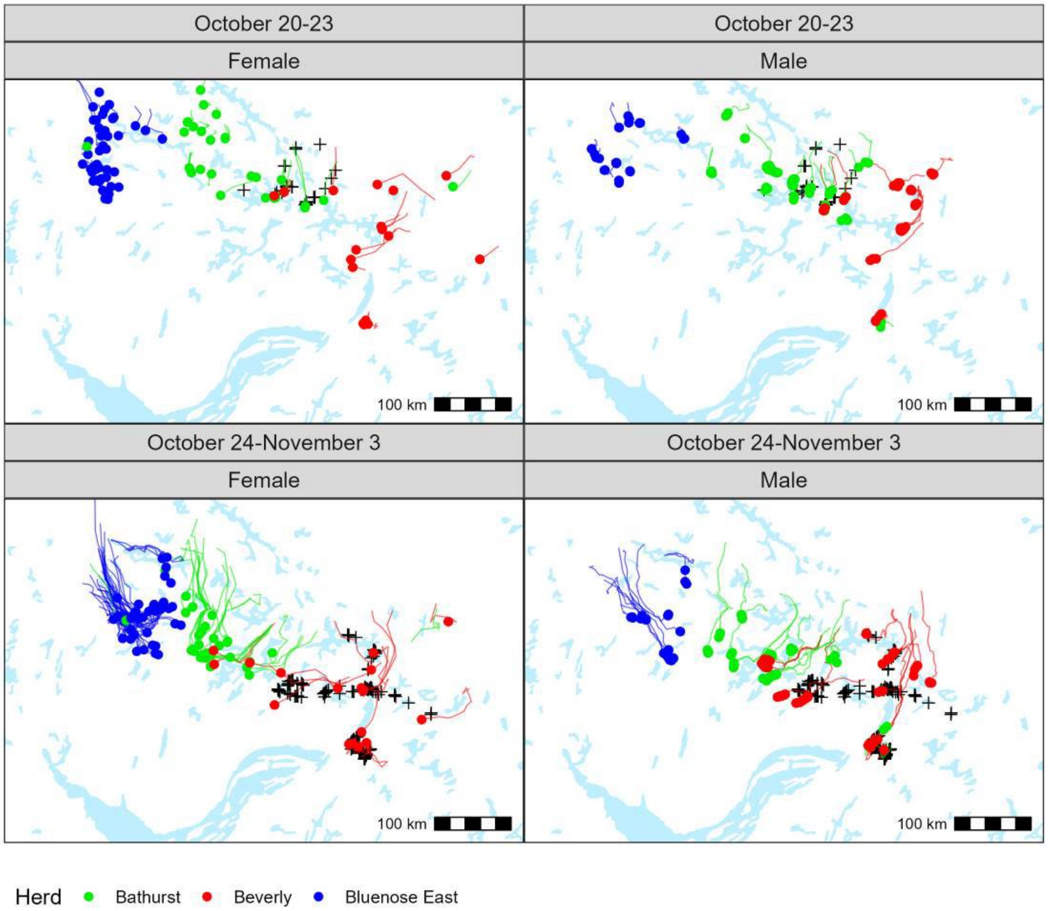


Figure 37. Collar locations and composition observations (+ signs) for 2 survey periods during the Fall 2022 Beverly composition survey. The first period (October 20-23) mainly targeted the Bathurst herd but did sample in the proximity of 5 Beverly cows. The second period primarily targeted the remainder of the Beverly herd. Paths of collared caribou during each sampling period are also shown.

One pattern evident during the 2023 Beverly calving-ground survey was high densities of bulls in most of the southern strata. Inspection of bull locations during the survey reveals that bulls were either in the proximity of, or within the 2023 survey strata, a condition not previously observed when compared to past surveys and telemetry data (**Figure 38**). More exactly, of 44 collared Beverly bulls, 28 (or 63%) were within the survey strata and only 16 were outside. Of the 16 bulls outside, only 2 (or 4.5%) were a substantial distance from the survey area (**Figure 39**). We believe that the un-seasonably early spring melt, and associated overflowing and fast-moving rivers, slowed and/or stopped the movement of breeding females into the more northern extents of their annual concentrated calving area. This barrier to movement held migrating breeding females within areas typically occupied by bulls based on telemetry and previous calving-ground survey observations. This condition reduced bull and cow segregation, causing breeding females to overlap into areas typically occupied by bulls during calving. **Figure 38** also suggests there was some mixing of the Bathurst and Beverly herds during the 2022 rut when the composition survey occurred. These observations suggest that most of the Beverly Herd (males and females) were within the June 2023 survey strata at the time of abundance flights. Using these observations, an alternative estimate of herd size was derived as the summation of bulls and cows (**Table 17**). This estimate is higher than the extrapolated herd estimate but lower than the total estimate of caribou on the calving ground. The remainder of caribou in this case would be yearling caribou which amounted to 10,731 (SE = 874.3, CI = 8,313 - 13,853) yearlings across all strata (excluding the low-density strata).

Table 16. Estimates of extrapolated herd size for the 2023 Beverly calving-ground survey based on estimates of adult females from the survey and estimates of proportion cows in the herd from the 2022 fall composition survey.

Method	N	SE	Conf. Limit		CV
Proportion females	152,131	13071.9	124,704	179,558	0.085

Table 17. Estimates of adult herd size as the summation of bulls and cows estimated in core survey strata during the June 2023 Beverly calving-ground survey.

Group	N	SE	Conf. Limit		CV
Bulls	74,404	5822.5	61,855	89,499	0.078
Cows	88,236	7343.3	75,564	103,033	0.083
Total	**162,640**	**9371.5**	**143,375**	**184,494**	**0.058**

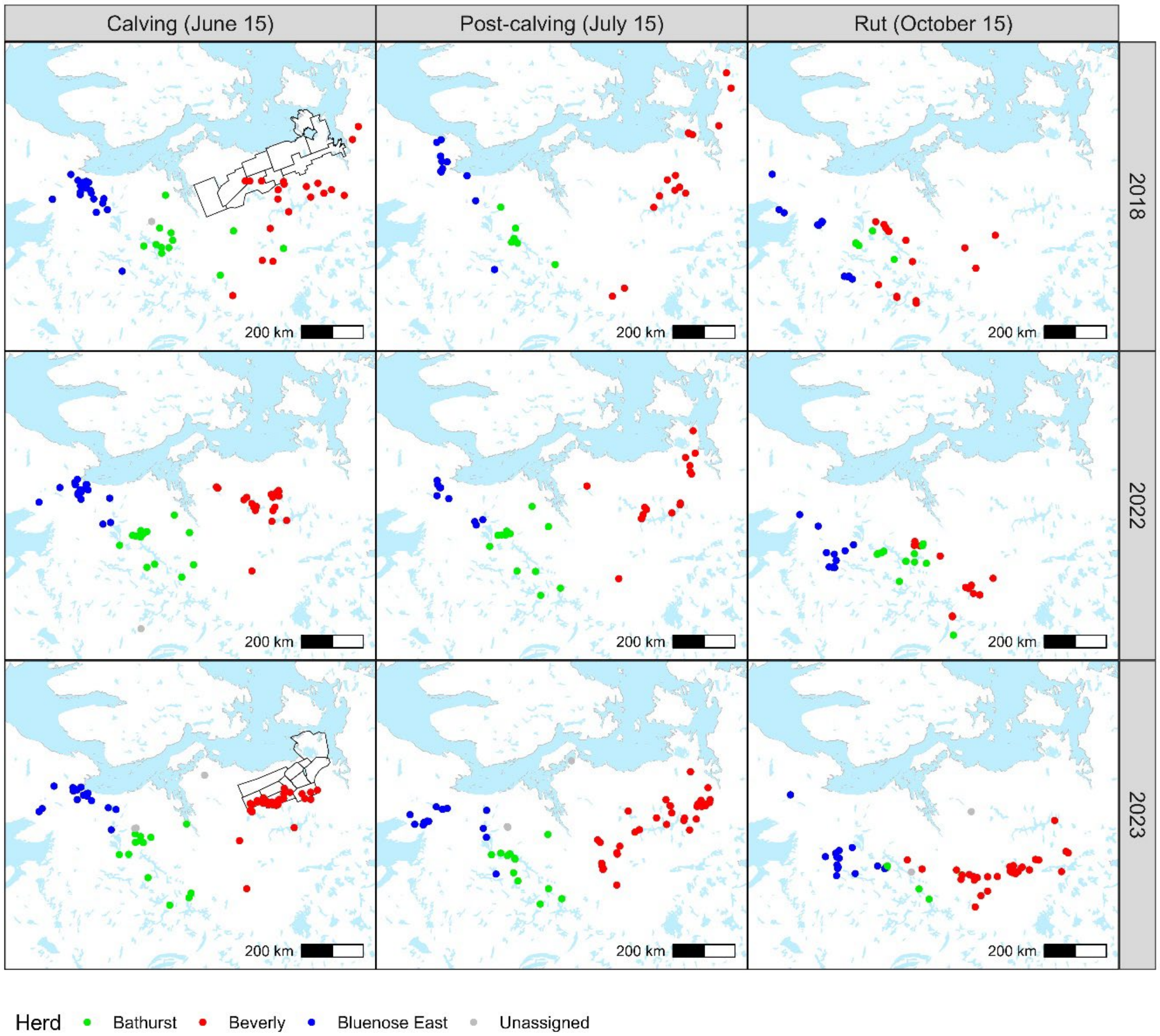


Figure 38. Locations of bulls for calving, post-calving, and rut in 2018, 2022 and 2023. Strata areas are shown for 2018 and 2023 when calving ground surveys occurred. Composition surveys occurred during the fall of 2022 during the rut.

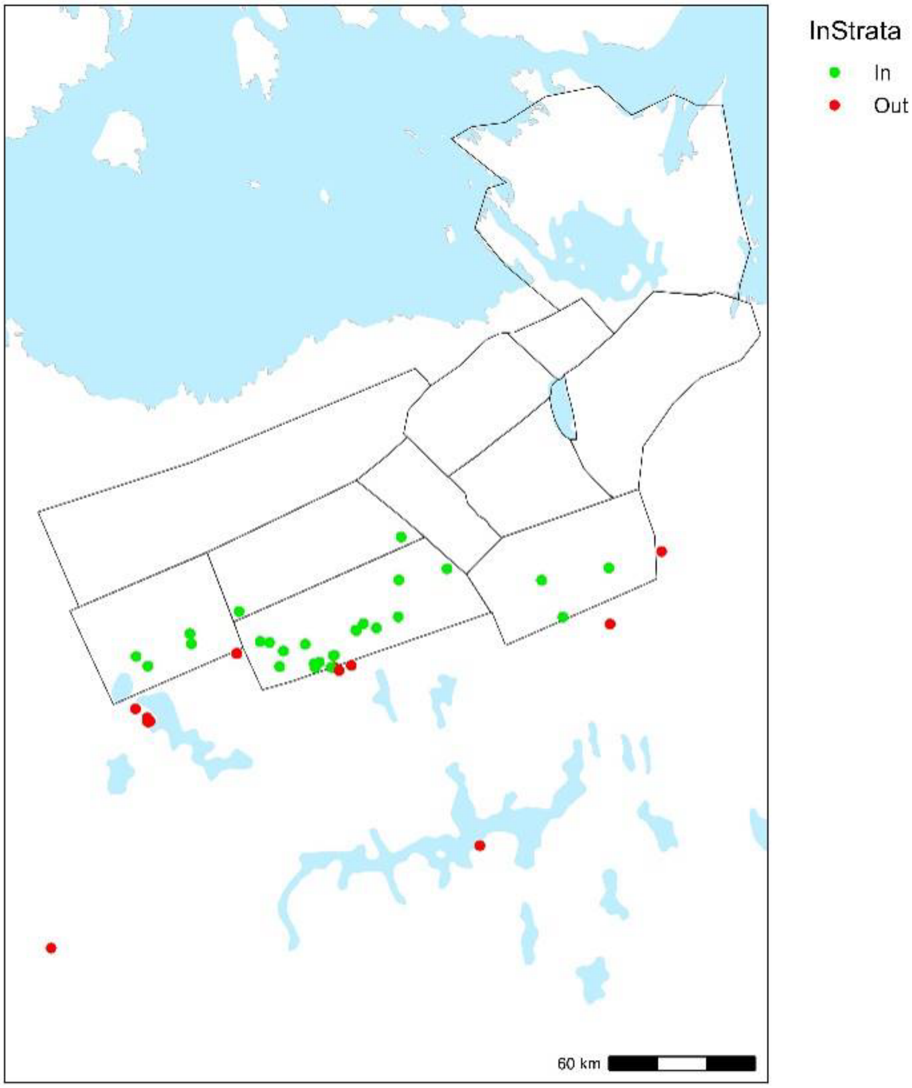


Figure 39. Closeup of locations of 44 Beverly bull collars on June 15, 2023 relative to survey strata. Locations are classified as to whether they are within or outside of the survey strata. One collar to the south is not shown.

4.4 ABUNDANCE TRENDS

Trends in adult females suggest an increase in 2023 from the 2018 survey and approximate stability compared to the 2011 survey (**Figure 40**). Estimates of yearly change for adult females indicate a significant yearly increase of 8% per year (CI=4-12%) of adult females between 2018 and 2023 (**Table 18**).

Reconnaissance data from abundance survey years (2011, 2018, and 2023) and reconnaissance survey years (2013 and 2016) provides a secondary assessment of trend and spatial distribution of caribou on the calving ground. A plot of segment densities indicates higher segment densities in 2013 and 2023 (**Figure 41**). However, very high segment densities are more prevalent in 2023 with segment densities above 50 caribou/km^2. A plot of transect densities from west to east also reveals notably higher transect densities in 2023 but also reduced coverage to western areas. Despite the difference in coverages, the overall number of caribou observed during the reconnaissance survey was two to four times higher than observed in any of the other survey years. Some areas of higher density were video surveyed, along with the visual counts, for the June 2023 reconnaissance survey that preceded the abundance phase. Similar cross-referencing methods (to the abundance survey video assessments) were used to reconcile visual and video polygons within the June 2023 reconnaissance. The proportion of caribou counted on orthomosaic polygons along reconnaissance transects is delineated in **Figure 42**. Peak densities (approximately 40 caribou/km^2) on some lines are at levels also observed during the visual survey.

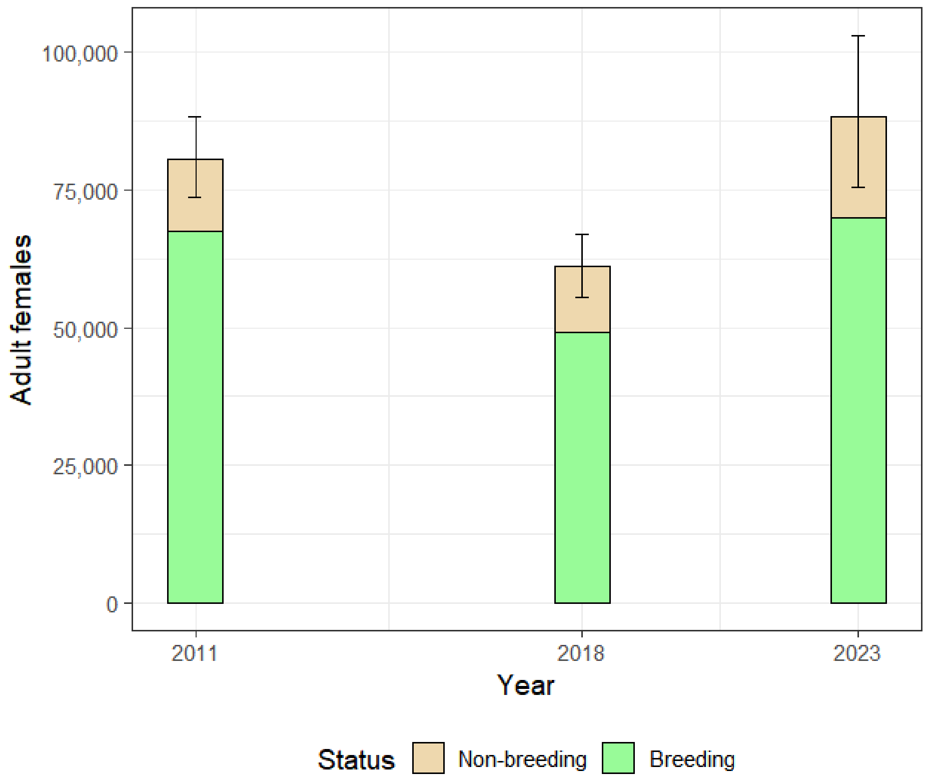


Figure 40. Adult female estimates by breeding status from 2011-23 Beverly abundance surveys.

Table 18. Estimates of gross and annual change for adult females between Beverly June calving-ground abundance survey efforts.

Years	Year 1		Year 2		Gross change				Yearly change (lambda)			
	N	SE	N	SE	GC	SE	Conf. Limit		λ	SE	Conf. Limit	
2018-23	61070	2887.8	88236	7343.3	1.44	0.14	1.20	1.74	1.08	0.02	1.04	1.12
2011-18	80705	3724.3	61070	2887.8	0.76	0.05	0.66	0.86	0.96	0.01	0.94	0.98
2011-23	80705	3724.3	88236	7343.3	1.09	0.10	0.91	1.31	1.01	0.01	0.99	1.02

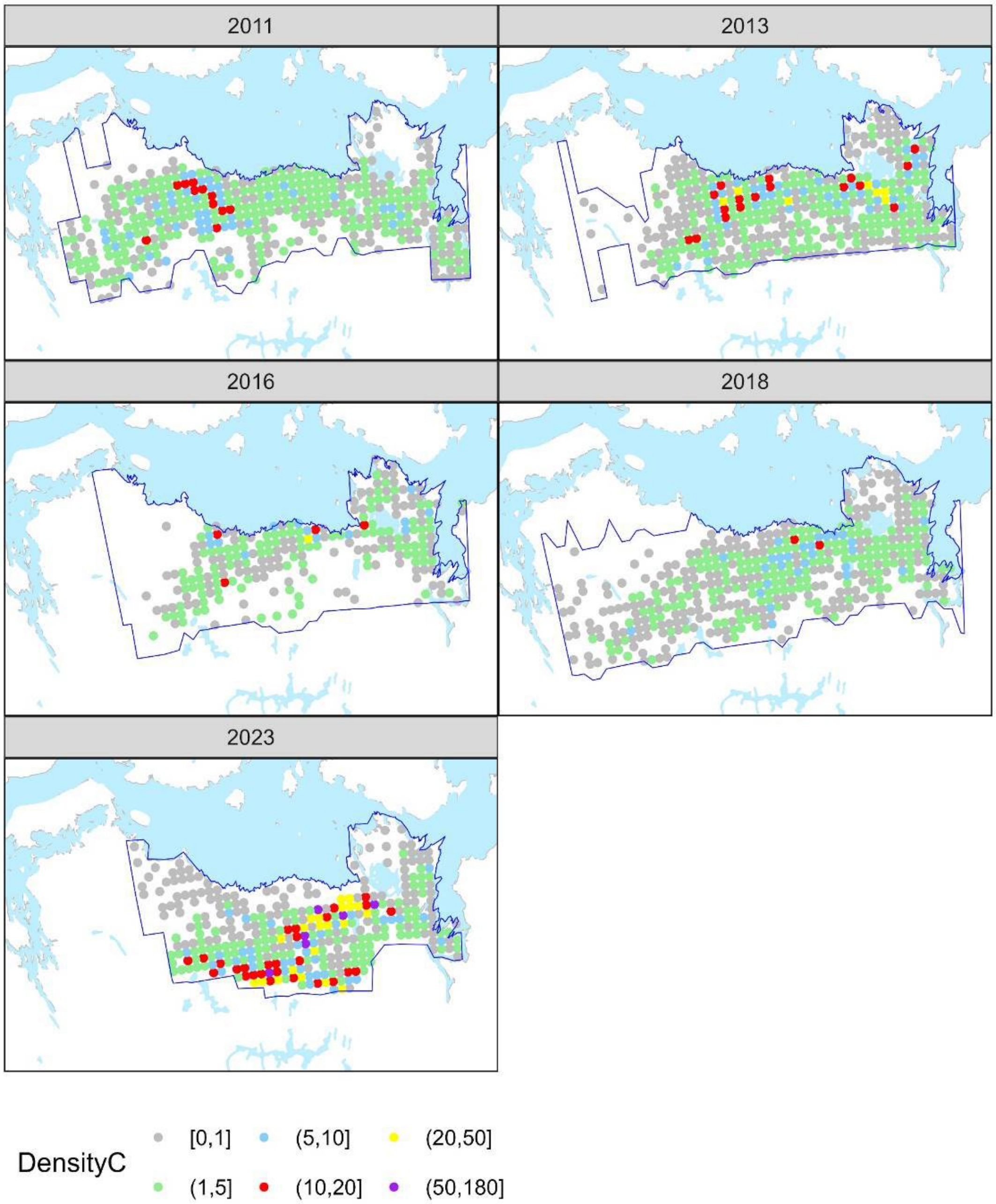


Figure 41. Segment densities (caribou/km^2) from June Beverly reconnaissance surveys. Densities are color coded based on ranges of densities observed at each segment flown. The extent of surveys is delineated by a blue polygon for each year.

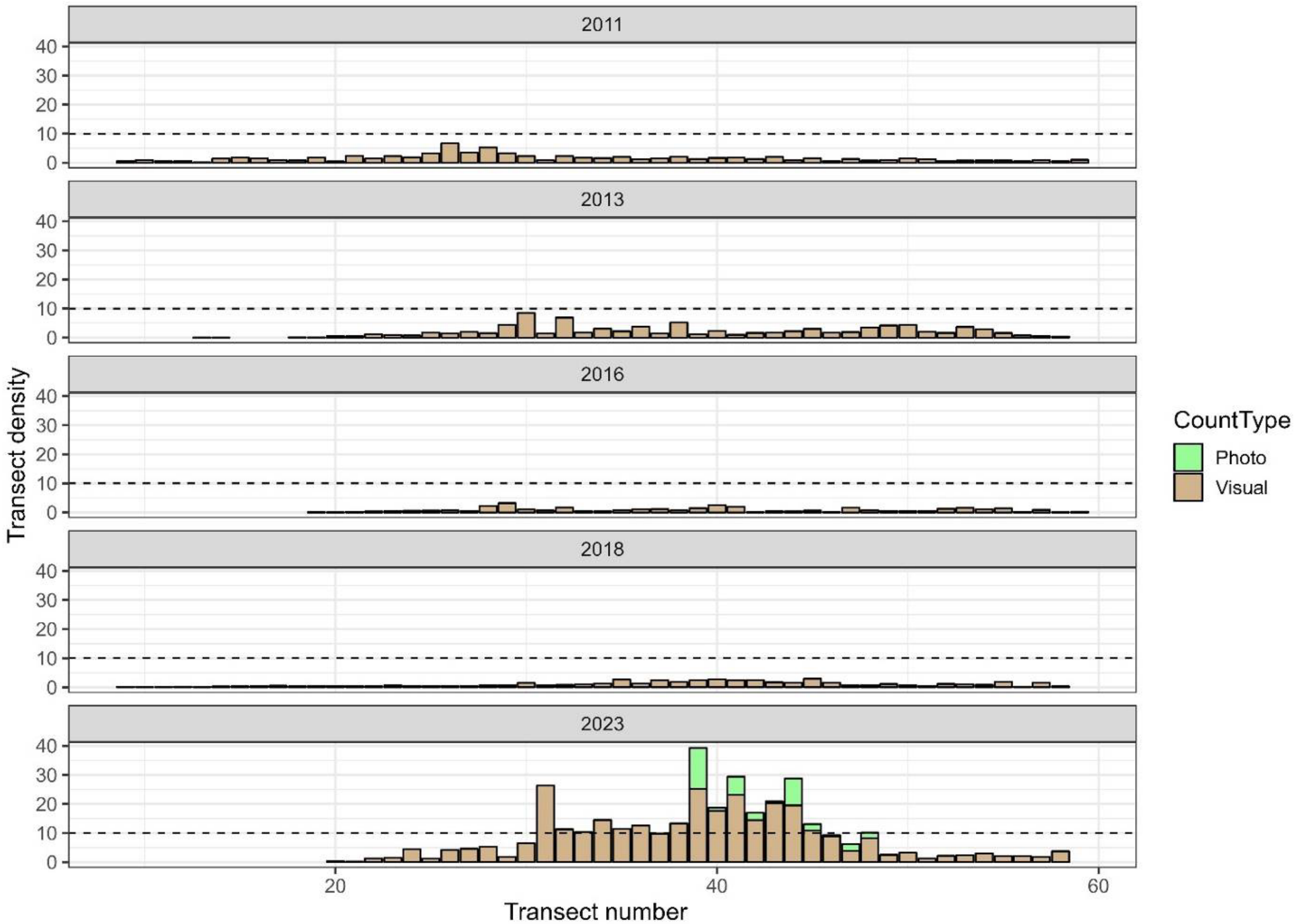


Figure 42 Caribou density (caribou/km^2) by reconnaissance transect line for each survey year. The proportion of caribou counted on photos is given as sub-bars for 2023 (**Figure 18**).

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 caribou from the Lorillard, Wager Bay, Ahiak, Qamanirjuaq, Beverly, Bluenose, and Bathurst herds were monitored daily. Collared bull data was only available for the Bathurst and Bluenose herds. All collar 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 (April) telemetry locations and migration paths of Nunavut's 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 43**). 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, below 20 for many herds, which ultimately limits the power to detect inter-herd movements (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 movement of caribou from the Bathurst to the Beverly calving-ground starting in 2018 (**Figure 44**). 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, and to the west, but not in the proximity, of the majority of calving 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. 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 anomalous as they were well east of the core Bathurst calving ground located, since the late 1990s, west of Bathurst Inlet. Therefore, there is some uncertainty in classifying caribou to a calving ground in this area of overlap (**Figure 45**). 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. 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 46**. 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 confluence 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 in and out of calving grounds can also be shown spatially by period (2011-2018 and 2019-2023) (**Figure 46**). Of most interest is whether there was directional movement into the Beverly calving-ground from 2019 to 2023 which could have contributed to the increase in Beverly abundance observed in June 2023. 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, however, these caribou occurred east of Bathurst Inlet in the ambiguous area between the two herds as shown in **Figure 45**, 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 48**. 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. 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. Therefore, increases in abundance are likely due to both immigration of caribou into the Beverly calving ground as well as demographic increase. This topic was explored further using an Integrated Population Model.

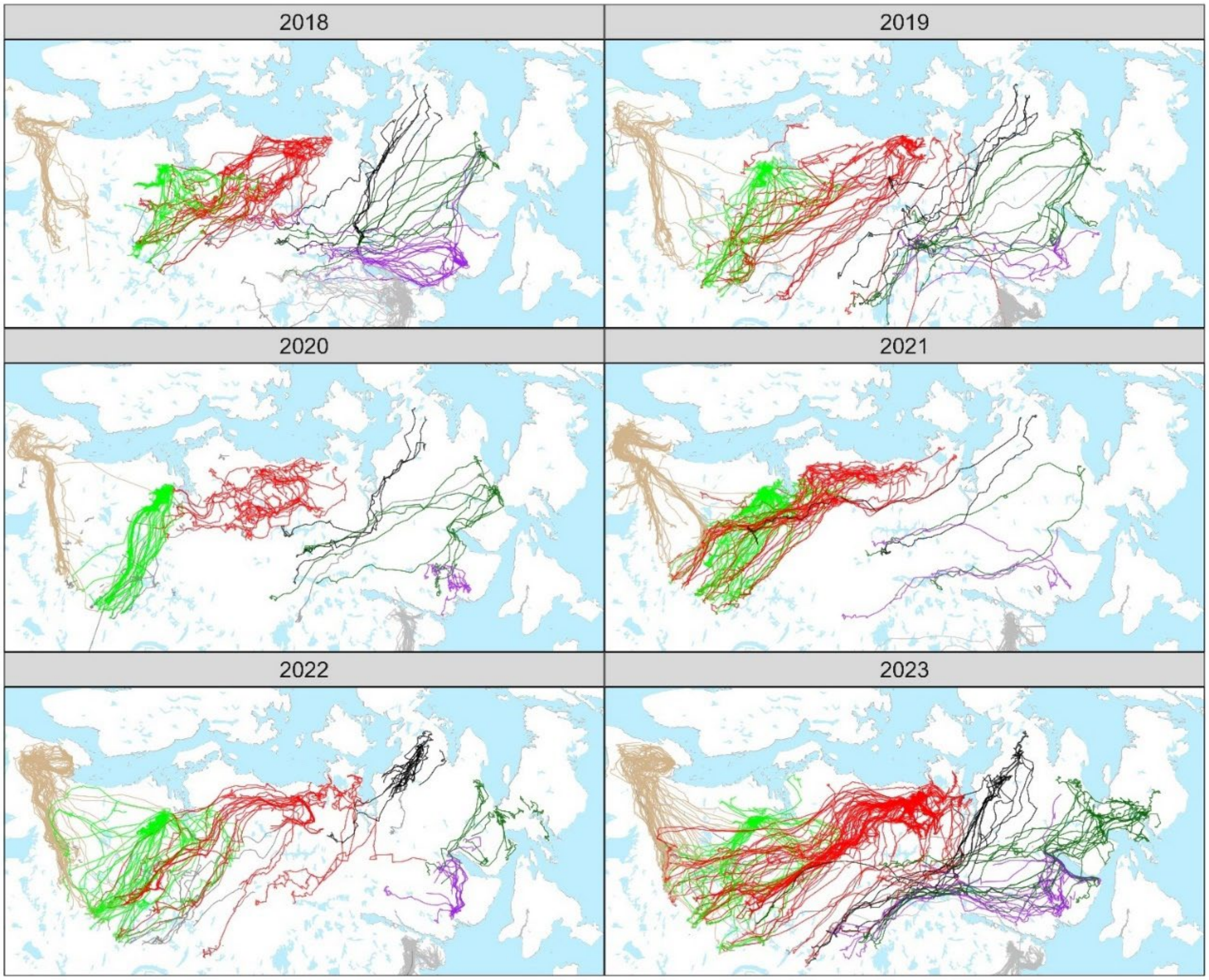


Figure 43. Migration paths (March to June 15) for the Bluenose-East (brown), Bathurst, (green), Beverly (red), Ahiak (black), Wager Bay (dark green), and Lorillard herds (purple). Collars were classified based on the calving ground that they calved in during 2022 and 2023.

Table 19. Sample sizes of adult female caribou that were monitored more than 1 complete year to determine known calving ground locations over a two year period.

Year	Bathurst	Beverly	Ahiak	Wager Bay	Lorrilard
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**

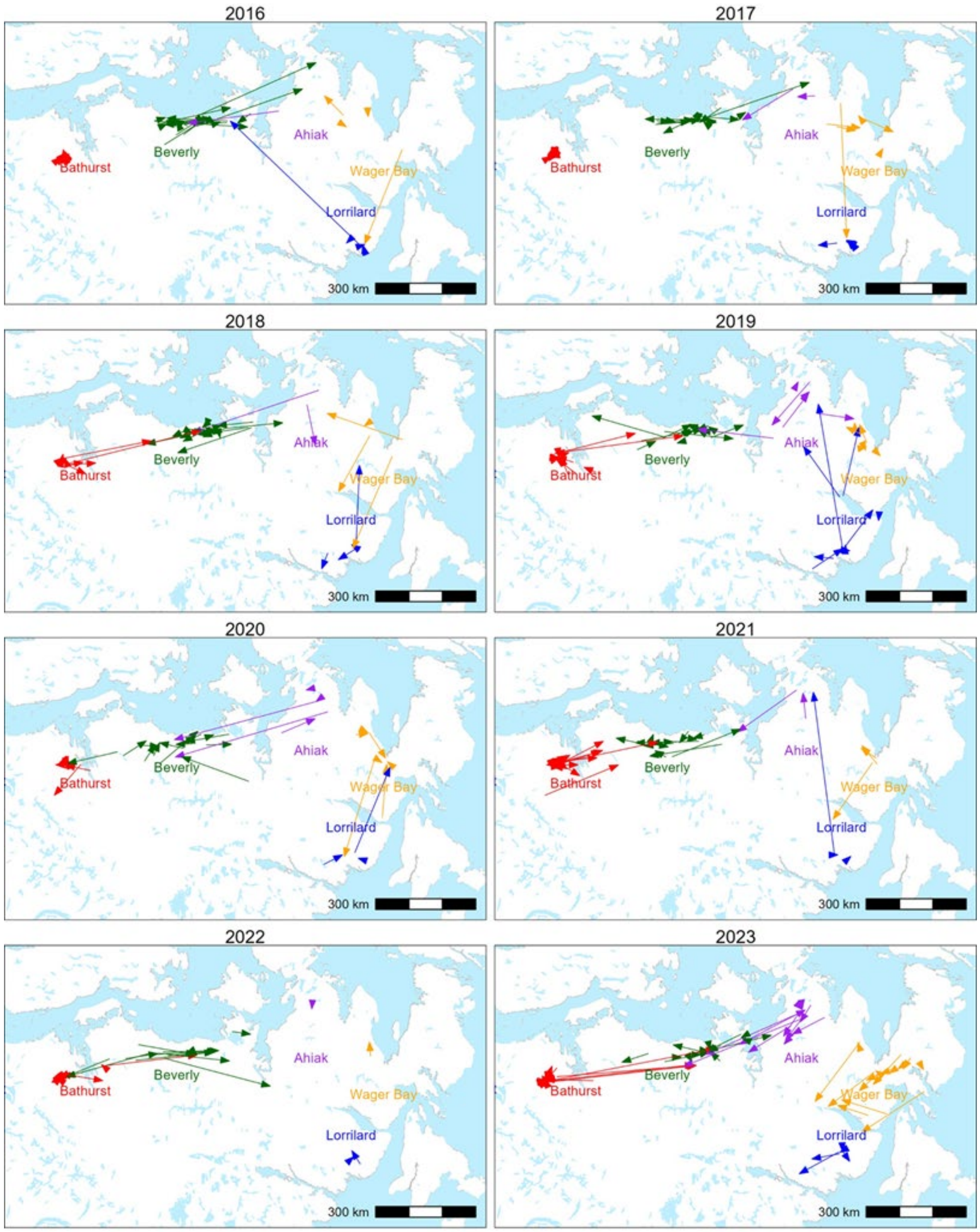


Figure 44. Mean calving ground locations for individual caribou in the previous year (tail of arrow) and current year (head of arrow) with the arrow colored according to the previous year calving ground. Each line and arrow indicates one collared caribou

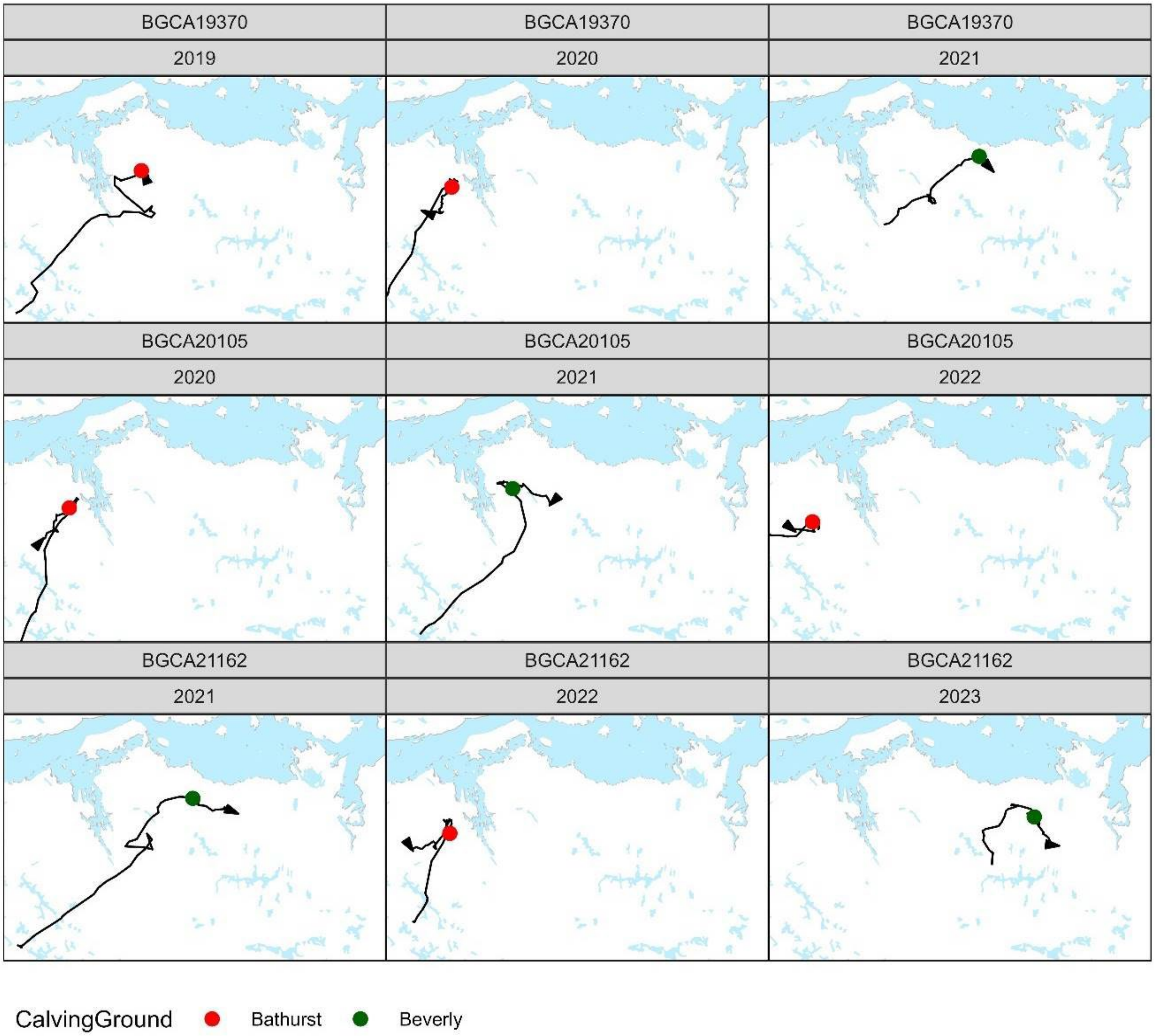


Figure 45. Calving locations (on approximately June 10th) and paths (May 1-June 30) for 3 collars that calved in-between the core Bathurst and Beverly calving grounds.

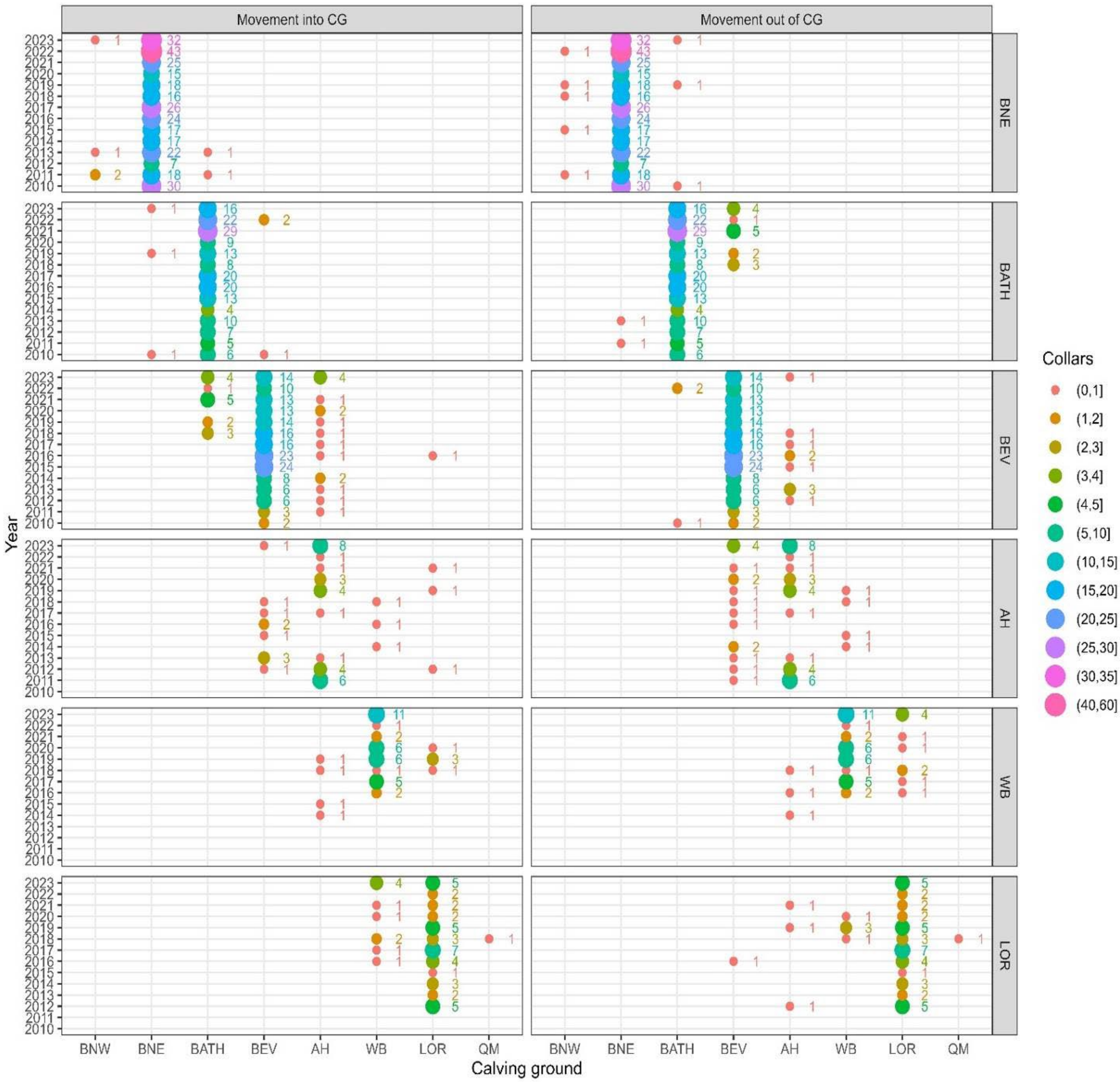


Figure 46. Graphical summary of movement events in and out of calving grounds. The left plot displays movements into the cg each year and the right are movements out, with columns indicating the herd. If a column is the same as the herd (i.e. LOR column in LOR herd plot) then sample sizes indicate caribou returning to the calving ground from the previous year (fidelity). This column is repeated for movements into and out of calving grounds.

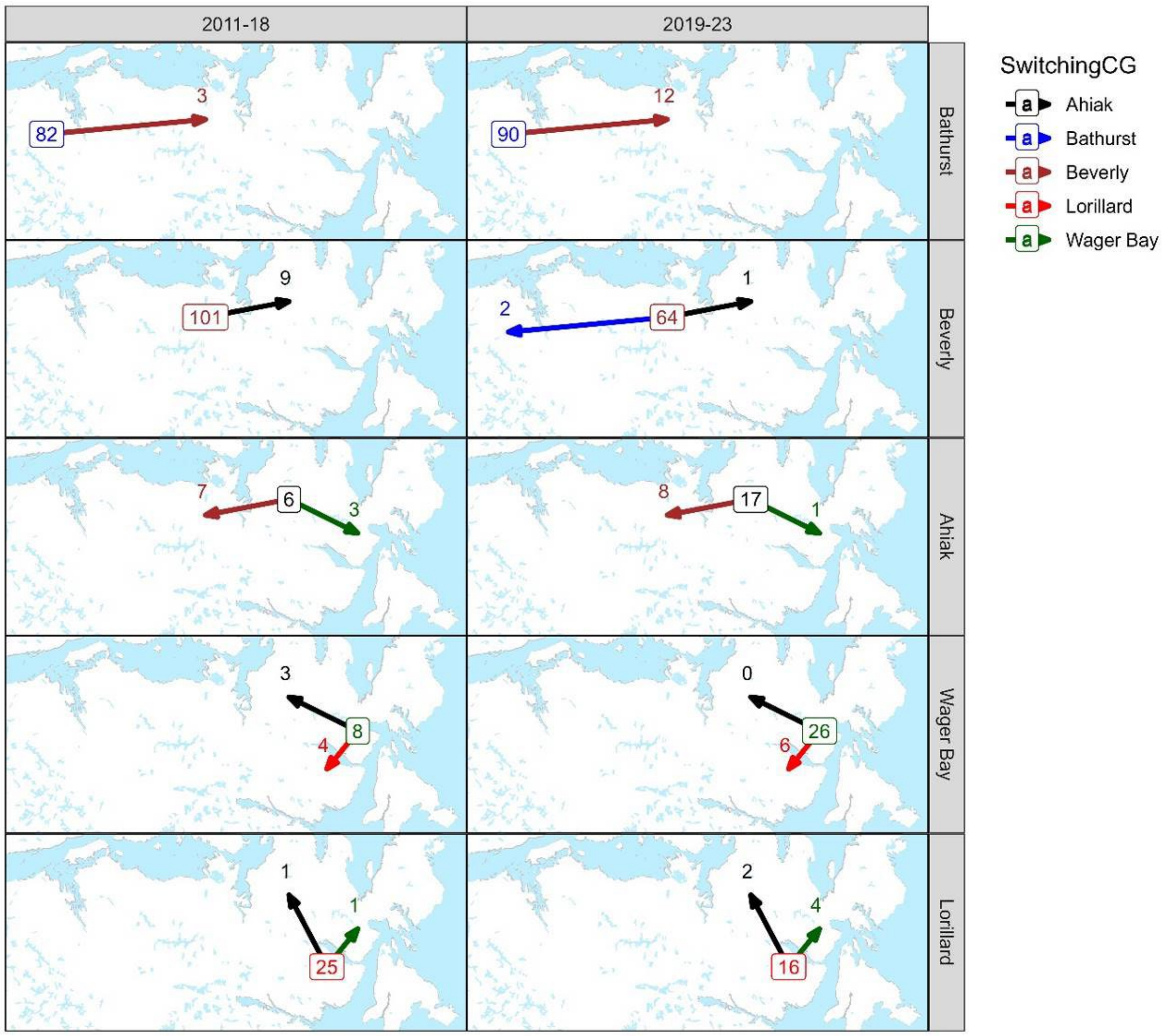


Figure 47. Frequencies of fidelity (numbers in boxes) and switching events of adult females from 2011-2018 and 2019-2023 for the Beverly and surrounding caribou herds.

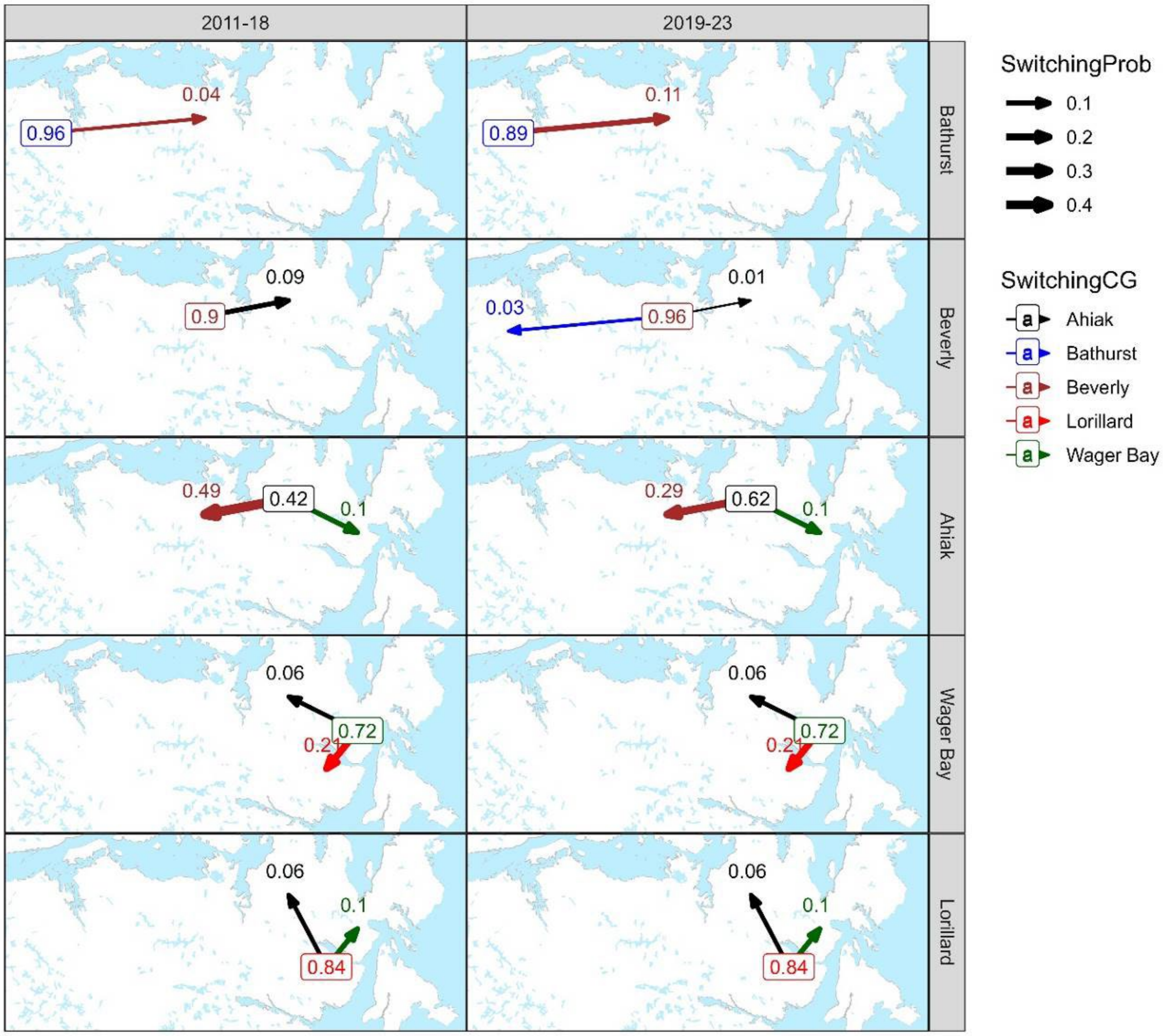


Figure 48. Estimates of fidelity to specific calving-grounds (numbers in boxes) and switching probabilities (arrows) of adult females switching calving-grounds from 2011-2018 and 2019-2023 for the Beverly and surrounding caribou herds. Estimates with confidence limits are given in Appendix B.

4.6 COLLAR 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 used data sets of collared adult female caribou maintained by the Government of the 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 on in a given year. A caribou that calved on the Beverly or Adelaide Peninsula area was considered a Beverly cow for this analysis (**Figure 49**). 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 50**). Yearly survival rates were then estimated based on the product of 1-monthly mortality rate for a given caribou year, which is the Kaplan-Meir survival rate estimator (Pollock et al. 1989). Estimates, however, were of lower precision due to lower collar sample sizes (**Figure 51**). 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.

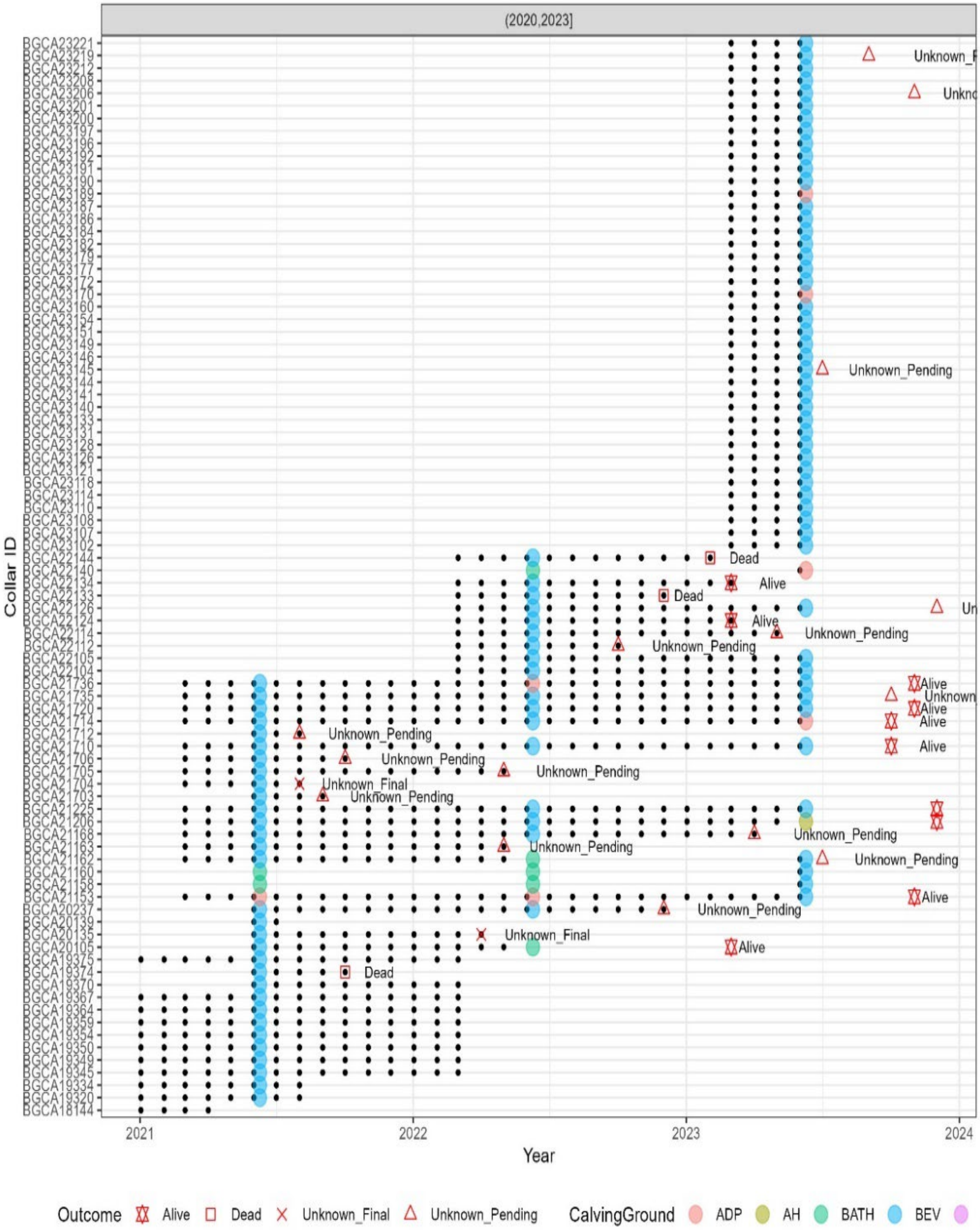


Figure 49. Collar histories of Beverly cows. Included is fate of each collar and the calving ground (colored dot) it utilized each June.

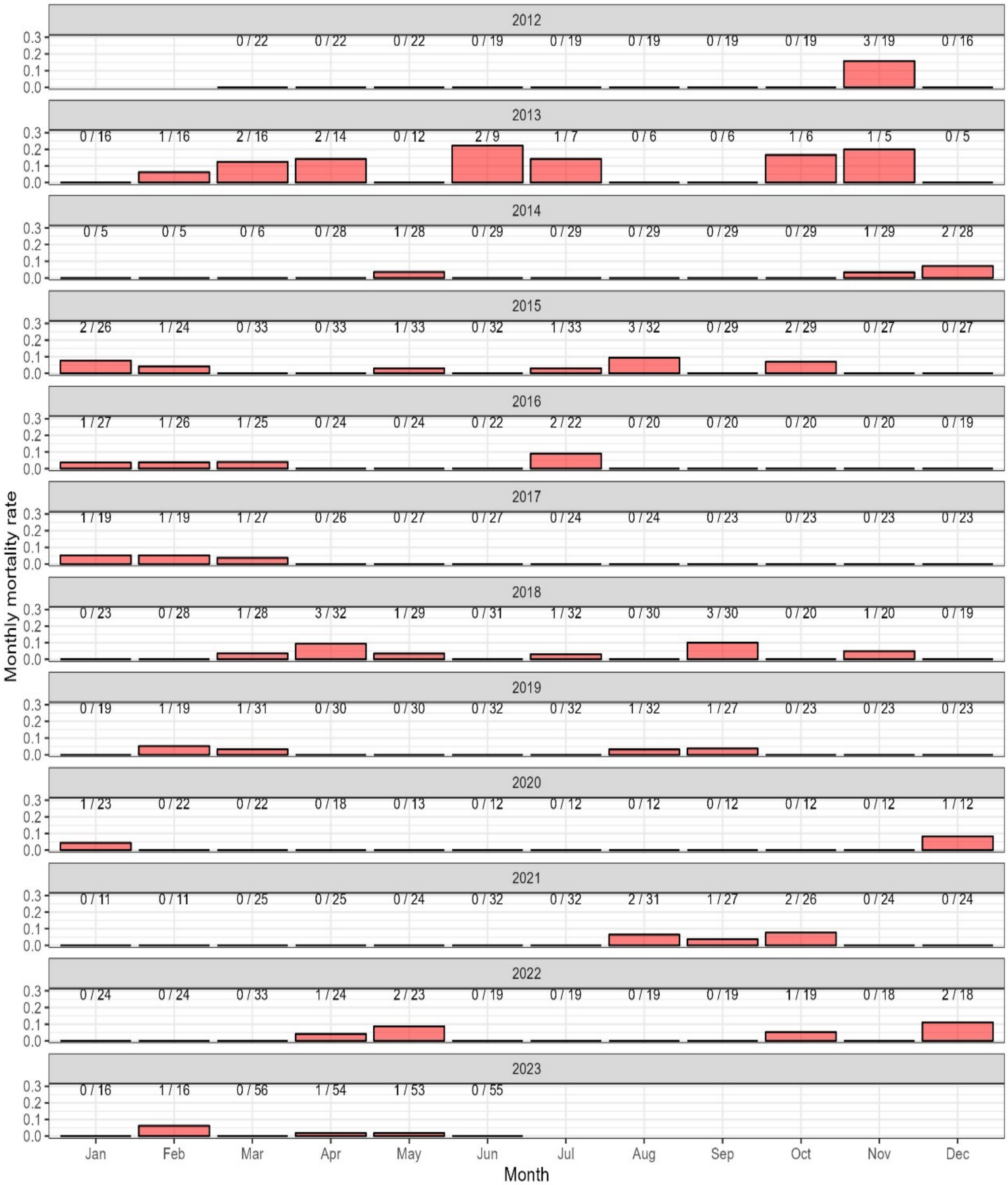


Figure 50. Monthly mortality rates for collared caribou from 2012 to 2023. Sample sizes of mortalities and collars monitored is given above each bar.

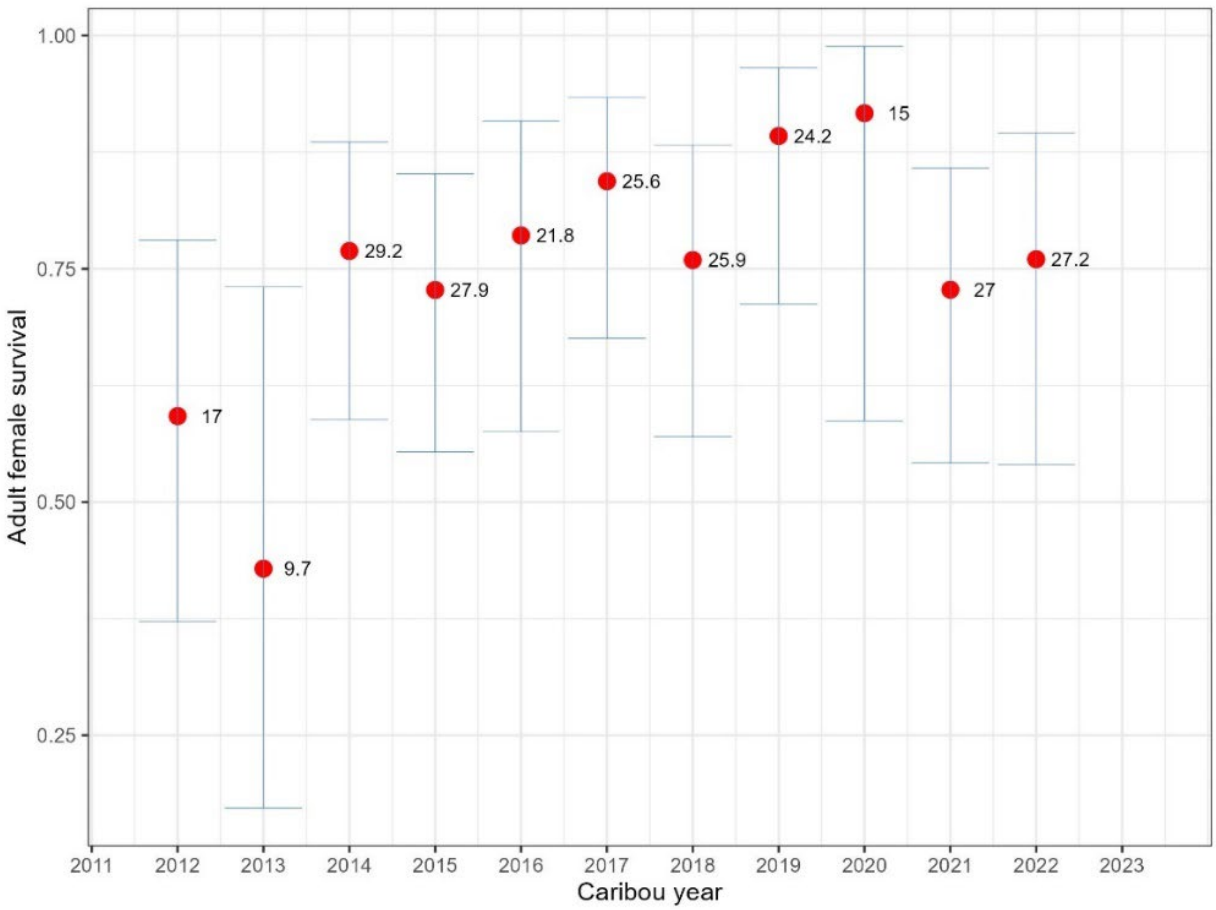


Figure 51. Yearly survival rates for collared adult females. The mean number of collars monitored is given next to each estimate.

4.7 INTEGRATED POPULATION MODEL - DEMOGRAPHIC ANALYSIS

4.7.1 Data sources

In addition to adult survival, other data sources for the IPM included spring and fall composition surveys, survival rates for bulls, and composition survey results from calving grounds (Adamczewski et al. 2023, Adamczewski et al. 2024; Campbell et al. 2013; Campbell et al. 2019). While limited, the data set does suggest some trends such as reasonable productivity (spring CC ratios > 0.4) and cow survival rates in the range of 0.8 or higher for many of the years measured (**Figure 52**). Also considered is the estimate of Ahiak adult females in 2011 and 2021 (Campbell et al. 2022) in unison with frequencies of collars moving to the Beverly (**Figure 46**).

An additional source of information was the estimated immigration of the Bathurst to the Beverly based upon the Bathurst IPM which models fidelity and movement of the Bathurst herd (Adamczewski et al. 2022, Boulanger et al. 2024). For this model fidelity of Bathurst cows to the Bathurst calving ground was estimated by the frequency of cows that calved on the Bathurst calving ground in successive years (**Figure 53**). As discussed previously, a proportion of cows emigrated to the Beverly calving ground most notably after 2018. Using estimates of fidelity, emigration/immigration, and adult cows, the number of cows present on the calving ground with and without immigration/emigration was estimated. The difference in these two numbers was then considered an estimate of cows from the Bathurst emigrating to the Beverly calving ground. This number was usually low but did increase up to nearly 2,000 adult Bathurst cows in 2018 with levels varying between 0 and 1,000 from 2019 to 2022. Note that these Bathurst cows are assumed to continue having calves based on fecundity rates of the Bathurst herd on the given year (**Figure 53**). Additionally, the actual impact of Bathurst adult cows immigrating to the Beverly herd is compounded through time as the newly recruited adult females continue to produce calves in successive years, further bolstering demographic growth within the Beverly herd as female calves themselves become breeding females and so on.

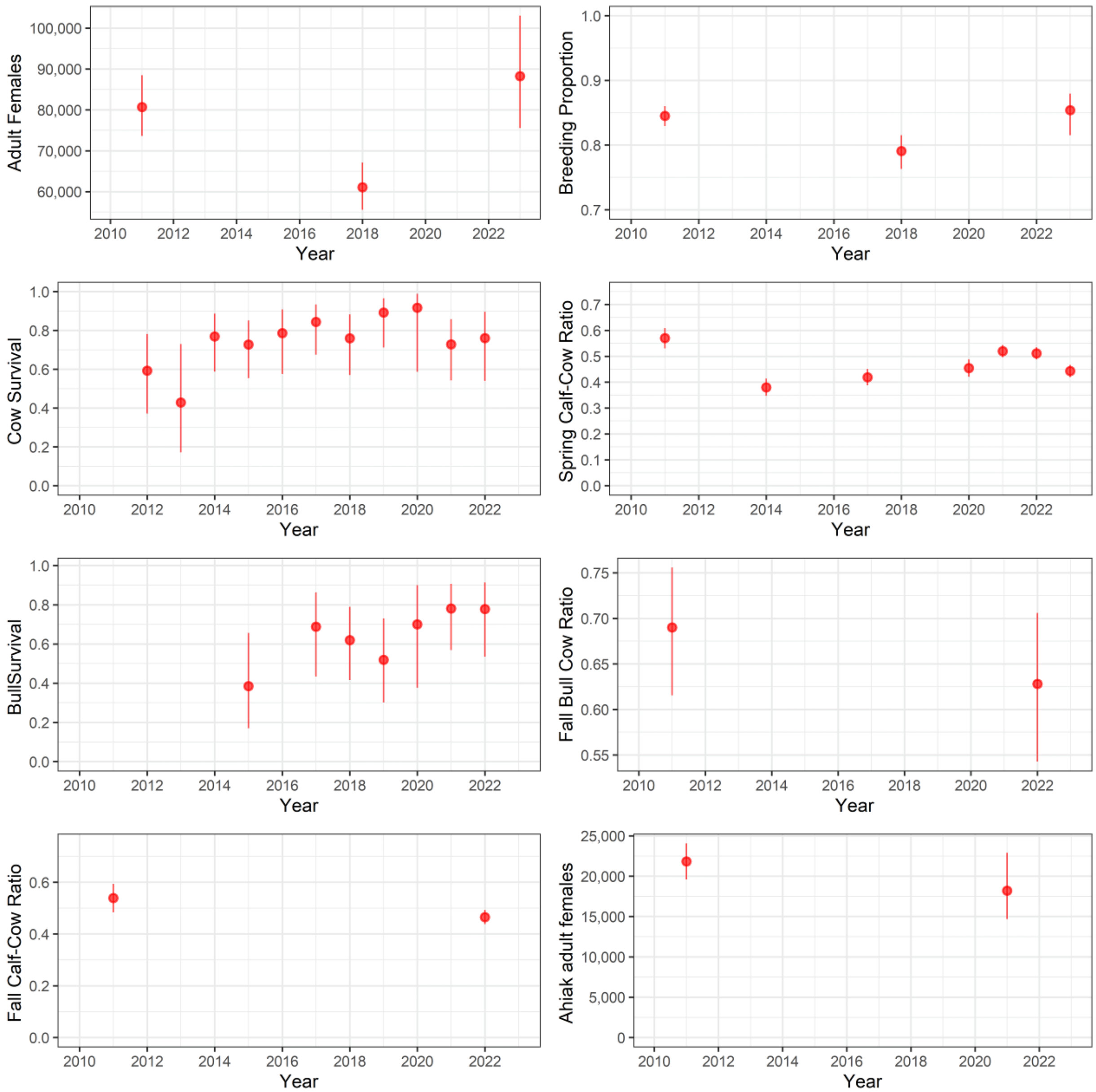


Figure 52. Field data used as input into the Integrated Population Model.

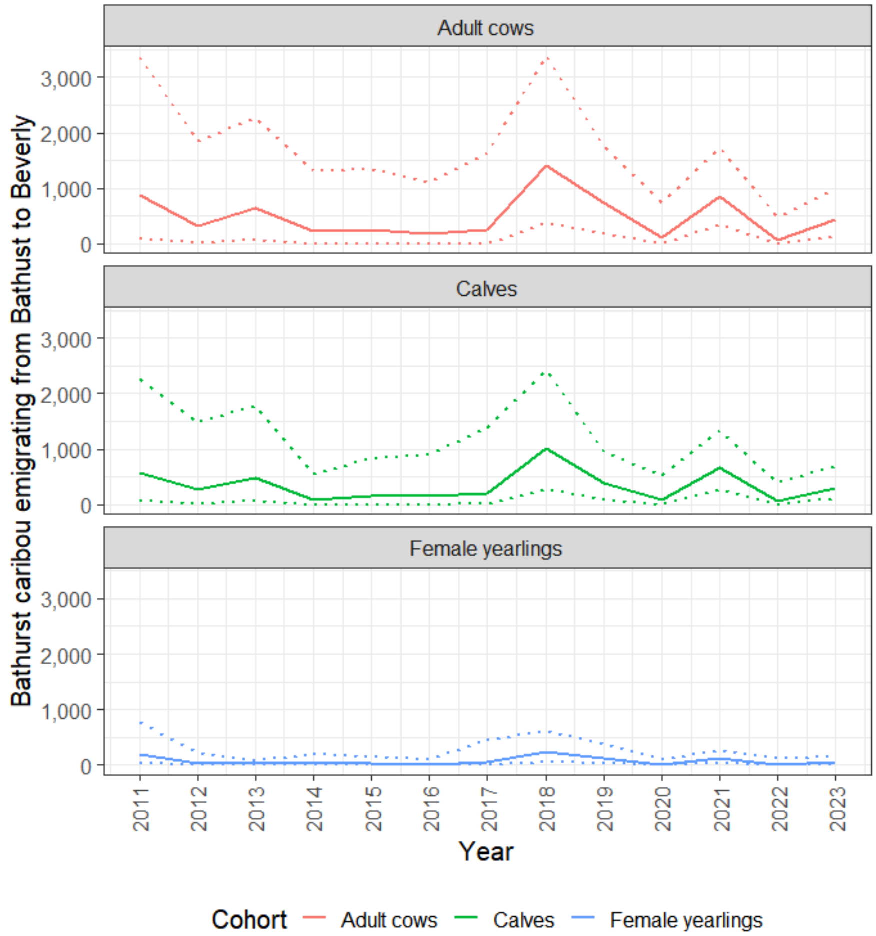


Figure 53. Estimated number of Bathurst caribou emigrating to Beverly based on IPM developed for the Bathurst herd (Boulanger et al 2024). The number of Bathurst adult cows emigrating is based on collar movements and other IPM data sources. The number of calves emigrating is the product of cows emigrating X the estimated pregnancy rate for a given year. The number of female yearlings emigrating assumes similar emigration rates for adult females. Dotted lines are the 95% confidence limits on predictions.

4.7.2 Model scenarios considered

The primary questions addressed by the IPM analysis were whether the observed increase in Beverly herd abundance could be due to demographic factors (survival and productivity) in comparison to effects of potential emigration from the neighboring Ahiak herd to the east, and Bathurst herd to the west. Three model scenarios were run to address these questions:

1. *Trend in Beverly due to demographic factors only:* For this model, trend and abundance in 2023 was estimated based solely on adult female and male survival rates and productivity from composition surveys as shown in **Figure 52**.
2. *Trend in Beverly due to demography + movement between Ahiak and Beverly:* For this model run the effect of emigration and immigration of adult females and accompanying calves to and from the Ahiak herd was added to the base demographic model. Demography (survival and productivity) of the Ahiak herd was assumed to be similar to the Beverly herd. The actual trend in the Ahiak was further constrained by estimates in 2011 and 2021 (**Figure 52**).
3. *Trend in Beverly due to demography + movement between Ahiak and Beverly and movement from the Bathurst herd:* The effect of movement of adult females and accompanying calves from the Bathurst herd (**Figure 53**) was then added to the Beverly-Ahiak demographic model developed in step 2. The actual Bathurst IPM was not incorporated into the analysis, only outputs were used. As discussed later, future models could incorporate the Bathurst IPM to better consider likely non-independence of movements between herds.
4. *Trend in Beverly due to demography + movement between Ahiak and Beverly and movement from the Bathurst herd + yearlings emigrating:* Scenario 3 was extended with the allowance of yearlings (in addition to adult females and accompanying calves) moving from the Beverly, Bathurst, and Ahiak calving grounds.

The main metrics used to compare scenarios are estimates of adult females and breeding females which are the main cohorts monitored by calving ground surveys as well as other demographic indicators. Adult females are proportional to overall herd size and therefore are an indicator of overall herd trend. We also show the fit to breeding females (adult females X proportion adult females breeding) which corresponds to the core segment of caribou targeted during calving ground surveys and therefore may be the best group to compare IPM predictions with field estimates.

*Base demographic model (**scenario 1**)*

The fit of the field data to the base Beverly demographic model was adequate with all IPM estimates (blue lines in **Figure 54**) falling within confidence limits of field estimates (red dots and confidence lines). The ability of a herd to increase depends on whether caribou are surviving (adult, yearling, and calf survival) and whether productivity (fecundity and calf survival) is high enough to offset caribou mortality. Adult female survival rates were approximately 0.8 in most years which is adequate for herd stability but will limit herd increase (Boulanger at all 2011). Productivity was high as indicated by calf-cow ratios of 0.5 or greater in most years as well as higher fecundity values. Fecundity or pregnancy rate was modelled for cows aged 2 and aged 3 and older therefore accounting for potential age structure effects on productivity with lower pregnancy rates for younger cows (**Figure 55**). Calf survival was 0.6 or higher for most years once again suggesting higher productivity.

An additional source of mortality was from the harvesting of adult cows and bulls (**Figure 56**). There are no solid estimates of harvest of caribou for the Beverly herd within either Nunavut, Northwest Territories, or Saskatchewan, the main harvesters of the herd. We assumed nominal levels of harvest with high uncertainty for females and males. This allowed the model to estimate harvest based on other data sources.

All estimates developed for the abundance of Beverly Herd adult females suggests a reasonable fit to all data points except the June 2023 adult and breeding female abundance estimates (this report), where the IPM estimate is below or just meets the lower confidence limit from the field estimate (**Figure 57**). We also show the fit to breeding females (adult females X pregnancy rate) which are more likely to include the core segment of older adult females which displays a slightly better fit than adult females. These results suggest that a demographic increase was plausible, however, demography alone does not entirely explain the higher 2023 estimate.

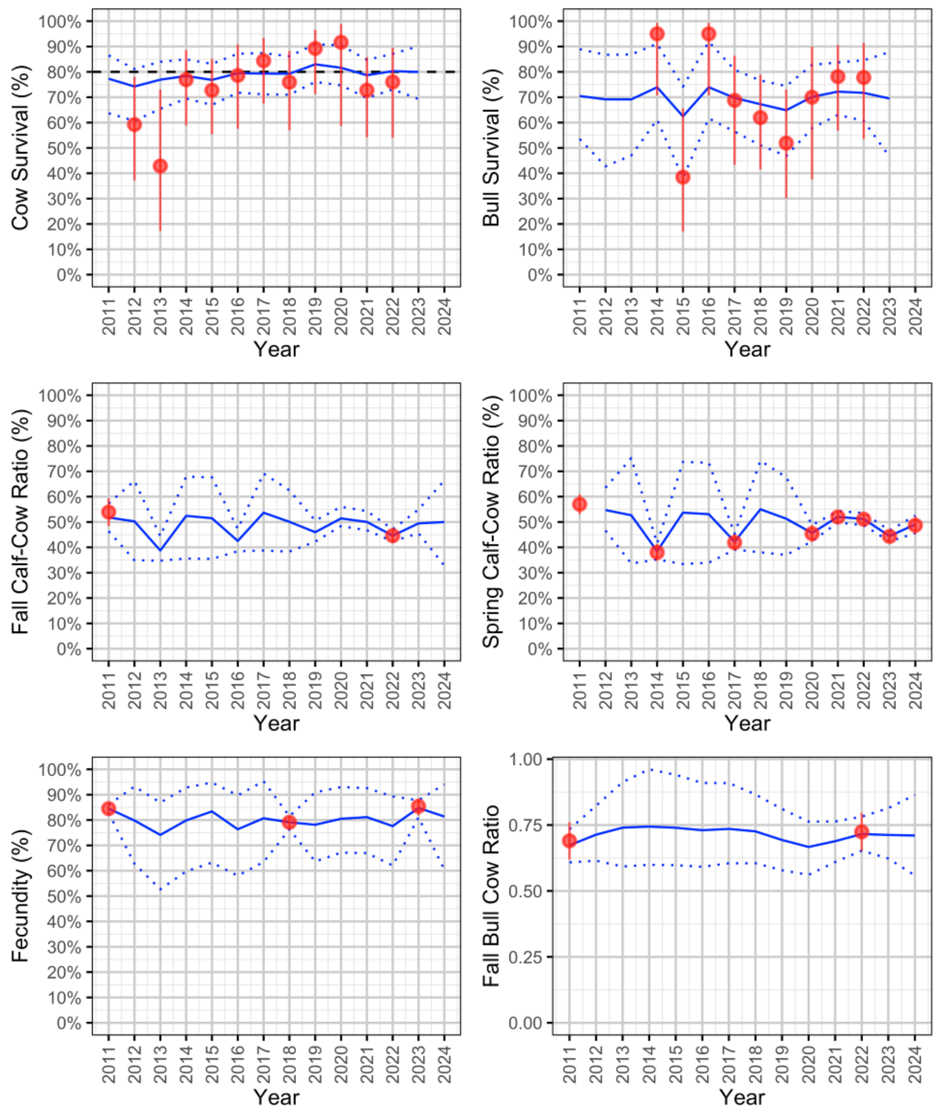


Figure 54. Fit of base demographic model to field measurements of Fecundity, fall composition, Cow survival, Bull survival, Spring composition, and Fall bull to cow ratio. Dotted lines are 95% confidence limits on predictions.

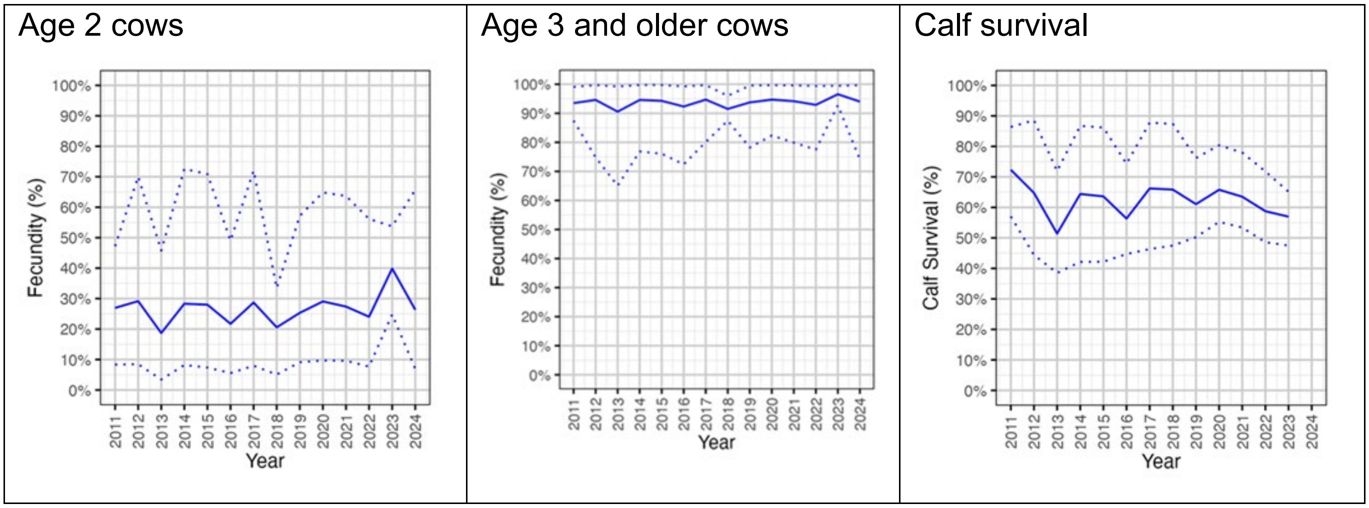


Figure 55. Estimates of fecundity (pregnancy rate) for cows age 3. Dotted lines are 95% confidence limits on predictions.

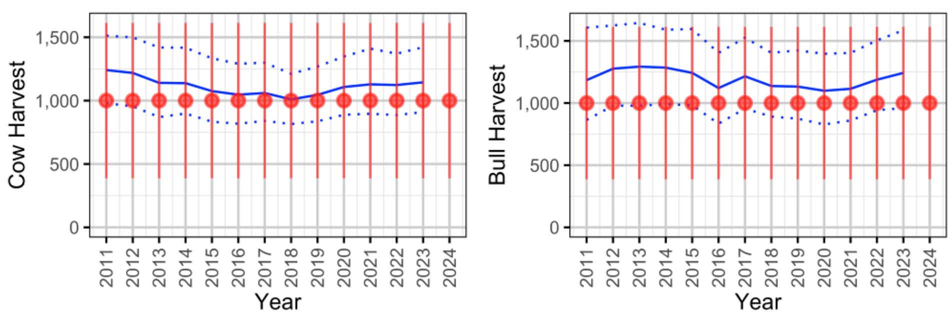


Figure 56. Estimates of harvest from IPM (blue line) compared to rough field estimates. Dotted lines are 95% confidence limits on predictions.

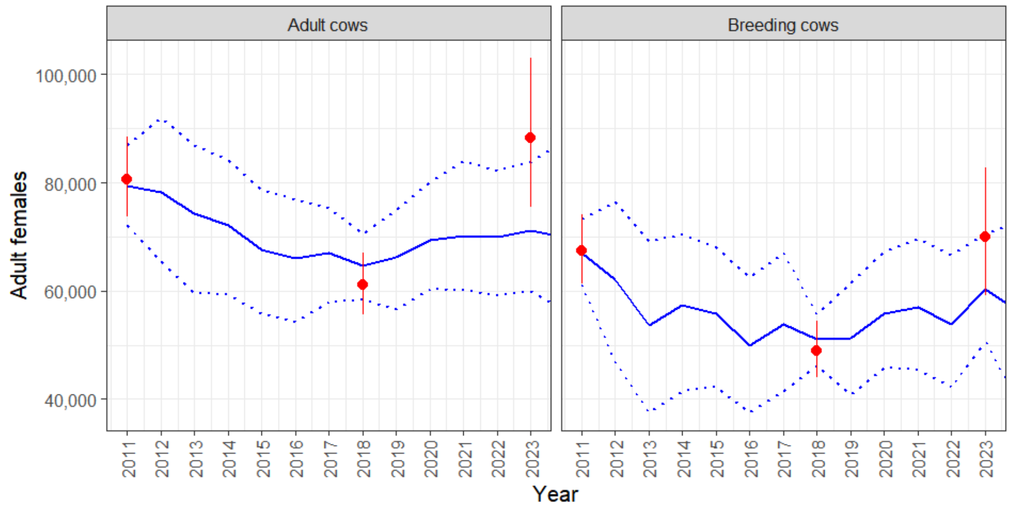


Figure 57. Estimates of adult and breeding females from the base Beverly demographic model. Dotted lines are 95% confidence limits on predictions.

*Base demographic model+Ahiak (**scenario 2**)*

IPM Survival and productivity rates from the base Beverly model were applied to the Ahiak herd to fit estimates of the Ahiak cows in 2011 and 2021. The resulting model predictions fit the field estimates well suggesting that sharing of demographic parameters between the Beverly and Ahiak was a reasonable strategy.

Estimates of % movement between the Beverly and Ahiak (and vice versa) was based on yearly collar estimates (**Figure 58**). Given low sample sizes, estimates for the Ahiak to Beverly movements were variable due to low sample sizes of collars (**Figure 46**) leading to very wide confidence limits on yearly estimates (**Figure 59**). For example, most estimates of movement for the Ahiak to Beverly were based on 2-5 known collars each year. In this case the IPM model gave very little weighting to these yearly estimates. Mean IPM estimates of movement were approximately 5% for Beverly to Ahiak and 30% for Ahiak to Beverly. Unfortunately, the IPM models suggest that there is only enough information to indicate a mean trend from these data sets.

We note that the relative difference in herd sizes (Beverly adult females being approximately 4.5 times more abundant than Ahiak adult females) means that the higher movement rate from Ahiak to Beverly does not necessarily mean that the net movement of caribou from the Ahiak calving-ground to the Beverly calving-ground was higher. To illustrate this, the relative number of adult females between calving grounds was estimated for each herd (**Figure 61**). In most years, a higher number of Ahiak females (black line) moved into the Beverly calving-ground compared to Beverly moving into the Ahiak calving-ground (brown line). However, when summed across years, the net movement of Ahiak caribou into the Beverly calving-ground involved approximately 3,600 Ahiak caribou. As a result, the estimate of adult females in June 2023 for the *demography + Ahiak herd* model was slightly higher than the *demography alone* model, suggesting a slight increase in abundance could be attributed to the movement of Ahiak herd females from the Ahiak calving-ground into the Beverly calving-ground (**Figure 61**).

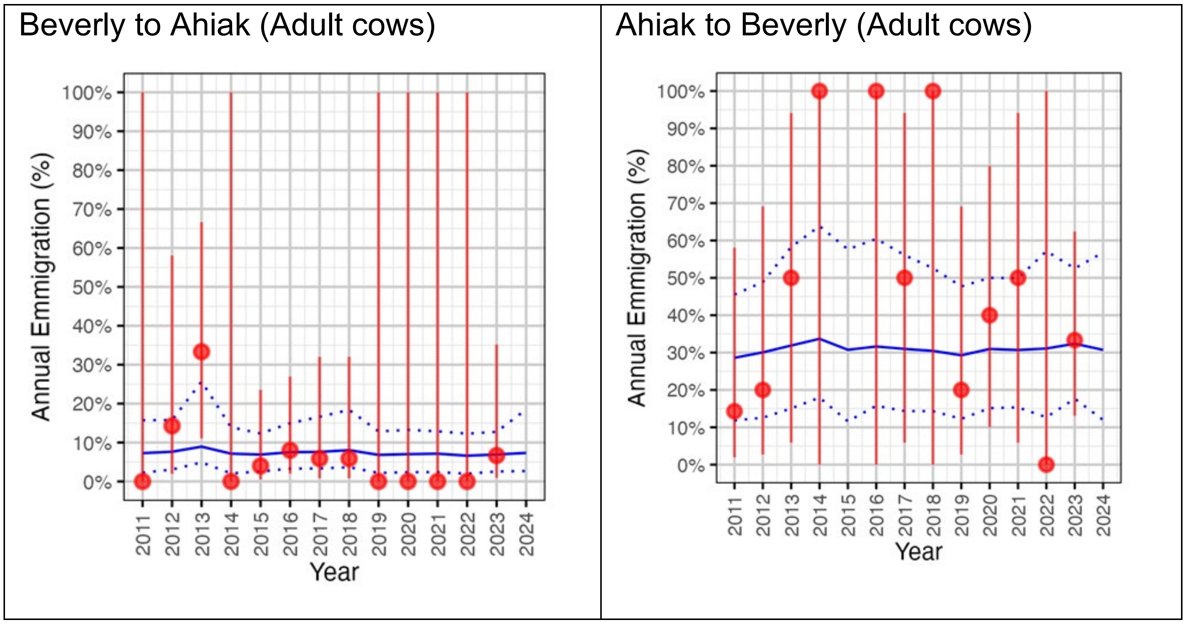


Figure 58. Estimates of percent (%) movement from Beverly to Ahiak (left) and Ahiak to Beverly (right) by year. Dotted lines are the 95% confidence limits on predictions.

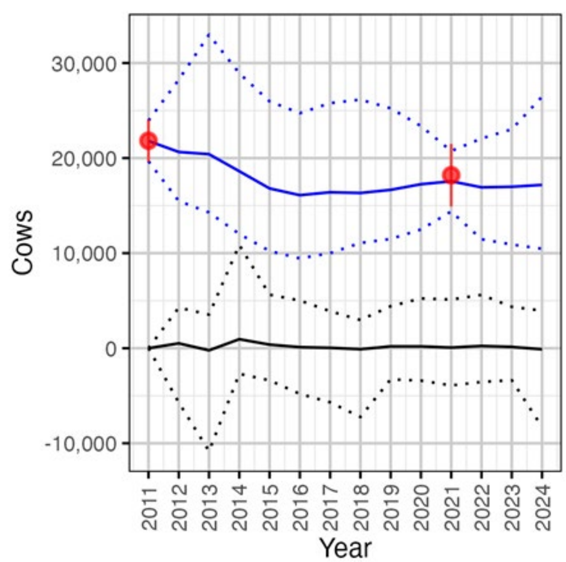


Figure 59. Estimates of adult females for the Ahiak herd (blue line) compared to field estimates. Also shown are estimates of emigration of the Ahiak to the Beverly herd for each year (black lines). Dotted lines are the 95% confidence limits on predictions.

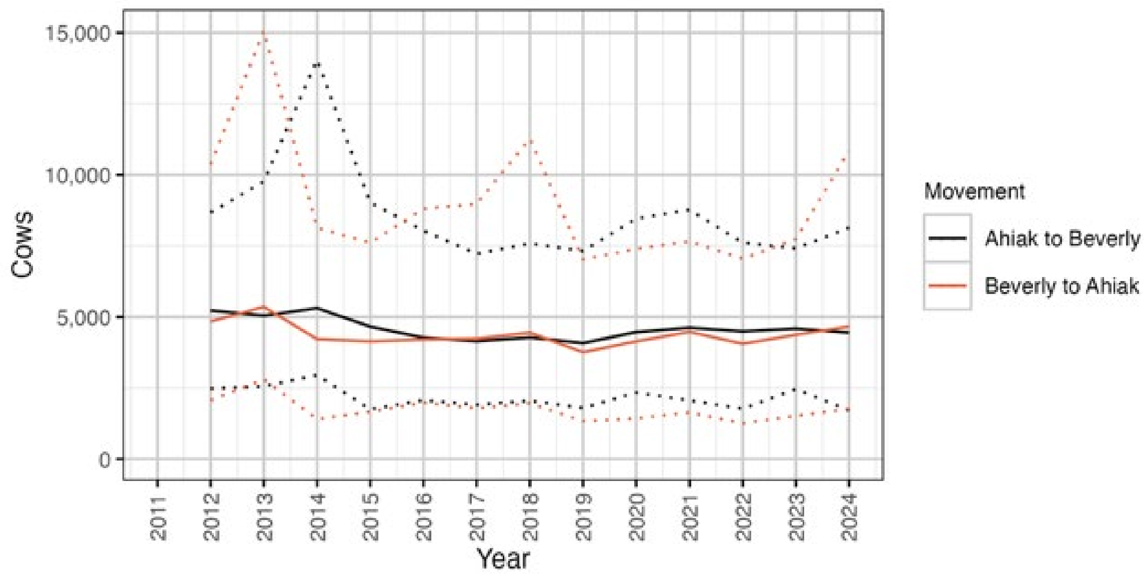


Figure 60. Estimates of adult females moving between Ahiak and Beverly calving grounds each year. Dotted lines are the 95% confidence limits on predictions.

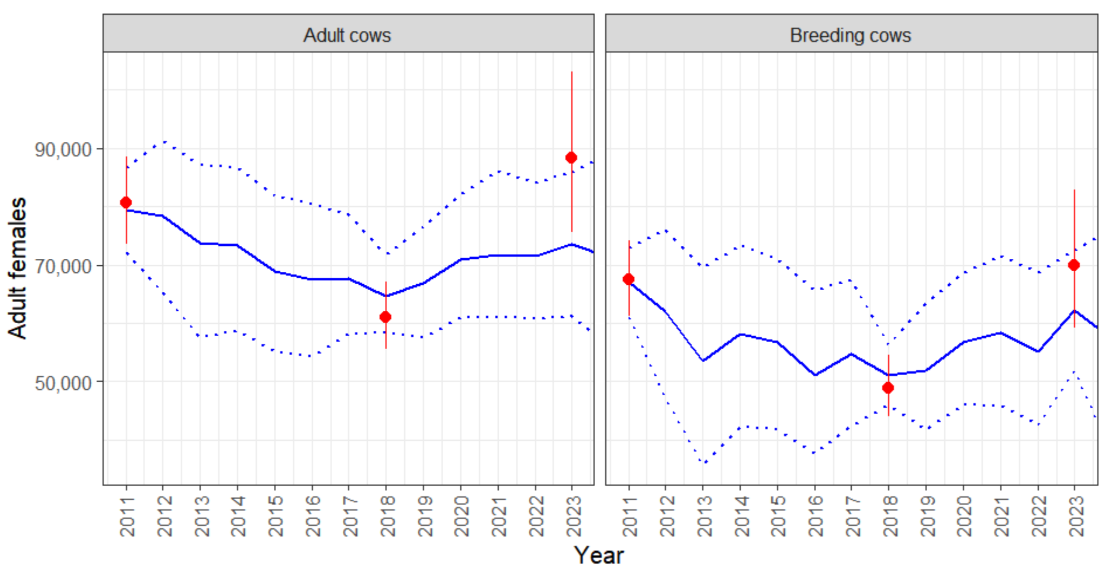


Figure 61. Estimates of adult and breeding females based on demography and movement between Ahiak and Beverly calving grounds. Dotted lines are the 95% confidence limits on predictions.

*Demography+Ahiak+Bathurst (**scenario 3**)*

The estimate of adult females entering the Beverly calving-ground from the Bathurst calving-ground was based solely on the Bathurst IPM as shown in **Figure 53**. A zoomed in version of adult females emigrating into the Beverly calving-ground is shown in **Figure 62**. Roughly 500-1,000 adult females were estimated to have emigrated into the Beverly herd since 2011. The net result of this IPM was a slight increase in the estimated abundance of adult female Beverly caribou in 2023 (**Figure 63**).

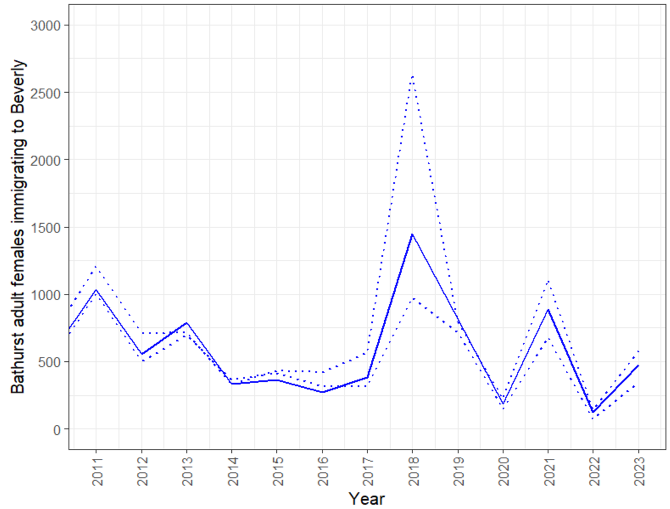


Figure 62. Estimate of Bathurst cows emigrating to the Beverly herd. Dotted lines are the 95% confidence limits on predictions.

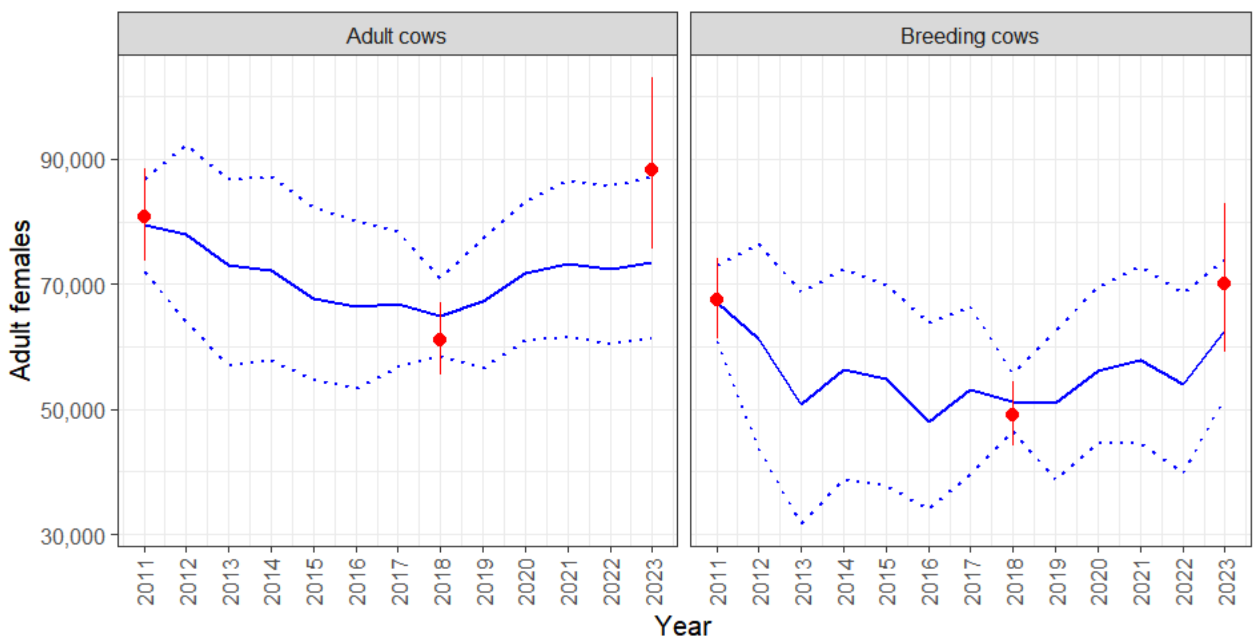


Figure 63. Estimates of Beverly adult and breeding females from the demography+Ahiak+Bathurst model. Red symbols = abundance estimates and associated 95% confidence intervals. Dotted lines are the 95% confidence limits on predictions.

Demography+Ahiak+Bathurst with female yearlings emigrating (scenario 4)

An additional scenario was run where female yearlings followed adult females to the calving grounds (at the same rate of fidelity/movement as the adult females). There was minimal difference in adult female estimates due to the fact that Ahiak and Beverly movement was roughly equal so the net movement would have mainly been yearling from the Bathurst herd **(Figure 64).**

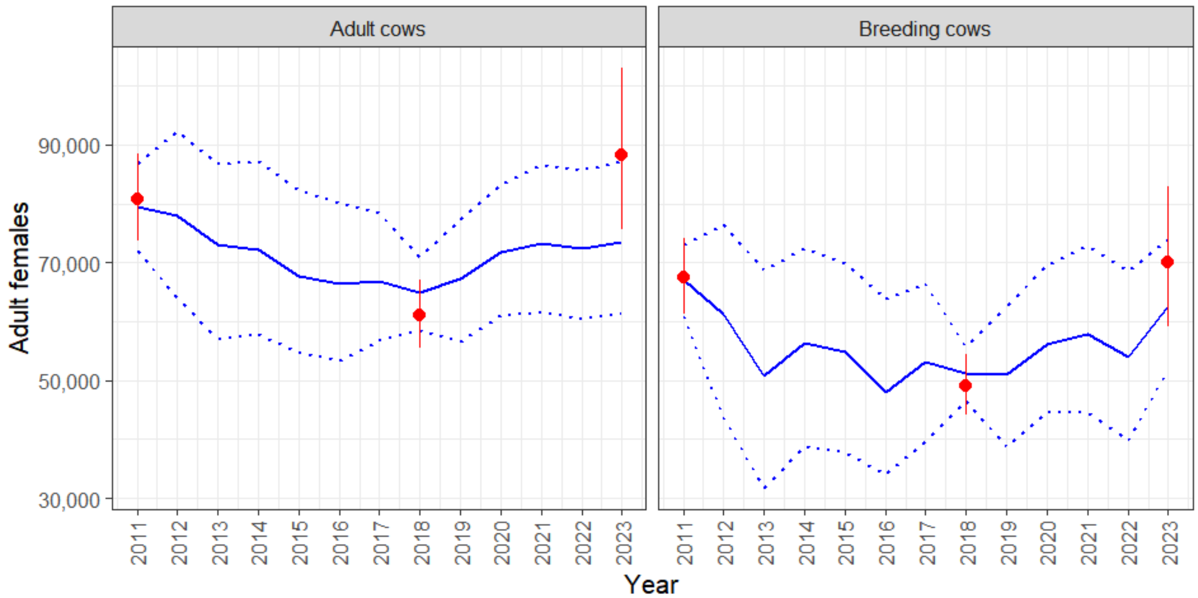


Figure 64. Estimates of Beverly adult and breeding females from the demography+Ahiak+Bathurst model with yearlings emigrating. Red symbols = abundance estimates and associated 95% confidence intervals. Dotted lines are the 95% confidence limits on predictions.

4.7.3 Comparison of estimates from IPM model scenarios

Comparisons of IPM scenario estimates of adult females in 2023 suggests a slight increase in estimates can be attributed to movement of caribou from the Ahiak and Bathurst herds with IPM estimates intercepting the lower confidence estimates of field estimates when movement was considered (**Figure 65**). The fit of the IPM to the breeding female estimate in 2023 is slightly better than adult females. One potential reason for this is that the breeding females have a higher probability of all occurring within the surveyed calving ground area. In contrast a small proportion of adult females may not be in the survey due to non-breeder status or inability to travel to the core calving ground area. Regardless, from a statistical perspective this result suggests that movement and demography could explain the unexpected increase in magnitude of the 2023 abundance estimate when compared to the 2018 abundance estimate. As discussed later, further enhancements to the IPM could be considered to more fully consider each scenario and its impact on the increase in Beverly herd abundance documented between June 2018 and June 2023.

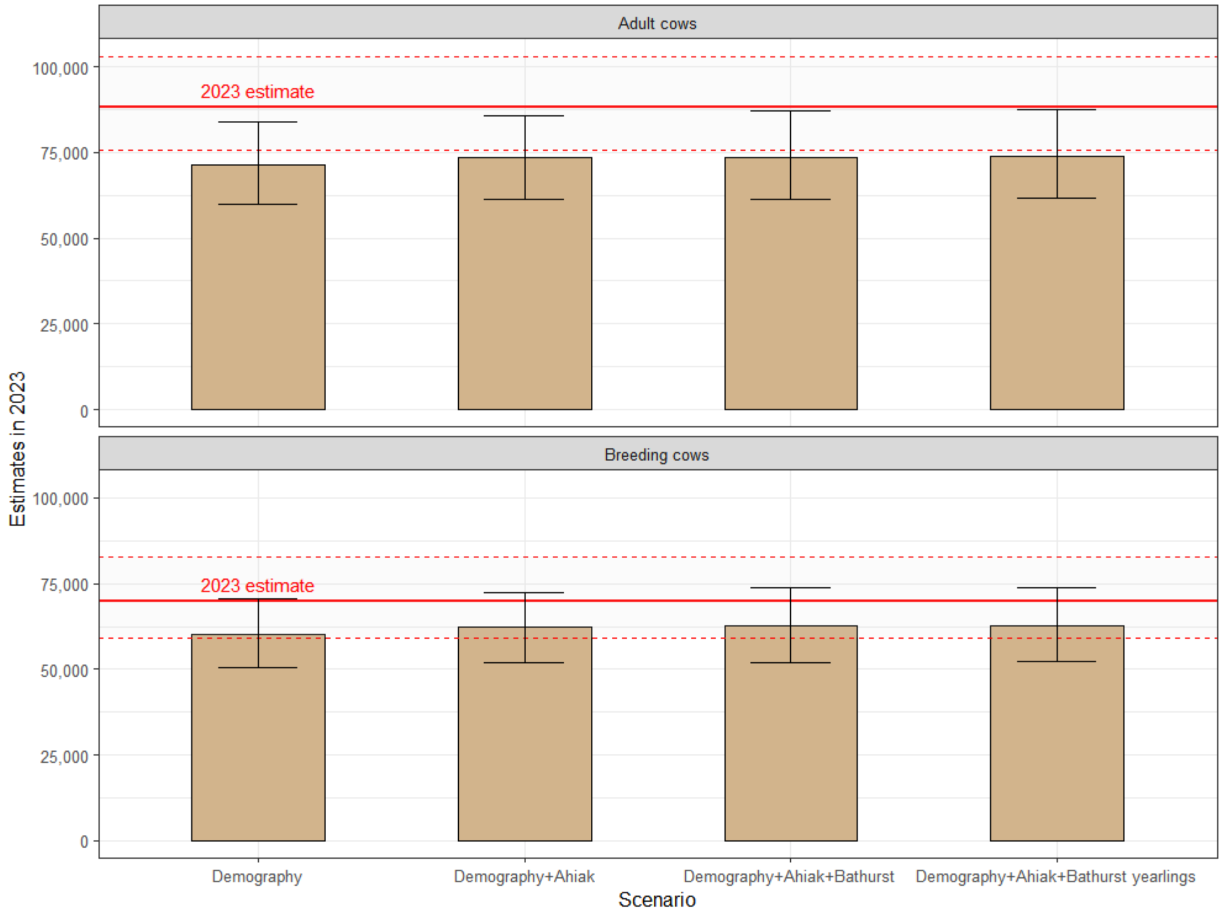


Figure 65. Comparison of estimates of adult and breeding females in 2023 from 4 IPM scenarios. Dotted lines are the 95% confidence limits on predictions.

5.0 CONCLUSIONS

5.1 GENERAL COMMENTS

Results from the Beverly 2023 survey suggest that the herd has increased significantly since the last survey in 2018 with an annual rate of increase of 8% (CI. 4-12%) for adult females. Demographic analyses suggest that this increase is likely due to higher productivity of caribou as well as potential movement from the neighboring Bathurst and Ahiak calving ground areas. Reconnaissance survey densities (**Figure 42**) and group sizes of caribou observed were larger than in 2018 also indicating an increase in overall herd size.

One of the main challenges of the survey was large group sizes that had not been observed in previous surveys, and were difficult to count using solely observers. We developed a video-assisted approach to obtain counts of caribou in high density strata which successfully corrected visual count estimates (**Figure 30**). The survey also occurred during a time of slightly higher movement levels (7 to 10 km per day). Inspection of net movements does not reveal any movements from high density strata when they were sampled. However, a group of collars did move into the central low from high east before the central low was sampled therefore inflating densities and abundance estimates in this stratum (**Figure 24**). Therefore, estimates from this stratum were excluded in the analysis.

The herd size estimate based on the summation of bulls and cows on the calving ground survey area is 6% higher (≈10,000 caribou) than the extrapolated herd estimate. This difference could simply be due to survey imprecision given overlap of confidence limits. The location of bulls on the calving ground in 2023 was unique compared to other survey years (**Figures 38 and 39**). It could be argued that the summation of bulls and cows provides a more direct estimate of herd size than the extrapolation estimate especially given challenges of assessing herd membership of bulls and cows during the fall composition surveys. However, in most years bulls are south of the calving ground survey area and therefore it is not possible to estimate herd size using the summation of bulls and cows.

5.2 HERD DEMOGRAPHY AND MOVEMENTS FROM OTHER HERDS

The Integrated Population Model analysis provided a method to assess various factors that potentially caused the increase in abundance. Overall analysis results suggest that while IPM estimates were lower than the 2023 field estimates, the confidence limits did overlap between field and IPM estimates suggesting results were not statistically different (**Figure 65**). IPM results suggested an increase in the Beverly which was due to both demographic factors and movements from adjacent calving grounds.

A demographic increase was suggested which was primarily due to higher productivity as indicated by higher calf cow ratios as opposed to higher survival rates. Relatively high productivity levels are suggested for the Beverly which was one of the main drivers of demographic increase given that the survival levels were moderate. Analysis of Bluenose-East and Bathurst herds demography relative to environmental covariates during this time period did suggest increased productivity due to cooler and wetter spring and summers (Boulanger et al. 2024). This type of analysis could also be repeated (using MERRA covariates) to assess if productivity was related to range and environmental conditions.

Field estimates of survival rate were averaging 0.8 which is low for an increasing herd. Based on a matrix model analysis, mean adult female survival levels ranging from 0.85 to 0.92 are required to produce an 8% annual increase in population size (Boulanger et al. 2024). One potential issue is that collar survival rates have been shown in some studies to be biased low (Rasiulis et al. 2014). The IPM partially offsets this issue by using other data sources to estimate survival in the herd. However, some data sources such as abundance estimates are sparse (3 surveys for the entire analysis) compared to annual survival rate estimates, and therefore the influence of these data sources is limited. We suspect that IPM estimates of survival would potentially increase if more indicators of positive growth, such as the 2023 survey estimate, were present in the data set. We also note that the use of environmental covariates, as was done for the Bathurst and Bluenose-East herds (Boulanger et al. 2022) could better inform variation in survival rates than the simple random effects model used in this analysis.

Movements of caribou from the Bathurst and Ahiak also contributed to the increase of the Beverly. Combinations of Ahiak and Beverly movement suggest that movements were relatively balanced between the 2 calving ground areas with only a slight net movement into the Beverly calving-ground (**Figure 60**). However, this still had a small effect on trend. One challenge is the low number of collared caribou available to estimate movement which led to very imprecise estimates of movement (**Figure 46**). The IPM estimated roughly stable movements of Ahiak to Beverly (**Figure 58**: i.e. 30%) which was offset by movements of Beverly to the Ahiak (**Figure 60**). The lack of variation detected in yearly movement rates may have been due to sparse data obscuring trends in the data set. The Bathurst also contributed to the increase; however, the amount was limited due to the relatively small size of the Bathurst herd (**Figure 62**).

One of the largest challenges of understanding movements and demography of caribou is the limited sample size and selective sampling associated with collared caribou. In general, collaring targets adult caribou and therefore survival, movements, and locations of younger caribou (2-3 years old) is not indicated within collar data. This issue combined with limited sample size of collars challenges estimates of movement rate between herds. For example, a power analysis conducted by Boulanger et al. (2024) suggested that power of collared caribou to switch between calving grounds was low unless collar sample sizes of caribou that had known herd membership (calved the previous year on a calving ground) was at least 20 to 30 caribou. This sample size often is not achieved for many herds (**Table 19**). This issue and the increasing overlap of herds on winter ranges which can lead to higher switching rates (Boulanger et al. 2024) creates an additional source of variation in herd trend and status.

The IPM approach attempts to use all the data sources available to estimate and understand herd status and trend. In this survey we combined the Ahiak and Beverly under the assumption of similar underlying demography between the 2 herds. Estimates from the Bathurst IPM were also used to estimate likely movement of the Bathurst into the Beverly. Eventually adding the Bathurst IPM into the Beverly IPM would more efficiently model movements between the 2 herds by considering likely covariance in movements between the 2 herds. For example, the increase in the Beverly and decrease in the Bathurst would be used to further inform and estimate movement/switching rates between calving grounds.

5.3 SURVEY METHODOLOGY

The 2023 survey was unique from previous surveys in that group sizes were too large in high density strata to allow visual counting creating a potential counting bias in estimates. This contrasts with previous surveys (i.e. 2018) where there may have been sightability bias due to poor survey conditions.

5.3.1 Video approach to confront large group sizes in 2023

The video/orthophoto approach provided a way to allow a secondary count of larger group sizes in high density strata. One challenge with this approach was that it was not possible to link visual observations with video observations. In addition, the video counts were sporadic meaning that survey lines contained both visual and video counts. We developed an iterative method that allowed pairing of observations with video counts within each orthophoto polygon. The main finding from this comparison is that visual counts underestimated larger groups (**Figure 27**), however, this was offset by confining counts to within the survey strip. Once the survey strip was considered, visual counts were higher than the orthophoto counts (**Figure 28**). So, this finding suggests that visual counts overestimated caribou within the survey strip when group size was very large.

5.3.2 Sightability issues in previous surveys

Survey conditions were less than optimal in 2018 which may have resulted in a negatively biased estimate if there were groups of caribou with very low sighting probabilities. While it is not possible to ascertain bias from field surveys, a few indirect sources indicate potential for slight negative biases. IPM estimates for adult cows in 2018 were 6% higher than the 2018 field estimates suggesting a potential negative bias in 2018 (**Figure 57**), however differences between the IPM and field estimate were within confidence limits of the field estimate so this difference could be due to statistical uncertainty. Empirical comparison of double observer and distance sampling estimates from past surveys suggest that double observer approach may underestimate abundance by 5-10% as detailed in Appendix C. Other comparisons also suggest that double observer estimates may be biased low. A comparison of paired photo and double observer survey lines during the Bluenose-East surveys in 2013 and 2023 surveys suggested that photo estimates were 7 to 14% higher, however, further analysis suggested that the main bias occurred on lines with higher densities of caribou where photo counts were higher with similar estimates at moderate densities (Boulanger et al. 2024).

The dependent double observer method attempts to account for lower sightability by estimating probability of detection of groups. However, one assumption of this approach is that caribou groups have equal sightability and any unequal sightability is accounted for by the use of covariates such as group size. Unaccounted heterogeneity (unequal sightability) could be caused by poor survey conditions causing some caribou groups to being easily observed with others showing low sightability. A particular challenge are ”salt and pepper” conditions which can cause some caribou to have much reduced sighting probabilities. Finally, unequal observer probabilities can create bias especially if the observers do not switch during the survey.

We note that negative biases (of 5-10%) in strip transect/double observer estimates from 2018 cannot explain the increase documented in the 2023 survey. Use of the IPM provides a way to offset biases with any particular technique. For example, the IPM estimate of herd size in 2018 (**Figure 57**) which is based on all data sources and provides a potentially improved estimate of herd size since it considers both past and future data points, and from this, estimates the most likely herd size.

We propose a hybrid distance sampling/double observer approach as detailed in Appendix C that will be more robust to sightability bias. This approach which involves also collecting binned distance data, should be possible to implement with relatively minor changes in field protocol. The main premise behind this approach is that distance sampling approach will be more robust to unequal sighting probabilities between caribou groups. Using this approach in combination with double observer methods should provide more robust survey estimates especially when sighting conditions are marginal. We also note that the video method developed in this report also can be used to cross check sightability and counts from observers.

6.0 RECOMMENDATIONS

It is suggested that future surveys consider surveying the core Bluenose East, Bathurst, Beverly, and Ahiak calving grounds within the same survey year. Both collar and IPM analyses demonstrate varying movement between these calving areas which complicates interpretation of stand-alone abundance estimates of these herds. If funding is limited, then the Beverly and Ahiak should be surveyed during the same year given the close linkage between caribou in these 2 herds.

One result from this survey is that it may not be possible to rely on visual only methods in future surveys if higher densities of caribou are observed. The video assistance approach developed in this project should be further developed to allow better linkage between observer and video observations. This could be done by Bluetooth linkage of phones or video recording devices with tablets used for observations. Alternatively, and with appropriate financial resources, photo planes could be stationed on site to photo survey areas of high density as is done for the Qamanirjuaq, Bathurst, and Bluenose East herds. Maintaining aircraft on standby outside of Nunavut, as in this survey, carries with it availability risks and associated holding costs that could be logistically and financially restrictive.

A reduced distance sampling double observer approach, as detailed in Appendix C, should be considered, to allow estimates with greater robustness from visual surveys. To implement this approach, we propose a 600m strip would be surveyed with 3 distance bins (0-200m, 200-400m, 400-600m). The main change from the present methodology would be a slightly wider survey strip. The only additional piece of information that would be required is what survey bin the majority of any caribou group occurs in. Also, observers would need to be reminded to pay the most attention to the closest survey bins.

In this study we developed an Integrated Population Model to help assess herd demography and trend. The current model utilizes a random effect approach to model temporal variation in demographic parameters. Environmental covariates could be used to refine the modelling of temporal variation as has been done for the Bathurst and Bluenose East herds. In addition, one finding of this analysis and the collar movement analysis is that there is likely some linkage between the Ahiak, Beverly, Bathurst, and Bluenose East herds given overlap between their winter ranges. This likely causes movement which may not be detected by examining collared caribou alone given low sample sizes as well as lack of representation of younger age classes. Both the Bluenose-East and Beverly herds exhibited increases that could not be easily explained by demography alone and one possible explanation is movement between the herds. One method to better assess movement and demography would be to link the Bluenose-East, Bathurst, Beverly, and Ahiak integrated population model. This model would then allow joint modelling of movements between all 4 calving grounds which would provide a more comprehensive assessment of the effect of movement as well as demography of all 4 herds.

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8.0 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, 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, D. Cluff, and C. Modeste-Burgin. 2024. Fall 2022 Composition Surveys of Bathurst, Bluenose-East and Beverly Barren-ground Caribou Herds. Environment and Natural Resources Government of the Northwest Territories Manuscript Report No. 314.

Banfield, A.W.F. 1951. The Barren ground Caribou. Canadian Wildlife Service Unpublished Report. 56 pp.

Boulanger, J., M. Campbell, and D. S. Lee. 2018. Estimating Abundance and Trend of the Qamanirjuaq Mainland Migratory Barren-Ground Caribou Subpopulation - June 2017. Government of Nunavut Department of Environment Technical Summary – No: 01-2018. Arviat, Nunavut.

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. 2020. Optimal survey design, survey intervals, and analysis strategies for caribou calving ground surveys, reconnaissance surveys, and composition surveys. ENR manuscript report No 283. Environment and Natural Resources, 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.

Buckland, S.T., A.J. Plumpyre, L. Thomas, and E.A. Rexstad. 2010. Design and Analysis of Line Transect Surveys for Primates. International Journal of Primatology. Volume 31. 833-847.

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., D.S. Lee, and J. Boulanger. 2019. Abundance trends of the Beverly mainland migratory subpopulation of barren-ground caribou (*Rangifer tarandus groenlandicus*) June 2011-June 2018. Government of Nunavut, Department of Environment File Report. Technical Report Series-No: 01-2018. 141 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.

Cook, D.R., and J.O. Jacobsen. 1979. A design for estimating visibility bias in aerial surveys. Biometrics 35: 735-742.

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.C. 1982. Composition of the Beverly Caribou Herd in the Fall of 1980. Northwest Territories Wildlife Service. File Report No. 26. 14 pp.

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. Serengetti 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, andB. Croft, editors. An estimate of breeding femalesand analyses of demographicsfor 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, T. M. 1995. Beverly Calving Ground Surveys June 1993 and 1994. Department of Renewable Resources GNWT, Yellowknife. File report No. 114:

Yannic, G., L. Pellissier, J. Ortego, N. Lecomte, S. Couturier, C. Cuyler, C. Dussault, K. J. Hundertmark, R. J. Irvine, D. A. Jenkins, L. Kolpashikov, K. Mager, M. Musiani, K. L. Parker, K. H. Røed, T. Sipko, S. G. Þórisson, B. V. Weckworth, A. Guisan, L. Bernatchez, and S. D. Côté. 2014. Genetic diversity in caribou linked to past and future climate change. Macmillan Publishers Limited, Nature Climate Change. Vol: 4, Feb. www.nature.com/natureclimatechange 137.

9.0 APPENDICES

9.1 APPENDIX A – INTEGRATED POPULATION MODEL DETAILS

The suggested citation for this analytic appendix is:

Thorley, J.L. and Boulanger, J. (2024) Beverly Caribou Herd Population Analysis 2024. A Poisson Consulting Analysis Appendix. (www.poissonconsulting.ca)

Background

Monitoring surveys of the Beverely barren-ground caribou (*Rangifer tarandus groenlandicus*) herd have been conducted intermittently since 2011. The surveys include June calving ground aerial surveys (Boulanger et al. 2017), as well as fall and spring sex and age composition surveys and monitoring of cows with satellite or GPS collars.

Data Preparation

The estimates of key population statistics with standard errors (SEs) were provided in the form of an csv spreadsheet and prepared for analysis using R version 4.4.1 (R Core Team 2024).

Statistical Analysis

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2003). For additional information on Bayesian estimation the reader is referred to McElreath (2020).

Unless stated otherwise, the Bayesian analyses used weakly informative prior distributions (Gelman, Simpson, and Betancourt 2017). The posterior distributions were estimated from 1500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of 3 chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that the potential scale reduction factor $\hat{R} \leq 1.05$ (Kery and Schaub 2011, 40) and the effective sample size (Brooks et al. 2011) ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61).

Where computationally practical, the sensitivity of the posteriors to the choice of prior distributions was evaluated by doubling the standard deviations of the priors and then using $\hat{R}$ to evaluate whether the samples were drawn from the same posterior distribution (Thorley and Andrusak 2017).

The parameters are summarized in terms of the point *estimate*, *lower* and *upper* 95% compatibility limits (Rafi and Greenland 2020) and the surprisal *s-value* (Greenland 2019). Together a pair of lower and upper compatibility limits (CLs) are referred to as a compatibility interval (CI). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles. The s-value indicates how surprising it would be to discover that the true value of the parameter is in the opposite direction to the estimate (Greenland 2019). An s-value of $>$ 4.32 bits, which is equivalent to a p-value $<$ 0.05 (Kery and Schaub 2011; Greenland and Poole 2013), indicates that the surprise would be equivalent to throwing at least 4.3 heads in a row on a fair coin.

The results are displayed graphically by plotting the modeled relationships between individual variables and the response with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their arithmetic mean and first level values, respectively, while random effects are held constant at their typical value (Kery and Schaub 2011, 77–82). Unless stated otherwise the typical value is the arithmetic mean. When informative the influence of a particular variables is expressed in terms of the *effect size* (i.e., relative change in the response variable) with the 95% CI (Bradford, Korman, and Higgins 2005).

The analyses were implemented using R version 4.4.1 (R Core Team 2024) and the embr family of packages.

Model Descriptions

The data were analyzed using a state-space population model (Newman et al. 2014).

Population

The cow and bull harvest, fecundity, breeding cow abundance, cow survival, bull survival, fall bull cow, fall calf cow and spring calf cow ratio data complete with standard errors were analyzed using a stage-based state-space population model similar to Boulanger et al. (2011). Key assumptions of the female stage-based state-space population model include:

- Calving occurs on the 11th of June (with a year running from calving to calving)
- Cow natural survival from calving to the following year varies continually and randomly by year.
- Bull natural survival from calving to the following year varies randomly by year.
- Cow and bull natural survival is constant throughout the year in any given year.
- Harvest of cows and bulls occurs on the 15th of January.
- Yearling survival to the following year is the same as cow natural survival.
- Calf survival varies between the summer and winter seasons and randomly by year.
- The calf sex ratio is 1:1.
- Fecundity varies randomly by year.
- In an average year two-year-old cows have a fecundity of 0.25.
- Female yearlings are indistinguishable from cows in the fall and spring surveys.
- The uncertainty in the number of cows in the initial year is described by a positively truncated normal distribution with a mean of 75,000 and a standard deviation of 25,000.
- The number of bulls in the initial year relative to the number of cows is described by a beta distribution with an alpha of 11 and a beta of 11.
- The number of calves in the initial year relative to the number of cows is described by a beta distribution with an alpha of 19 and a beta of 3.
- The number of yearlings in the initial year relative to the number of cows is described by a beta distribution with an alpha of 11 and a beta of 11.
- The number of two-year-old cows in the initial year relative to the number of cows is described by a beta distribution with an alpha of 3 and a beta of 19.
- The uncertainty in each data point is normally distributed with a standard deviation equal to the provided standard error.

Further details on the model can be obtained upon request from the authors.

Tables

Population

Table 1. Parameter descriptions.

Parameter	Description
Annual	The year as a integer starting at 1
BreedingCowsSE[i]	The standard error for BreedingCows[i]
BreedingCows[i]	The data point for the number of breeding cows in the i^{th} year
BreedingProportionSE[i]	The standard error for BreedingProportionSE[i]
BreedingProportion[i]	The data point for the log-odds proportion of cows breeding in the i^{th} year
BullSurvivalSE[i]	The standard error for BullSurvival[i]
BullSurvival[i]	The data point for log-odds bull survival from the $i\text{-}1^{th}$ year to the i^{th} year
CowSurvivalSE[i]	The standard error for CowSurvival[i]
CowSurvival[i]	The data point for log-odds cow survival from the $i\text{-}1^{th}$ year to the i^{th} year
FallBullCowSE[i]	The standard error for FallBullCow[i]
FallBullCow[i]	The data point for the bull cow ratio in the fall of the i^{th} year
FallCalfCowSE[i]	The standard error for FallCalfCow[i]
FallCalfCow[i]	The data point for the calf cow ratio in the fall of the i^{th} year
HarvestedBullsSE[i]	The standard error for HarvestedBulls[i]
HarvestedBulls[i]	The data point for the number of bulls harvested in January of the i^{th} year
HarvestedCowsSE[i]	The standard error for HarvestedCows[i]
HarvestedCows[i]	The data point for the number of cows harvested in January of the i^{th} year
SpringCalfCowSE[i]	The standard error for SpringCalfCow[i]
SpringCalfCow[i]	The data point for the calf cow ratio in the spring of the i^{th} year
bBreedingCows1	The number of breeding cows in the initial year
bBullsCows1	The bull to cow ratio in the initial year
bFecundityCow	The log-odds proportion of three year and older cows breeding in a typical year
bFecundityTwolingCow	The log-odds proportion of two year old cows breeding in a typical year
bHarvestRateBull	The log-odds probability of a bull being harvested in a typical year
bHarvestRateCow	The log-odds probability of a cow being harvested in a typical year

Parameter	Description
bSurvivalBullAnnual[i]	The random effect of the ith Annual on bSurvivalBull
bSurvivalBull	The log-odds bull survival in a typical year
bSurvivalCalfAnnual[i]	The random effect of the ith Annual on bSurvivalCalfSummerAnnual and bSurvivalCalfWinterAnnual
bSurvivalCalfSummerAnnual	The log-odds summer calf survival if extended for one year
bSurvivalCalfWinterAnnual	The log-odds winter calf survival if extended for one year
bSurvivalCowAnnual[i]	The random effect of the ith Annual on bSurvivalCow
bSurvivalCow	The log-odds cow (and yearling) survival in a typical year
sSurvivalBullAnnual	The SD of bSurvivalBullAnnual
sSurvivalCalfAnnual	The SD of bSurvivalCalfAnnual
sSurvivalCowAnnual	The SD of bSurvivalCowAnnual

Table 2. Model coefficients.

term	estimate	lower	upper	svalue
bBullsCows1	0.597	0.493	0.707	10.55
bCalvesCows1	0.755	0.685	0.824	10.55
bCows1	79229.291	72304.779	86920.280	10.55
bFecundityCow	2.853	1.778	5.032	10.55
bHarvestRateBull	-3.529	-3.808	-3.250	10.55
bHarvestRateCow	-4.127	-4.343	-3.940	10.55
bSurvivalBull	0.784	0.436	1.249	8.23
bSurvivalCalfSummerAnnual	-0.325	-0.841	0.398	1.66
bSurvivalCalfWinterAnnual	1.720	0.560	4.229	10.55
bSurvivalCow	1.442	1.161	1.738	10.55
bTwolingsCows1	0.136	0.043	0.257	10.55
bYearlingsCows1	0.570	0.372	0.748	10.55
sFecundityAnnual	0.684	0.239	1.901	10.55
sSurvivalBullAnnual	0.347	0.023	1.113	10.55

term	estimate	lower	upper	svalue
sSurvivalCalfAnnual	0.452	0.085	1.041	10.55
sSurvivalCowAnnual	0.352	0.051	0.795	10.55

Table 3. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
14	16	3	500	100	702	1.01	TRUE

References

Boulanger, John, Bruno Croft, Jan Adamczewski, Dean Cluff, Mitch Campbell, David Lee, and Nic Larter. 2017. "An Estimate of Breeding Females and Analysis of Demographics for the Bathhurst Herd of Barren-Ground Caribou: 2015 Calving Ground Photographic Survey." 267. Government of Northwest Territories.

Boulanger, John, Anne Gunn, Jan Adamczewski, and Bruno Croft. 2011. "A Data-Driven Demographic Model to Explore the Decline of the Bathurst Caribou Herd." *The Journal of Wildlife Management* 75 (4): 883–96. https://doi.org/10.1002/jwmg.108.

Bradford, Michael J, Josh Korman, and Paul S Higgins. 2005. "Using Confidence Intervals to Estimate the Response of Salmon Populations (Oncorhynchus Spp.) to Experimental Habitat Alterations." *Canadian Journal of Fisheries and Aquatic Sciences* 62 (12): 2716–26. https://doi.org/10.1139/f05-179.

Brooks, Steve, Andrew Gelman, Galin L. Jones, and Xiao-Li Meng, eds. 2011. *Handbook for Markov Chain Monte Carlo*. Boca Raton: Taylor & Francis.

Gelman, Andrew, Daniel Simpson, and Michael Betancourt. 2017. "The Prior Can Often Only Be Understood in the Context of the Likelihood." *Entropy* 19 (10): 555. https://doi.org/10.3390/e19100555.

Greenland, Sander. 2019. "Valid *p* -Values Behave Exactly as They Should: Some Misleading Criticisms of *p* -Values and Their Resolution With *s* -Values." *The American Statistician* 73 (sup1): 106–14. https://doi.org/10.1080/00031305.2018.1529625.

Greenland, Sander, and Charles Poole. 2013. "Living with p Values: Resurrecting a Bayesian Perspective on Frequentist Statistics." *Epidemiology* 24 (1): 62–68. https://doi.org/10.1097/EDE.0b013e3182785741.

Kery, Marc, and Michael Schaub. 2011. *Bayesian Population Analysis Using WinBUGS : A Hierarchical Perspective*. Boston: Academic Press. http://www.vogelwarte.ch/bpa.html.

McElreath, Richard. 2020. *Statistical Rethinking: A Bayesian Course with Examples in R and Stan*. 2nd ed. CRC Texts in Statistical Science. Boca Raton: Taylor; Francis, CRC Press.

Newman, K. B., S. T. Buckland, B. J. T. Morgan, R. King, D. L. Borchers, D. J. Cole, P. Besbeas, O. Gimenez, and L. Thomas. 2014. *Modelling Population Dynamics: Model Formulation, Fitting and Assessment Using State-Space Methods*. http://dx.doi.org/10.1007/978-1-4939-0977-3.

Plummer, Martyn. 2003. “JAGS: A Program for Analysis of Bayesian Graphical Models Using Gibbs Sampling.” In *Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003)*, edited by Kurt Hornik, Friedrich Leisch, and Achim Zeileis. Vienna, Austria.

R Core Team. 2024. “R: A Language and Environment for Statistical Computing.” Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Rafi, Zad, and Sander Greenland. 2020. “Semantic and Cognitive Tools to Aid Statistical Science: Replace Confidence and Significance by Compatibility and Surprise.” *BMC Medical Research Methodology* 20 (1): 244. https://doi.org/10.1186/s12874-020-01105-9.

Thorley, Joseph L., and Greg F. Andrusak. 2017. “The Fishing and Natural Mortality of Large, Piscivorous Bull Trout and Rainbow Trout in Kootenay Lake, British Columbia (2008–2013).” *Pe*

9.2 APPENDIX B-MULTI-STATE MODEL ESTIMATES OF MOVEMENT BETWEEN CALVING GROUNDS.

Period	Current year calving ground	Previous year calving ground	events	Estimate	LCI	UCI
2011-18	Ahiak	Ahiak	6	0.418	0.124	0.696
2011-18	Ahiak	Beverly	9	0.085	0.045	0.155
2011-18	Ahiak	Lorillard	1	0.061	0.02	0.173
2011-18	Ahiak	Wager Bay	3	0.064	0.021	0.18
2011-18	Bathurst	Bathurst	82	0.965	0.896	0.989
2011-18	Bathurst	Beverly	0	0	0	0
2011-18	Beverly	Ahiak	7	0.487	0.259	0.721
2011-18	Beverly	Bathurst	3	0.035	0.011	0.104
2011-18	Beverly	Beverly	101	0.9	0.804	0.953
2011-18	Lorillard	Lorillard	25	0.837	0.604	0.937
2011-18	Lorillard	Wager Bay	4	0.213	0.118	0.352
2011-18	Wager Bay	Ahiak	3	0.095	0.036	0.228
2011-18	Wager Bay	Lorillard	1	0.102	0.043	0.223
2011-18	Wager Bay	Wager Bay	8	0.723	0.468	0.861
2019-23	Ahiak	Ahiak	17	0.615	0.422	0.845
2019-23	Ahiak	Beverly	1	0.015	0.002	0.098
2019-23	Ahiak	Lorillard	2	0.061	0.02	0.173
2019-23	Ahiak	Wager Bay	0	0.064	0.021	0.18
2019-23	Bathurst	Bathurst	90	0.886	0.819	0.939
2019-23	Bathurst	Beverly	2	0.027	0.004	0.074
2019-23	Beverly	Ahiak	8	0.29	0.153	0.48
2019-23	Beverly	Bathurst	12	0.114	0.061	0.181
2019-23	Beverly	Beverly	64	0.958	0.828	0.994
2019-23	Lorillard	Lorillard	16	0.837	0.604	0.937
2019-23	Lorillard	Wager Bay	6	0.213	0.118	0.352
2019-23	Wager Bay	Ahiak	1	0.095	0.036	0.228
2019-23	Wager Bay	Lorillard	4	0.102	0.043	0.223
2019-23	Wager Bay	Wager Bay	26	0.723	0.468	0.861

9.3 APPENDIX C-- USE OF A REDUCED DISTANCE SAMPLING AND DOUBLE OBSERVER METHODOLOGY TO IMPROVE ROBUSTNESS OF CALVING GROUND SURVEY ESTIMATES

Introduction

This analysis explores the use of a reduced distance sampling combined with double observer methodology to improve the estimation of sightability and subsequent abundance estimates from calving ground surveys. Some of the recent calving ground surveys have been challenged by poor survey conditions (Boulanger et al. 2019, Campbell et al. 2019, Boulanger et al. 2022) which created potential challenges with comparison of surveys such as the 2023 calving ground surveys that had ideal survey conditions. In this paper we assess potential negative bias in double observer methods and propose a reduce distance sampling / double observer methodology that should improve the robustness of calving ground survey abundance estimates.

The current calving ground survey methodology uses a 400 meter strip transect combined with a double observer mark-recapture modelling effort method to estimate sightability and abundance. The two observers in this case represent an initial detection of caribou (the mark) and a potential re-detection of the caribou group (the recapture) hence double observer methods are analyzed using a mark-recapture analysis approach. This approach was adopted in 2011 to accommodate higher densities of caribou observed on calving grounds which prevented the use of full distance sampling methods, which require greater observer training and the ability to observe caribou across a relatively wide survey strip (1500m) with classification of groups into 5 distance bins (Campbell et al. 2012).

Distance sampling methods have been applied in Nunavut for caribou surveys (Campbell et al. 2015, Campbell et al. 2019, Campbell. et al. 2021) that occurred in spring or fall periods and therefore had lower densities of caribou making it possible to apply the distance sampling method. Results from all of these surveys estimate that detection probability declines with distance within the 400m survey strip. Comparison of distance sampling estimates with double observer 400m strip transect estimates suggest that that the double observer approach does not adequately estimate sightability with estimates being 5-11% lower than double observer distance sampling estimates (Campbell et al. 2015, Campbell et al. 2019). The likely reason for this is that heterogeneity (unequal detection probabilities) of caribou groups within the survey strip creates a positive bias in estimated detection probabilities from double observer surveys leading to a negative bias in estimates. This issue is especially relevant for the dependent double observer method used in many surveys that allows observers to communicate finding but also places restrictive assumptions on detection probability variation such as each observer in a pair having equal detection probability (Buckland et al. 2004). The general mechanism for bias in double observer detection probability with distance is that as distance from the plane increases and detection probability decreases observers become more likely to just observe the more obvious caribou groups and both miss the less obvious groups leading to non-independence of observer detection probabilities (Buckland et al. 2010). This non-independence basically creates heterogeneity variation leading to a positive bias in detection probability (only the easy to observe groups are detected usually by both observers) and a resulting negative bias in abundance. The amount of bias likely varies with overall sightability. If survey conditions are good (low snow years such as 2023) the bias is likely minimal, however, in years of poor sightability such as in some previous calving ground surveys then higher levels of bias are possible.

One unique attribute of distance sampling is that it is relatively robust to heterogeneity variation as long as sightability on the survey line is 1 or is estimated using double observer methods due to pooling robustness of the distance sampling approach (Buckland et al. 1993, Rexstad et al. 2023, Laake and Collier 2024). For this reason, the general approach used in distance sampling surveys is to focus mark-recapture/double observer methods on estimating detection on the survey line with distance sampling used to model and estimate the decline in detection probability with distance (Laake et al. 2008a, Laake et al. 2008b). We suggest that it is advantageous to collect and include distance sampling data during aerial surveys as it provides a way to confront likely heterogeneity bias that challenges double observer methods.

Methods

The general approach we propose is the use of distance sampling with a reduced number of bins and overall strip distance surveyed. This approach should be less overwhelming than a full distance sampling approach but still may allow a better estimate of sightability and more robust estimates. To assess this approach, we used empirical comparisons and a simulation study.

For the empirical comparisons, we subset distance sampling data sets from the Baffin 2024 (Campbell et al in prep) and South Hampton Island surveys (Campbell et al. 2019) to create reduced data sets and reran the analyses with the reduced data sets to produce estimates. These estimates were then compared with full data set estimates as well as double observer estimates that do not include distance sampling using the *mrds* R (Laake et al. 2012) package. Detailed analysis results are given in survey reports from each project and are not detailed in this report.

We also conducted a brief simulation study to assess whether unbiased estimates could be derived using reduced bins. For these analyses, we simulated the detection function from the Baffin 2024 and then analyzed the simulated data using the 2 and 3 bin designs. Simulations were focused on the distance sampling component of the analysis and assumed detection on the survey line was 1 with no variation in detection functions. We considered hazard rate and half normal models for estimation and assessed whether there was adequate power to select the appropriate detection function model with each design. Simulations were evaluated in terms of overall estimator bias, confidence interval coverage (proportion of simulations where confidence limits from the estimate overlapped the true value), and precision. Sample sizes of observations were generated to roughly approximate sample sizes from the Baffin Island survey. Five hundred simulations were conducted for each design. Simulations were conducted using the *dsims* R package (Marshall 2022).

Results

Southampton Island

The 2017 Southampton Island caribou survey employed a double observer distance sampling approach with 5 survey bins as shown in Figure 1. The data set consisted of 962 observations used to fit the detection function. A hazard rate detection function was selected which allows a “shoulder” of constant detection which in this case extended for the 0-200m survey bin before declining in subsequent bins. Detection also varied by observer order, snow cover and the log of group size for the distance detection function. For the double observer model detection varied by observer order and snow cover. Detection on the survey line was estimated to be 0.94 (CV=0.013).

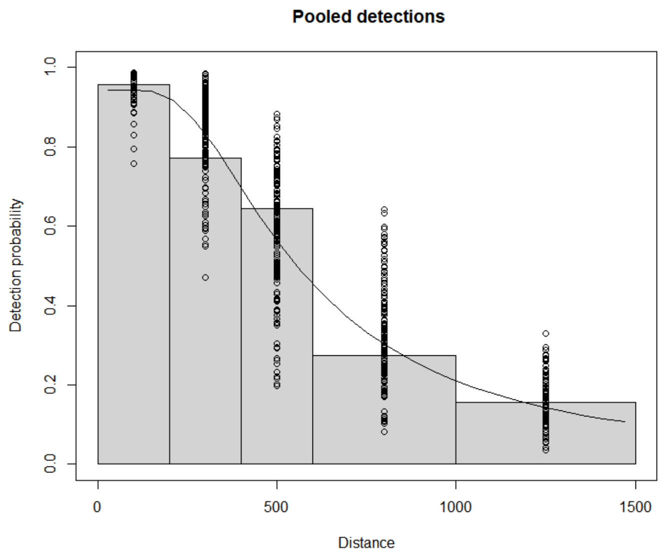

Figure 1. Distance sampling detection function for the full MRDS analysis of Southampton Island.

For the mark-recapture portion of the analysis it is possible to plot double observer sightability estimates for each distance bin to assess if double observer detection probabilities were reduced with distance (Figure 2). It can be seen that there is a slight decline up to the 600m bin but minimal change overall. This plot illustrates the effect of heterogeneity variation. With no heterogeneity variation this plot would be similar to Figure 1 with a decline in detection with distance. Instead, observers both only observe the more sightable groups with increasing distance leading to an overestimate of detection probabilities and a negative bias in double observer-only estimates.

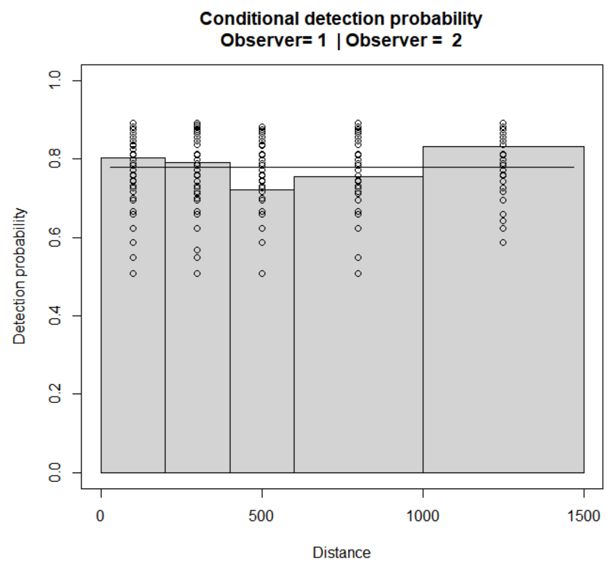

Figure 2. Distance sampling detection function for the full MRDS analysis of Southampton Island. Each bar is the conditional double observer detection probability based on the ratio of caribou groups observed by the secondary observer to overall groups detected.

Figure 3 shows estimated based on subsetting the full data set. The first bar represents abundance from the full data set for comparison with the 1, 2, and 3 bin estimates. Hazard rate (the detection function that allows a larger shoulder area) and half normal (a simpler detection function that restricts the shoulder distance) were considered along with mark-recapture/double observer models with 1 bin (as used in calving ground surveys) and 2 bins (with distance as a covariate to estimate decline in detection across the 2 bins). In general, reasonably similar estimates occur when 2 and 3 bins were used with the best agreement for the hazard rate (HR) model with 3 bins. The hazard rate model did not converge when only 2 bins were used, however, in this case the half-normal still provided an estimate of reasonable agreement. The double observer/mark-recapture only estimates were 5% lower than the full MRDS estimates for this survey.

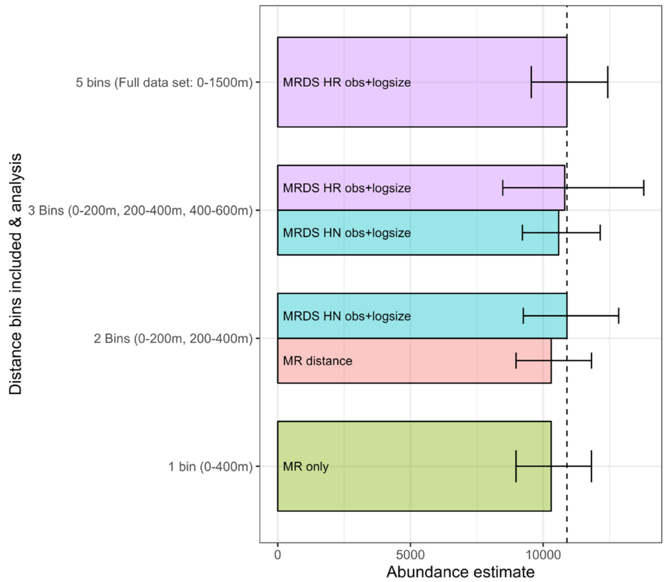

Figure 3. Southampton Island 2017 analysis. The same double observer/mark-recapture model (obs+snow) was used for all analyses shown. The dashed line indicates the estimate using the full 5 bin (0-1500m) data set.

<u>Baffin 2024 fixed wing survey</u>

The fixed wing only data set (a portion of the survey was conducted via helicopter which was less relevant) which consisted of 827 observations was used for this analysis. The detection function for the South Baffin Island 2024 survey was relatively similar to the Southampton Island survey with a hazard rate detection function estimating a shoulder area of approximately 200m before declining at successive distances (Figure 4). Sightability on the survey line was estimated as 0.96 (CV=0.029). Plotting double observer estimates of sightability with distance revealed a decline in estimated detection probabilities, however, detection probability estimates at further survey bins were still much higher than distance sampling estimates.

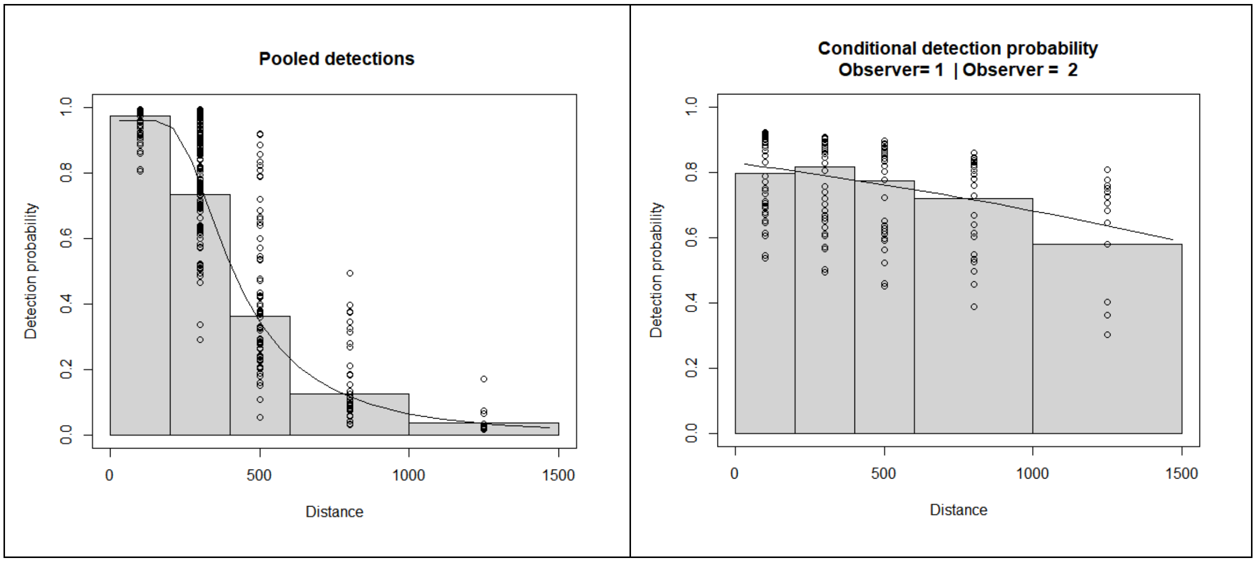

Figure 4. Distance sampling detection function for the full MRDS analysis of Baffin Island (left) and double observer estimates of detection with distance (right).

At the time of this report, estimates for the Baffin Island project had not been released so we use relative abundance, which is the estimate for each model divided by the estimate of the full MRDS model (Figure 5) for comparisons. Estimates when the data was subsetted to reduced numbers of bins were different than South Hampton Island with 3 bins required to obtain an estimate using a hazard rate model that was similar to the full estimate. At 2 survey bins, only the half-normal model converged leading to higher (+10%) estimates presumably due to the half-normal model underestimating the area of constant sightability in the vicinity of the plane. If only double observer model methods were used, estimates were 10% lower than the full MRDS model estimates.

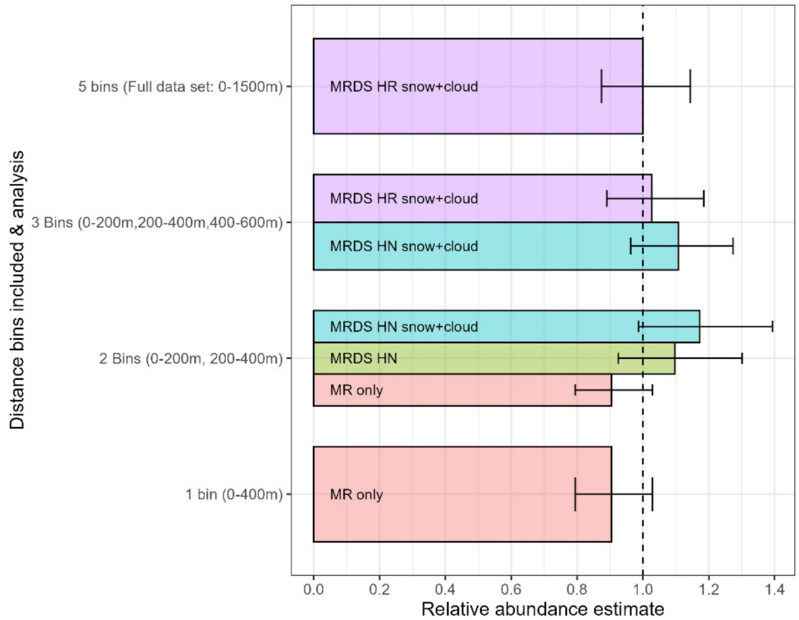

Figure 5. Baffin Island 2024 analysis. Estimates are given as relative abundance, which is the estimate for each model divided by the estimate of the full 5 bin MRDS model. The same double observer/mark-recapture model (ob6+ob11+distance+logsize) was used for all analyses shown. The dashed line indicates the estimates using the full 5 bin (0-1500m) data set.

Simulation study

One of the main questions addressed by the simulation study was whether the reduced bin designs could produce unbiased estimates of abundance. The main source of bias would be the inability of distance models to adequately estimate the shoulder area of constant sightability near the plane and/or the reduction in detection across the range of distances used in the survey. An additional source of bias could be lack of resolution in the data to allow selection of the hazard rate model compared to the simpler half-normal model. For simulations a hazard rate generating model used was based on the Baffin Island detection function with a shoulder of approximately 200m of constant sightability in the vicinity of the plane (Figure 4). A hypothetical study area based on the High East Beverly strata was simulated with a population of 3000 caribou. Figure 6 shows an example of one run of the simulations. For estimation, the data was binned in 5 distance bins (0-200, 200-400, 400-600, 600-1000, and 1000-1500m). Single caribou were simulated with no group size variation in detection probabilities.

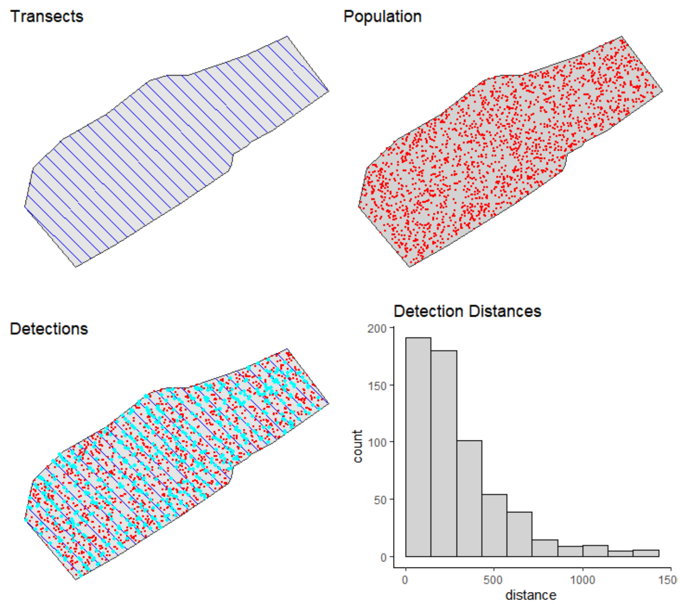

Figure 6 Example of one simulation run with transects, simulated caribou (red dots), detections (blue dots) and simulated distance data. The actual bins used for analyses were (0-200,200-400,400-600,600-1000, and 1000-1500m).

Simulations generated 686 to 919 detections of caribou depending on the number of bins included in the simulation (Table 1). These sample sizes were approximately similar to the South Hampton and Baffin Island data sets. Simulation study results suggested that the hazard rate model could provide unbiased estimates with 97% confidence interval coverage when 3 bins of sampling were used for the analysis (Figure 7 and Table 1). When 2 bins were used, estimates were slightly positively biased with occasional large estimates with non-model convergence in 3% of simulations, however confidence interval coverage was still adequate (94%). In contrast, estimates from the half-normal detection function were positively biased in most simulations with 2 or 3 bins of sampling with lower confidence interval coverage. When AIC model selection was used to choose between the hazard rate and simpler half normal model the hazard rate model was chosen in 61% of simulations with 2 or 3 bins sampled. As a result, estimates from simulations using AIC model selection resulted in an overall positive bias due to the half normal model being selected in simulations. If 5 bins were simulated, the hazard rate model was selected in 100% of simulations and estimates were unbiased.

Table 1. Simulation results. The mean number of caribou detected, method used to obtain estimates (AIC selection of HR or HN, or HN and HR models), % mean bias, confidence interval coverage (% of simulations where the confidence interval included the true value), mean CV of estimates, proportion of simulations using AIC where the hazard rate (HR) model was selected, and proportion of simulations where models did not converge.

Distance Bins used	Sampling width (m)	Mean caribou detected	Model method	Bias (%)	Conf. Interval Coverage	Mean estimate CV	Proportion AIC HR selected	Proportion failures
5	1500	919.3	AIC	0.2	0.96	0.046	1.00	0.00
3	600	803.2	AIC	4.4	0.73	0.079	0.61	0.00
2	400	684.9	AIC	3.5	0.90	0.055	0.61	0.04
3	600	805.5	HN	9.0	0.57	0.094		0.00
2	400	686.0	HN	5.0	0.87	0.074		0.00
3	600	805.0	HR	0.3	0.97	0.049		0.00
2	400	689.2	HR	3.4	0.93	0.063		0.03

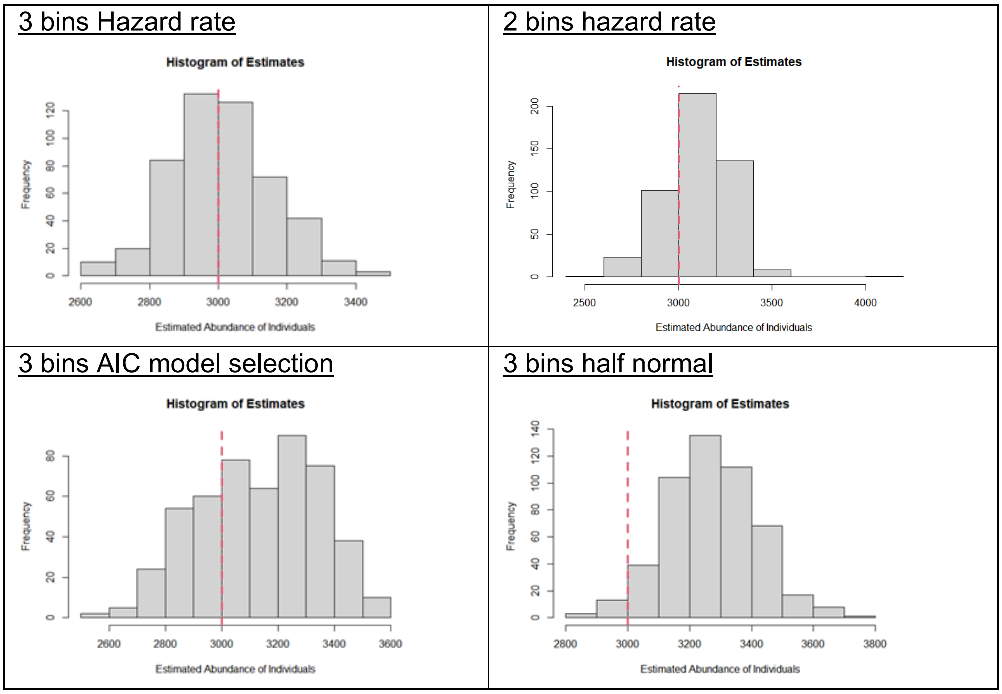

Figure 7. Examples of the distributions of simulated estimates compared to true value (red line) for each simulation run.

Discussion

Results from this analysis suggest that it is possible to get robust estimates using a reduced distance sampling and double observer approach. Of the data formulations considered the 3-bin (0-200m, 200-400m, 400-600m) provided the most reliable estimates based on both empirical comparisons and the simulation study. One reason for this is that it was possible to fit a hazard rate model that assumes an area of constant sightability near the plane (which is likely) with 3 bins of data. If 2 bins are used, then the half-normal model had to be used which is more restrictive in shoulder width leading to a reduced shoulder area and an overestimate of abundance.

Empirical comparisons provided a useful first step in assessing this methodology, however they were limited in that only one outcome of the survey is considered, and the true abundance was not known. The simulation study allowed an estimate of actual bias which further supported empirical comparisons. The simulation study was a simplification of field efforts given that detectability on the line was assumed to be 1 and group size variation was not simulated. Therefore, the levels of precision from the simulation study will be optimistic. However, simulation results provide the same general conclusion as empirical comparisons which is reassuring.

Empirical comparison of double observer and distance sampling estimates from past surveys suggest that double observer approach may underestimate abundance by 5-10% which is a reasonable difference but not enough to change general survey conclusions. Other comparisons also suggest that double observer estimates may be biased low. For example, IPM analysis of the Beverly 2023 survey also suggests that adult female estimates were approximately 5% lower in 2018 that IPM predictions. A comparison of paired photo and double observer survey lines during the Bluenose-East surveys in 2013 and 2023 surveys suggested that photo estimates were 7 to 14% higher, however, further analysis suggested that the main bias occurred on lines with higher densities of caribou where photo counts were higher with similar estimates at moderate densities (Boulanger et al. 2024). Regardless, negative biases in strip transect/double observer estimates cannot explain the increase documented in the 2023 survey or the increase documented in between 2018 and 2023 for the Bluenose-East herd. However, it is possible that double observer estimates showed a greater degree of negative bias in years such as 2021 Bluenose-East survey when survey conditions were poor. In this case, the proposed approach may provide a better estimate of abundance when survey conditions are challenging.

One additional consideration with visual survey estimates is potential counting bias when densities of caribou are higher. In the Beverly 2023 survey it was found that visual estimates may be biased high when densities are very high due to challenges of determining whether caribou were within the survey strip. In this case, the video-assisted approach provides a secondary way to count caribou and can complement the use of double observer and distance methods. In general, it is assumed that visual surveys will be applied at moderate densities of caribou (<10 caribou/km^2) with video or photo plane methods used when densities are higher.

Simulation results suggest that unbiased estimates can be obtained with 2 or 3 bin sampling, however the 3-bin approach (0-200,200-400, 400-600m) is preferable to reduce the risk of not having enough data to adequately determine the shoulder area of constant sightability. For example, the 2-bin design only selected the hazard rate model in 61% of simulations leading to a positive bias if the half-normal model was used for estimates. One strategy to confront this issue would be to only consider a hazard rate model for the analysis. The hazard rate model is considered to be "model robust" in that it can still produce unbiased estimates when the width of the shoulder of constant sightability near the survey line is not large (Buckland et al. 1993). Further simulations could be conducted to explore a greater range of survey conditions.

The main difference between the South Hampton and Baffin Island surveys in this analysis and calving ground surveys is the reduced densities of caribou which made it easier to apply distance sampling methods. For example, on the Baffin Island survey densities were less than 1 caribou per km^2 and therefore would be considered low density in a calving ground survey. During calving ground surveys observers and data recorders are more preoccupied with counting caribou groups and therefore successful application of this approach requires minimal additional complexity for observers and data recorders. However, we suggest the only additional piece of information that would be required is what survey bin the majority of any group occurs in. Also, observers would need to be reminded to pay the most attention to the closest survey bins (if the 3 bin approach is used). We propose that this additional complexity is worth considering given the likely robustness of this approach compared to just using the double observer method for calving ground survey estimates.

Literature cited

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.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance Sampling. Estimating Abundance of Biological Populations. Chapman & Hall, London.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2004. Advanced Distance Sampling - Estimating abundance of biological populations. Oxford Press.

Buckland, S. T., J. Laake, and D. L. Borchers. 2010. Double-observer line transect methods : levels of independence Biometrics 66:169-177.

Campbell, M., J. Boulanger, and D. Lee. 2020. Long-term trends in abundance and distribution of the Southampton Island caribou herd: 1978 – 2019 Government of Nunavut, Department of Environment.

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. Goorts, D. S. Lee, J. Boulanger, and T. Pretzlaw. 2015. Aerial Abundance Estimates, Seasonal Range Use, and Demographic affiliations of the Barren-Ground Caribou (Rangifer tarandus groenlandicus) on Baffin Island – March 2014. Department of Environment, Nunavut Wildlife Research Division, .

Campbell, M., D. Lee, and J. Boulanger. 2019. Calving Ground Abundance Estimates of the Beverly Subpopulations of Barren-Ground Caribou (Rangifer tarandus groenlandicus) – June 2018. Technical Summary. Government of Nunavut.

Campbell., M., J. Ringrose, J. Boulanger, A. Roberto-Charron, K. Metheun, C. Mutch, T. Davison, and C. Wray. 2021. An Aerial Abundance Estimate of the Dolphin and Union Caribou (Rangifer tarandus groenlandicus x pearyi) herd, Kitikmeot Region, Nunavut – Fall 2020, Government of Nunavut, Technical Report Series No 01-2021. 146 pp. .

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.

Laake, J. L., and B. A. Collier. 2024. Understanding implications of detection heterogeneity in wildlife abundance estimation. The Journal of Wildlife Management 88:e22516.

Marshall, L. 2022. dsims: Distance Sampling Simulations R package.

Rexstad, E., S. Buckland, L. Marshall, and D. Borchers. 2023. Pooling robustness in distance sampling: Avoiding bias when there is unmodelled heterogeneity. Ecology and Evolution 13:e9684.