2019 Status of Ameralik caribou population, South region, West Greenland

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Authors: Christine Cuyler[1], Tiago A. Marques[2], Iúri J.F. Correia[3], Aslak Jensen[4], Hans Mølgaard[5] and Jukka Wagnholt[6]

[1] Pinngortitaleriffik – Greenland Institute of Natural Resources, P.O. Box 570, 3900 Nuuk, Greenland
[2] CREEM, University of St Andrews, School of Mathematics and Statistics, Scotland
[3] University of Lisbon, Faculty of Sciences, Portugal
[4] Solviaq 15, 3900 Nuuk, Greenland
[5] P.O. Box 122, 3911 Sisimiut, Greenland
[6] Tusass, P.O. Box 1002, 3900 Nuuk, Greenland

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Pinngortitaleriffik – Greenland Institute of Natural Resources
P.O. Box 570, 3900 Nuuk, Greenland

Phone: +299 36 12 00
E-mail: info@natur.gl
www.natur.gl

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By

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[2] CREEM, University of St Andrews, School of Mathematics and Statistics, Scotland
[3] University of Lisbon, Faculty of Sciences, Portugal
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Raw data may be accessed by contacting Pinngortitaleriffik – Greenland Institute of Natural Resources, Department of Mammals and Birds.

Summary

This report presents results from the aerial survey carried out by helicopter in early March 2019, for the Ameralik caribou population inhabiting the northern portion of the South region in West Greenland. This population was last surveyed in March 2012, making new estimates of abundance and density necessary. In 2001 and 2006 survey method was strip transect counts. In 2012, methods changed to Distance Sampling. The March 2019 helicopter survey again used Distance Sampling methods.

For March 2019, the Ameralik caribou population abundance was estimated at 19,503 caribou (95% CI: 12,404 – 30,665; CV = 0.219; SE = 4268), with density 4.2 ± 0.9 caribou/km^2 (95% CI: 2.6–6.6). Overall survey coverage was 9.7% (truncated data), which is a substantial improvement from the 2.15% coverage for 2001 and 2006 strip transect count surveys. Further, it is even improved relative to 8.6% coverage of the 2012 Distance Sampling systematic transects.

Despite 18 years of harvest management aimed at controlling caribou abundance and density, the March 2019 Ameralik caribou population size is large and appears to have increased 67% since 2012. The 2012 and 2019 surveys were similar in coverage and method. There is little overlap in the Confidence Intervals for the 2012 and 2019 population estimates. Further, the 2019 CV (0.22) indicates good precision in the 2019 population estimate. The three combined make it reasonable to assume a trend of increasing population size over the 2012-2019 period.

The density estimate for the Ameralik population was 4.2 caribou per km^2 in area of survey effort. This value is much greater than the management recommended target of 1.2 caribou per km^2 (Kingsley & Cuyler 2002, Cuyler et al. 2007). At almost four-fold the target density, Xeric Inland's 5.8 caribou/km^2 may have influenced the observed poor 2019 calf recruitment and sex ratio (below). Exceeding the target caribou density is assumed to raise the risk of overgrazing and thus decline in caribou abundance.

Relative to the 2006-2012 period, late-winter calf percentage was similar, however, calf recruitment declined somewhat from previous values. In contrast, the 2019 sex ratio of 22 bulls per 100 cows was poor and considerably lower than previous values, i.e., 83, 81, 62 in 2001, 2006, 2012, respectively, for animals age > 1-year. Population trend beyond 2019 is uncertain, and there is

always the possibility of future catastrophic stochastic events, including extreme weather and pathogen outbreaks.

Environmental conditions during the 2019 survey provided extraordinary camouflage for caribou. Pooling environmental covariates into a single index for camouflage will improve detection function modelling. Skilled observers and flying helicopter low and slow were critical factors permitting detection of caribou, specifically because 17% of all groups remained stationary.

Beyond population parameters, results of interest included relatively high elevations, mean 647 m, used by the Ameralik caribou population in early March. This reflects the relative scarcity of low elevations in the region and likely also avoidance of human disturbance in lowlands. Further, and in contrast to other caribou populations in West Greenland, most (92%) cows possessed antlers in the Ameralik population.

Eqikkaaneq (kalaallisut)

Uani nalunaarusiami saqqummiunneqarput nunap immikkoortuani tuttassiissutinik aqutsiviusumi qulimiguulik atorlugu martsip aallartilaarnerani 2019-imi tuttunik kisitsinernit inernerit. Tuttut taakku pineqartut nunatta kitaata kujataata avannaatungaani uumasuupput. Tuttutoqatigiiaat kingullermik kisinneqaramik periuseq atorneqartoq tassaavoq, qulimiguulimmit takusat aalajangersimasumik kisinneqartarnerat, taaguuteqartinneqartoq Distance Sampling methods. Periuseq marts 2019-imi kisitsisoqarnerani aamma atorneqarpoq.

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Tuttunut tunngasorpiaat saniatigut misissuinerit takutippaat, Ameralimmi tuttoqatigiiaat immamiit agguaqatigiissillugu 647 m missaanni qatsissusilik angullugu uninngaarniarnerusimasut. Sumiiffik pineqartoq atsissuin-napajaarsuugami qularnanngitsumillu inuit ingalassimaniarlugit tuttut Ameralimmi qatsinnerusumiinniarsimapput. Aamma Ameralimmi kulavaat Kalaallit Nunatta kitaani immikkoorutigalugu tamangajammik, tassa 92 %-ii, nassunissimapput.

Resumé (dansk)

Denne rapport omhandler resultater fra helikoptertællingen af rensdyr i Ameralik-bestanden i den nordlige del af region Syd i Vestgrønland foretaget i begyndelsen af marts 2019. Bestanden blev sidst optalt i marts 2012. Tællingerne i 2001 og 2006 blev udført som transekt-tællinger. I 2012 ændrede man metoden til "Distance Sampling" (DS). Ved helikoptertællingen i marts 2019 anvendtes ligeledes DS.

Ameralik-bestanden blev i marts 2019 anslået til 19.503 rensdyr (95 %-konfidensinterval: 12.404-30.665; variationskoefficient = 0,219; standardafvigelse = 4268), med en tæthed på 4,2 ± 0,9 rensdyr/km² (95 %-konfidensinterval = 2,6-6,6). Transekterne der blev fløjet dækkede 9,7 %, hvilket er en væsentlig forbedring i forhold til dækningen på 2,15 % fra transekt-tællingerne i 2001 og 2006. Dækningen er endda forbedret i forhold til DS tællingen i 2012, hvor dækningen var på 8,6 %.

På trods af, at man i 18 år har forsøgt at regulere bestandsstørrelsen og bestandstætheden, var Ameralik-bestanden i marts 2019 stor og ser ud til at

være øget med 67 % siden 2012. Tællingerne i 2012 og 2019 havde lignende dækning og anvendte samme metode. Der er ikke meget overlap mellem konfidensintervallerne for bestandsestimaterne i 2012 og 2019. Desuden, angiver CV (0.22) god præcision i bestandsestimatet for 2019. De tre tilsammen gør det rimeligt at antage en tendens med stigende bestandsstørrelse i perioden 2012-2019.

Ameralik-bestandens tæthed blev estimeret til 4,2 rensdyr pr. km^2 i det område, hvor tællingen blev foretaget. Dette er langt højere end de anbefalede 1,2 rensdyr pr. km^2 (Kingsley & Cuyler 2002, Cuyler et al. 2007). En overskridelse af den anbefalede bestandstæthed formodes at øge risikoen for overgræsning og dermed risikoen for nedgang i rensdyrbestanden.

I forhold til perioden 2006-2012 var andelen af kalve sidst på vinteren den samme. Kalverekrutteringen faldt dog noget i forhold til tidligere værdier. Kønsfordelingen i 2019 på 22 hanner (tyre) pr. 100 hunner (simler) var derimod skæv og betydeligt lavere end de foregående værdier, dvs. 83, 81 og 62 hanner pr. 100 simler i henholdsvis 2001, 2006 og 2012 for dyr ældre end 1 år. Bestandens udvikling efter 2019 er usikker, og der er altid en risiko for katastrofale uforudsigelige og tilfældige vejrforhold i fremtiden på grund af klimaforandringer og patogen udbrud.

Vejrforholdene under 2019-optællingen gjorde, at rensdyr var specielt godt camouflerede. Ved at samle vejrmæssige kovarianter i et enkelt camouflageindeks forbedres "detection function modelling" (en proces i DS-udregningerne). Det var muligt at spotte rensdyrene, fordi der blev anvendt dygtige observatører, og helikopteren fløj lavt og langsomt. Det var især vigtigt, fordi 17 % af alle rensdyrflokkene stod stille.

Ud over bestandsparametre viste undersøgelsen, at Ameralik-bestanden opholdt sig i relativt højtliggende områder (i gennemsnit 647 m over havets overflade) i begyndelsen af marts. Det afspejler den relative knaphed på lavtliggende områder i regionen og formentlig også, at dyrene desuden undgår at blive forstyrret af mennesker i lavtliggende områder. Undersøgelsen viste også, at de fleste simler (92 %) i Ameralik-bestanden har gevirer – i modsætning til hunner i andre rensdyrbestande i Vestgrønland.

Introduction

Caribou and reindeer (*Rangifer tarandus spp.*) throughout the Arctic are bound closely with indigenous hunting traditions and culture. In modern Greenland, they also provide economic opportunities for commercial and recreational hunters. In West Greenland (60.5°–69°N), where the largest populations occur, caribou also play a central role in the terrestrial ecosystem, given the otherwise low mammalian diversity. West Greenland has been divided into seven *Rangifer* regions based on natural barriers and caribou genetics (Linnell et al. 2000, Jepsen et al. 2002). From south to north these regions are: Isortoq, Ivittuut, Paamiut, South, Central, North and Naternaq, for which separate harvest management may apply. Together, these regions contain several caribou populations. This report focuses on the 2019 helicopter survey in the northern portion of the South region (Fig. 1), which contains the caribou population named Ameralik and corresponds with the Government of Greenland's caribou management hunting area 4, which is under Nuuk Kommunia (municipality).

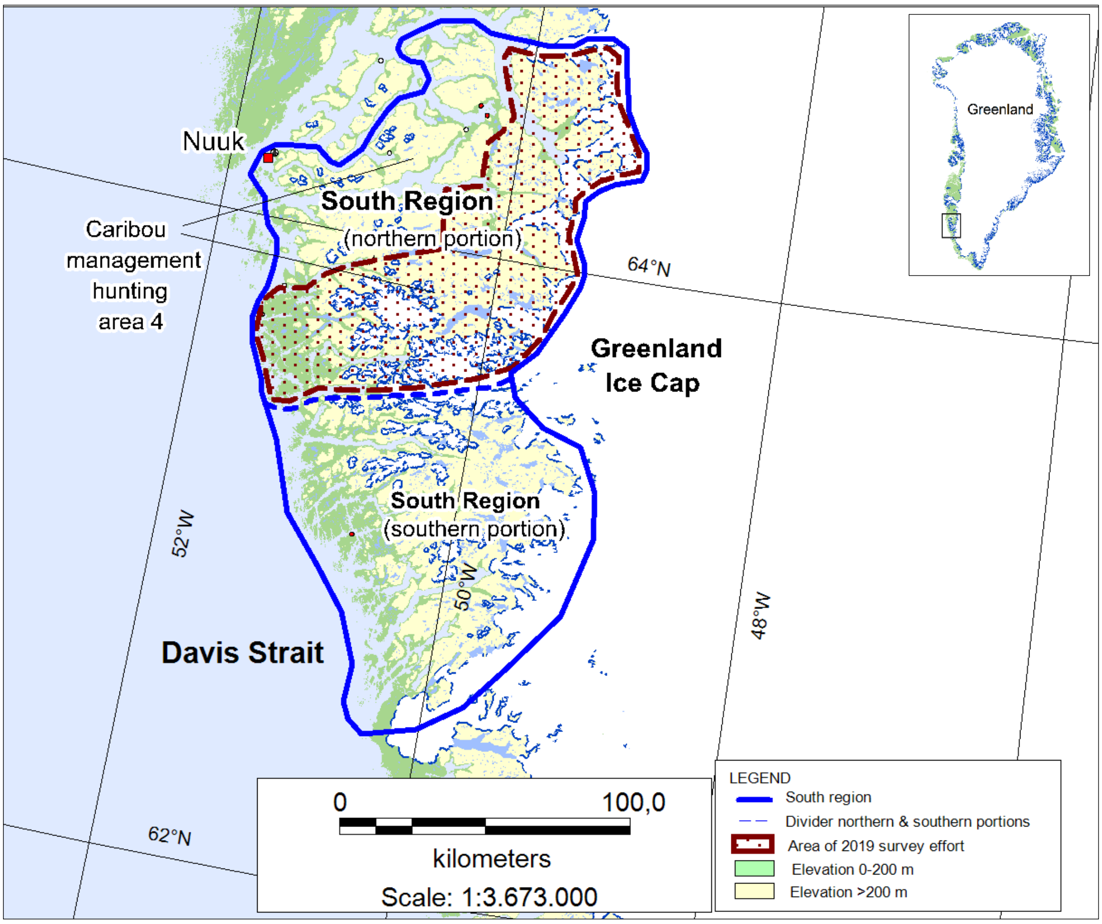

Figure 1. Borders of the South region, of which the northern portion corresponds to the Government of Greenland caribou management hunting area 4 and contains the Ameralik caribou population.

Survey methodology for the Ameralik caribou population changed over the 2001-2012 period (Cuyler et al. 2016) Thus, assuming a trend for population abundance over the entire 2001-2012 period is precluded by the change in survey methodology from the strip transect counts of 2001 and 2006, to Distance Sampling (DS) in 2012. Regardless, the estimated abundance and density of Ameralik caribou population dropped from 2001 to 2006 and then appeared relatively stable from 2006 to 2012 (Table 1).

Initially, the relatively high density for Ameralik caribou population in 2001 suggested density-dependent forage limitation was a risk, because it might cause unstable abundance and decline. Therefore, the Government of Greenland's wildlife management aimed at reducing Ameralik abundance and density to a target stocking rate of 1.2 caribou per sq km (Cuyler et al. 2007). The target density was based on studies elsewhere that document associations between observed densities and changes in caribou productivity, dispersal, and range condition, as described in Cuyler et al. (2007). Therefore, initially hunting quotas increased substantially followed by unlimited harvests. The autumn hunting season, which was originally 1-month was lengthened several times over the years. A winter hunting season with quota was later added and it became permissible to harvest all sexes and ages (details Cuyler et al. 2016). In contrast, prior to 2000, harvest management typically encouraged bull-only hunting. Already by 2006, calf percentage and recruitment rose for the Ameralik caribou population and further increase was observed in 2012.

Table 1. Late winter population parameters, Ameralik caribou population, South, West Greenland. Obtained by aerial (helicopter) surveys; strip transect counts in 2001 and 2006, and Distance Sampling in 2012 (Cuyler et al. 2003, 2007, 2016).

Parameter	2001	2006	2012
Population size estimate	31,880	9,680	11,700
90% Confidence Interval (CI) – lower	24,721*	6,515	8,500
90% Confidence Interval (CI) – upper	39,305*	13,147	15,900
Coefficient of Variation (CV)	-	0.21	0.18
Standard Error (SE)	-	-	-
Density per sq km	3.7	1.16	1.66
Mean group size ± SD	4.3 ± 3.65	5.4 ± 3.06	4.2 ± 3.3
Max group size	28	15	24
Calf percentage **	17.8 %	24.8 %	28.2 %
Recruitment (Calf /100 Cow) **	40	59.8	63.5
Sex ratio adults (Bull /100 Cow) **	83	81	62

*80% CI

**Age classes; calves (age < 1-year), adults (age > 1-year)

Present survey

The Circumpolar Rangifer Monitoring & Assessment network (CARMA) advises monitoring caribou populations every three years to enable detection of changes in abundance, density, and demographics. The latter would include sex/age structure and calf recruitment. The last survey of the Ameralik caribou population was March 2012. Since then, there have been long and unlimited autumn harvests and, albeit short, winter hunting seasons have been common. In early March 2019, the Greenland Institute of Natural Resources (GINR) examined by aerial helicopter survey the Ameralik caribou population in the South Region (hunting area 4) of West Greenland.

These 2019 surveys used systematic line transects and Conventional Distance Sampling (CDS), in which distances from a line transect to animals detected are recorded and from those distances, abundance and density of animal populations are estimated (Buckland et al. 2001, Thomas et al. 2010). This was the second time systematic line transects and CDS were applied to survey the Ameralik caribou population to obtain estimates of abundance and density. This first time was in 2012. Meanwhile, methods for collecting demographics (sex, age, calf recruitment) data remained unchanged since 2001.

This report investigates the DS data sets for caribou observations obtained during GINR's March 2019 caribou survey of the Ameralik caribou population in the South region (northern portion). Initially, we use DS analyses to present pre-calving estimates for 2019 abundance and density of the Ameralik caribou population.

Further, this report presents information on immediate caribou reaction (movement or lack thereof) to the helicopter fly-by of the caribou groups detected. The demographics data set is also analyzed, and we report the late winter pre-calving sex, age, and calf recruitment.

Methods

Study area

Common to West Greenland, the northern portion of the South region surveyed exhibits a climate gradient on a west-east axis. Climate and weather for the western seacoast is wet maritime, being under the maritime influences of the year-round ice-free Davis Strait and the low-pressure oceanic storm systems that sweep in from the southwest. However, the climate becomes increasingly dry continental as one moves east towards the Greenland Ice Cap. The inland of the northern portion of the South region is dry owing to the 1500–2000 m elevations associated with the Sermilik fjord, Sermeq glacial tongue and multiple glaciers. See Appendix 1 for place name details. The high elevations physically block the oceanic storm systems, creating a precipitation shadow on the northeastern side making an already dry area truly xeric (Appendix 2, Figs. 25-38; Appendix 6, Figs. 57-79).

In addition to caribou, there are just three wild mammals present in the South region: arctic hare (*Lepus arcticus* Rhoads), arctic fox (*Vulpes lagopus* Linnaeus), and recently muskoxen (*Ovibos moschatus* Zimmermann) (Cuyler et al. 2016). The arctic fox is the only terrestrial mammalian predator, as large mammalian predators are absent. In addition to the three wild mammals, feral domestic sheep (*Ovis aries*), have maintained a small presence in Austmannadalen for several decades (Cuyler et al. 2016) (Appendix 3). These originate from sheep farming attempts near the village of Kapisillit. The recent occurrence of muskoxen was through natural emigration from the population inhabiting the North region (ca. 66°–67°45′N; 49°30′–54°W) of West Greenland. Animals expanded southward, first into the Central region and later into the Nunatarssuaq area of the South region (Cuyler et al. 2016). Since 2012, sporadic sightings of muskoxen have also been reported on the Kangerluat (west of Kapisillit), and even to the south shore of the Ameralia arm of the Ameralik Fjord (Cuyler unpublished). Expansion is possible because the region borders are semi-permeable permitting limited animal movement between adjacent regions. Nevertheless, the borders are assumed effective barriers preventing mass animal movements (Linnell et al. 2000).

The South region (ca. 63°30′–64°30′°N; 49°–51°40′W) lies completely within Nuuk Kommunia. Greenland's capital city, Nuuk, with ca. 18,800 inhabitants, is situated near the mouth of Nuuk fjord in the northwestern tip of this region. About 75 km east of Nuuk in an arm of the Nuuk fjord lies Kapisillit, a village of ca. 52 people. Aside from the crew manning the Buksefjord hydro power station there are no other permanent settlements in the northern portion of the South region, which is seasonally ice-free and covers an area of 7,000–8000 km^2, including lakes, rivers, and islands (Cuyler et al. 2003, 2007, 2016). The northern border is provided by the Nuuk fjord. The southern border is delineated by the Sermeq glacial tongue and Sermilik fjord. The western border is the permanently ice-free seacoast of the Davis Strait, and the eastern border is the Greenland Ice Cap.

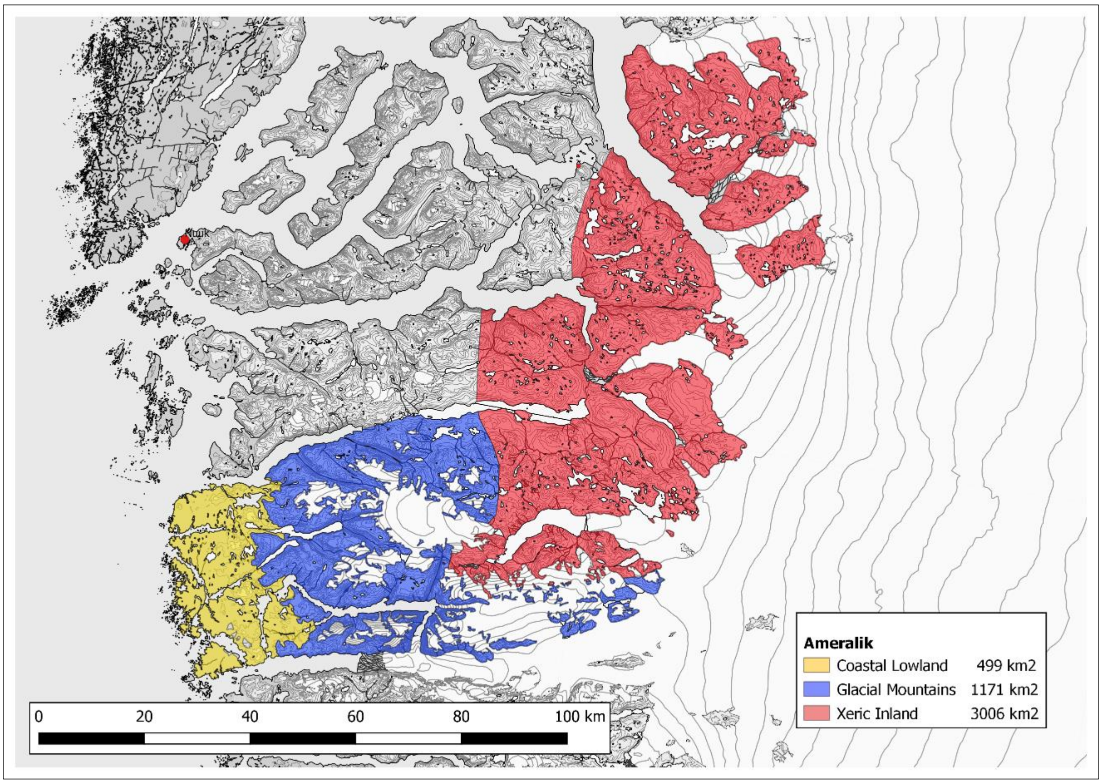

Figure 2. Area covered by 2019 caribou survey of northern portion of South region (4,676 km²), which is inhabited by the Ameralik caribou population. Three different colours illustrate the three sub-areas, designated as Coastal lowland, Glacial mountains, and Xeric inland. Greenland's capital city, Nuuk, is the red diamond at the tip of the thin long grey peninsula in upper left corner.

A comparison of figures 1 and 2, illustrates that the aerial survey effort in 2019 did not cover all the South region's northern portion. This contrasts with the 2001, 2006 and 2012 surveys. In 2019, the northwest section was omitted owing to recently permitted snowmobile use in grey area (Fig. 2), as disturbance by snowmobile was expected to alter caribou distribution. The 2019 survey concentrated effort to only those areas where snowmobile use continued to be prohibited in the open land. This was an area of 4,676 km^2, (excluding lakes, rivers, sand, glaciers, and islands), which also coincided with most caribou detections in the 2012 aerial survey (Cuyler et al. 2016).

Aside from a mountainous coast just south of the city of Nuuk, rugged coastal lowlands (< 200 m elevation) prevail between the Ameralik and Sermilik fjords. Moving east the terrain rises to elevations of up to ca. 1000 m and glaciers become common, specifically in the middle and southern portions. Generally, elevations are > 300 m.

Field methods

Since 2000, early March has been the chosen period for caribou surveys because caribou dispersion is high, group size is small with low variability and daily movement is at the annual minimum (Cuyler et al. 2007, 2011, 2016; Poole et al. 2013). The former two reduce variance among transects, diminish counting error, and maximize precision, while the latter lowers movement between or along transects. The aerial survey period for Ameralik caribou was 08-14 March 2019. The platform for observation was a helicopter AS350. Pilot monitoring of helicopter radar altimeter made maintenance of a constant altitude possible by constantly adjusting for terrain features while flying low (40 m, ca. 120 feet) and slow (ca. 65 km/hour).

Participants included three observers, all with previous survey experience: GINR's senior scientist Christine Cuyler, professional hunter Aslak Jensen (Greenland Association of Professional Hunters (KNAPK)) from Nuuk and Sisimiut hunting officer Hans Mølgaard. Cuyler always sat in front and was the data recorder. Cuyler (Observer 2) focused on detecting caribou directly on track line (center line, 0-line) before animals fled offline owing to approaching helicopter. Jensen and Mølgaard (Observer 1 and 3, respectively) were seated in the rear of the helicopter, on either side. The side they sat on alternated each time the helicopter was refueled, which was usually once daily and sometimes twice. Jensen and Mølgaard could not view the track line but observed animals for all distances beyond. Verbal contact among the observers permitted the digital audio recording of all observations and most importantly, prevented any double counting of groups detected by more than one observer. Two audio devices (SONY IC recorder, ICD-SX712) were used to record separately the observations specific to the left and right side of the line transect. Audio recording devices were on continual recording for each line transect. At the end of each survey day, audio data was downloaded to computer for storage and back-up. Observations were later paired with Global Positioning System (GPS) coordinates of the helicopter at the time of observation. For each detection, the audio recording included distance to (see below) caribou group, as well as group size and behavior and name of the observer. Ground surface and weather conditions were also recorded. Manual click-counters, logging the number of caribou seen by an individual observer, provided low-tech back-up for double-checking the digital audio observations for each line transect.

Survey design

Aligning line transects perpendicular to known gradients within the surveyed area can maximize precision of the resulting estimate by lowering the encounter rate variance (Buckland et al. 2001). Thus, the transect axis direction (east-west axis) was chosen as perpendicular to previously known animal distribution gradients in March and the west-east climate gradient from wet maritime to dry continental. An initial line transect was computer generated at random in each sub-area (see below), and others followed at 10 or 20 km apart. The line transects flown provide the maximum area coverage possible given the financial resources available. Because some a priori transects were combined during survey, line identification numbers are not consecutive.

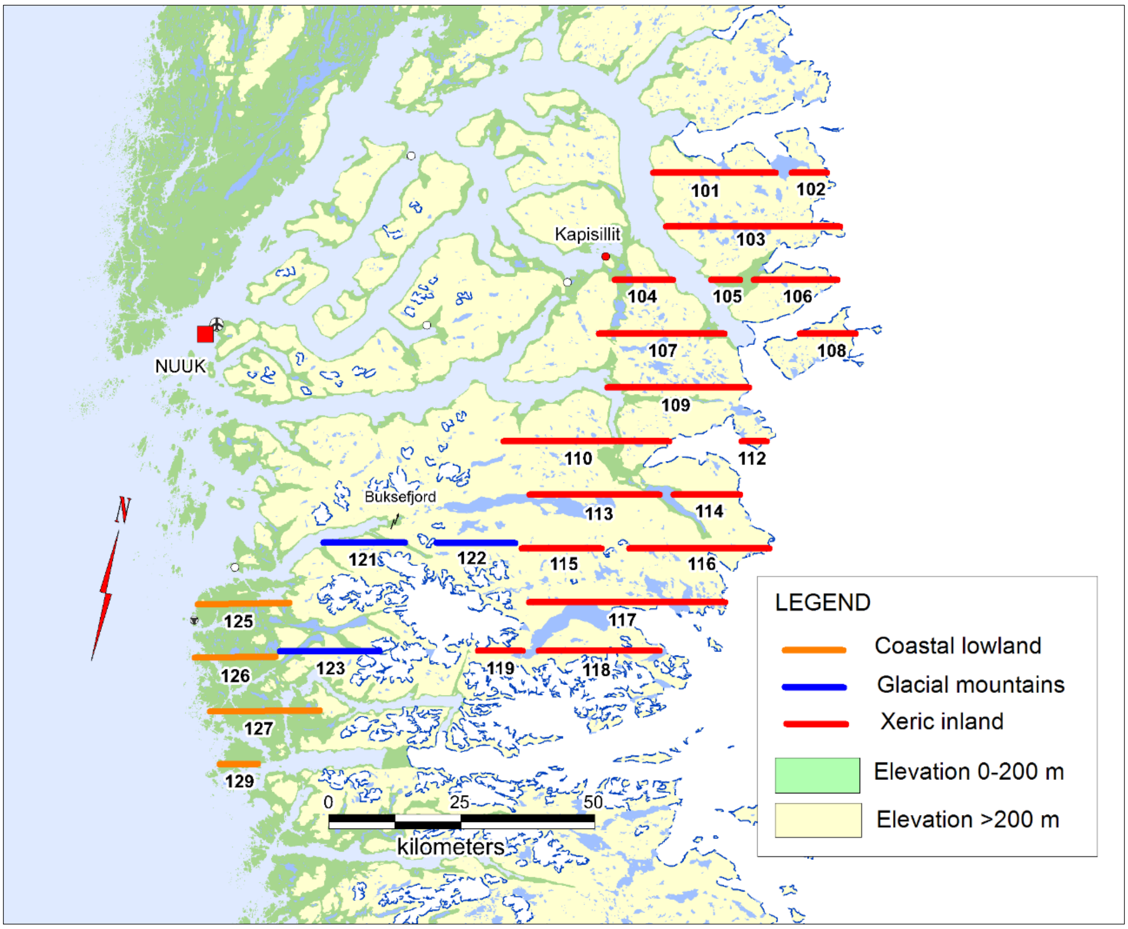

Figure 3. The 25 line transects used in the 2019 survey of South Region (northern portion), Ameralik caribou population, employing the same three colours as applied to the three sub-areas in above figure 3: Coastal Lowland (orange, 4 lines), Glacial Mountains (blue, 3 lines), and Xeric Inland (red, 18 lines). Transects separated by 10 km, except Glacial Mountains which were separated by 20 km. Line transect numbering is not consecutive, as some a priori lines became amalgamated during survey.

The surveyed northern portion of South region area, 4,676 km², was divided into three sub-areas, named Coastal Lowland (499 km²), Glacial Mountains (1,171 km²), and Xeric Inland (3,006 km²) (Fig. 2). The sampling design for the

2019 survey considered 25 systematic parallel line transects of variable length placed over the three sub-areas (Fig. 3). Line transects for Coastal Lowland and Xeric Inland were separated by 10 km and those for Glacial Mountains by 20 km. To avoid possible numbering confusion with the concurrent caribou survey of the Central region, in the South region line transect identification numbers began from 101.

Distance to a detected caribou group (object-of-interest) was before caribou movement occurred. Tightly cohesive behavior identified groups of multiple individuals. Excepting groups on the track line, which was distance 0 m, distance was the observer's instantaneous and subjective estimate of the distance to center of the caribou group. Exact distance measurement from the track line (aka 0-line or center line) to a caribou group was effectively never possible because of practical considerations (details in Cuyler et al. 2021). Therefore, like all previous helicopter caribou surveys in Greenland, for distance measurement perpendicular to the track line, we approximated with rough "*distance bins*", i.e., in meters, 0-50, 50-100, 100-200, 200-300, 300-400, 400-500, 500-600, 600-700, 700-800, and 800+. *Bin* value recorded for a group was always the upper limit of the *bin* applied. For analysis, we did not correct for the 40m altitude of the helicopter. Instead, we recoded the reported upper distance values to the mid-distance for a specific *bin* owing to three reasons. First, a caribou group could be at any distance within the *bin*., e.g., a group recorded in distance bin 300 m, was located somewhere between 200 and 300 meters. Second, placing a caribou group within the correct *bin* relied heavily on observer ability to estimate distance to the observed animals in rugged terrain. Third, although for level ground (itself rare) the estimated direct line distance from observer (sitting in helicopter at 40 m altitude above ground) to a caribou group would be greater than the perpendicular distance from the track line to that group, those differences were small at 100 m and negligible beyond 200 m (i.e., in meters 8, 4, 3, 2, 2, 2, 1, and 1). Regarding the 0-50 m *bin*, we assumed observer ability sufficient to compensate for 40 m altitude and assign a perpendicular 50 m distance correctly because immediately adjacent to the helicopter/track line. Further, to aid observer ability to estimate distances, before starting survey the helicopter hovered at 40m altitude while each observer used a "Leica laser range finder 1600" to gauge distances across level airport ground to a priori known perpendicular distances. Then observers marked their window with masking tape delineating the approximate distances for each *bin*. While on survey, in the absence of caribou and where vertical terrain features occurred, observers used the laser distance finders to test their ability to estimate distance, i.e., to the terrain feature. On rare occasions, observers were able to use the laser range finders for bin distance to a detected stationary group.

Once all recorded distances were recoded to mid-distance, to model the detection function all the detections were pooled across observers with the helicopter functioning as a single observer. The pooled data were used to estimate a detection function, then estimate the detection probability and finally to estimate the density of the caribou within the surveyed area (Buckland et al. 2001). The detection function, $g(y)$, describes the probability of detecting an object-of-interest given that is at a distance y, from the track line, thus being a non-increasing function of y (Buckland et al. 2015). For line transects, y is the perpendicular distance from the track line to the detected object. Within DS methods, the probability of detection is explained recurring to these observed distances (Buckland et al. 2001).

Distance sampling

The caribou group was the selected object-of-interest on which detectability was modelled, i.e., individual caribou within a group were not considered. The individual line transects were the sample unit for design-based conventional DS analysis of the 2019 survey. Details for how this study's DS analyses were performed are in Appendix 3. Thus, estimated CVs (Coefficients of Variation) from the models are referring to the transects, and total CV estimation is obtained by dividing the estimated standard error by the respective estimate. The estimated standard error is obtained as a pooled estimate for entire region and accounting for transects and their variability, it incorporates the variance from the detection function (Buckland et al. 2001).

The recorded distances to the observed caribou groups were used to estimate a detection function. With this, both the caribou detection probability and density within the surveyed area could be estimated (Buckland et al. 2001). The detection function, $g(y)$, describes the probability of detecting an object of interest (caribou group) given that it is at a distance y, from the track line, thus being a non-increasing function of y (Buckland et al. 2015). For line transects, y is the perpendicular distance from the track line to the detected object. Within DS methods, the probability of detection is explained recurring to these observed distances (Buckland et al. 2001).

Prior to DS analysis, the raw data was first processed for inconsistencies. Then extensive exploratory data analysis was completed, including evaluation of observed distances, before proceeding to determining the detection function through model fitting and selection (Buckland et al. 2001; Marques et al. 2011; Thomas et al. 2010). To determine the detection function, several models were considered, (Thomas et al. 2010). Typically, the model presenting the lowest AIC value is chosen. Details regarding DS theory, methods and analysis are available in Buckland et al. (2001, 2015), and a briefer summary is provided in Appendix 4, with a summary of DS assumptions in Appendix 5. For analysis, we used R Statistical Software (https://www.r-project.org/).

Demographics

Sex, age, and late-winter calf recruitment observations were obtained after most of the DS survey was completed. All caribou sighted were sexed and aged following a brief overpass with the helicopter. Sex and age criteria have remained unchanged since 2000 (details in Cuyler et al. 2011, 2016). Briefly, female sex was determined by the presence or absence of a vulva and/or urine patch on the rump of both adults and calves, i.e., antler size, shape, presence, or absence, were not used to determine sex. Two age classes were used, calf (age ≤ 10-months) and adult (age > 1-year). Age was determined by body size. 10-month-old calves, male and female, being considerably smaller than all other age classes in March. Calf percentage is given relative to the total number of caribou sexed and aged. Calf recruitment is value for late-winter and provided as the number of calves per 100 cows. Group size was based on proximity and group cohesion during possible flight response. To obtain demographics and recruitment values, on 14 March, large areas of the South region (northern portion) were flown, including the areas surrounding line transects 107, 109 and 110, the length of the Austmannadalen Valley and the highlands between there and the town of Kapisillit, the valley leading from Naujat kûat south to Isortuarssuk Lake and around shores of the latter and in general the mountains between Ameralik Fjord and Nuuk.

Elevations where caribou detected

Early March elevation use by caribou was approximated using GPS dataset for helicopter elevation/position and matching timestamps with those of the digital audio recording of caribou observations. GPS and digital recorder timestamps were synchronized before survey began. Before analysis, 40 m helicopter altitude was subtracted from all elevations. Thereafter, and lacking a reliable constant correction factor, negative values were deleted.

Natural mortality

In the past, if locals/hunters observed several caribou carcasses in the terrain or on sea ice, this resulted in alarm about an assumed negative trend for the entire population. To put carcass observations into perspective, since 2000, all technical reports for Greenland caribou surveys have included, for that specific survey year, the expected number of annual adult caribou deaths resulting from natural mortality, i.e., not due to harvest. Age distributions among harvested Greenland caribou populations have suggested a natural mortality of from 8 to 10% per annum (Loison et al. 2000, Cuyler & Østergaard 2005). Meanwhile, natural mortality rates from 4 to 8% were reported for North American populations without predators (Bergerud 1967, 1971, Skoog 1968, Kelsall 1968, Heard & Ouellet 1994), albeit these are now considered low (Bergerud et al. 2008) and density-independent factors, e.g., adverse weather, can increase mortality (Gates et al. 1986). Bergerud (1980) proposed a standard adult mortality rate of 10% for all North American caribou populations, and more recently Bergerud et al. (2008) suggested 7.7% for an increasing population with predators. Large predators are absent in the South region, and inland xeric conditions provide stable weather conditions. Although natural mortality rates vary among years (Bergerud et al. 2008), given the above, an assumed standard natural mortality rate of 8-10% (Kingsley & Cuyler 2002) for Greenland caribou likely yields a reasonable estimate of annual mortality. This rate is applied to the 2019 abundance estimates to provide wildlife managers with a rough number of expected caribou deaths due to natural mortality within the survey year.

Results

Survey logistics & unprocessed data

The aerial survey by helicopter of the Ameralik caribou population occurred within the period 01-14 March, which period was shared with the survey of the Akia-Maniitsoq caribou population. Poor weather made three days non-flyable, as did airport closures on two Sundays. DS data for the Ameralik caribou population was obtained over three days (08, 09 and 12 March). Demographics data was obtained 14 March. Typical of AS350 helicopters carrying three passengers and pilot, refueling was necessary after about 3 hours of flight time, an additional 15-20 minutes were possible when wind conditions and distance to nearest airport permitted. Helicopter flight time totaled 17 hours and 03 minutes. Time flown was divided between line transect DS survey (11 hours; 05 minutes) and the demographics survey (05 hours; 58 minutes). The 2019 survey used 25 line transects for a total distance flown of ca. 453 km, i.e., Coastal Lowland 60 km, Glacial Mountains 48.5 km and Xeric Inland 344.5 km (Table 2). Given the 453 km of line transects flown, an optimistic calculation of survey coverage of the South region's surveyed Ameralik area (4,676 km²) would be 19-29%, i.e., topography permitting and assuming maximum strip width of 1000-1500 m to either side of the helicopter. However, for analyses (see DS analysis, page 24), the strip width was truncated to 500 m. Thus, coverage averaged 9.2% for the final abundance estimate. The observed raw totals were 231 caribou groups, which included 1,123 caribou. Mean group size was 4.6 ±3.83 caribou, and median group size was 4 caribou.

Table 2. Summary of unprocessed results: Survey of Ameralik caribou population by helicopter in the South region, 08-12 March 2019.

Parameter	South region sub-area			Total
	Coastal Lowland	Glacial Mountains	Xeric Inland	
Flight altitude (m)	40	40	40	**40**
Flight speed (km/hr)	60-70	60-70	60-70	**60-70**
Sub-area size (km²)	499	1,171	3,006	**4,676**
Number of lines	4	3	18	**25**
Distance flown (km)	59.83	48.51	344.37	**452.71**
Strip width[1] (m)	1000-1500	1000-1500	1000-1500	**1000-1500**
Surveyed area ca. (km²)	120 - 179	97 - 145	689 - 1,033	**905 - 1,358**
Coverage[2]	24-36 %	8.3-12.4 %	23-34.4 %	**19.4-29.0 %**
Coverage post-truncation[3]	12.0 %	4.1 %	11.5 %	**9.7 %**
Total caribou observed	45	23	1055	**1123**
# Groups observed	5	7	219	**231**
Mean group size	9.0	3.29	4.82	**4.6**
Std Deviation group size	± 5.24	± 3.04	± 3.64	**± 3.83**
Median group size	8	2	4	**4**
Maximum group size	17	10	23	**23**
Minimum group size	1	1	1	**1**

[1] Strip width provided is to one side of helicopter only. Must double for total strip width.
[2] Coverage prior to truncation of strip width to 500 m.
[3] Coverage after truncation of the strip width to 500 m for DS analyses (see page 24).

Data processing

The raw data set was in Excel format containing the survey variables, including region, sub-area, respective areas (km²), transect identification, recorded distances, group size, and GPS coordinates. Sometimes included with caribou group observations were flight characteristics such as helicopter side and velocity, as well as survey characteristics such as solar glare, visibility, dead ground, snow covering and depth, and surface conditions providing camouflage backgrounds for the caribou. Data pertaining to habitat changes were removed because these concerned habitats exclusively i.e., there were no caribou observations associated. The remaining variables were properly restructured within R Statistical Software.

The data set was subject to some prior processing before analysis. Comment fields were deleted. Variable names were recoded to make them sensible in R. All caribou observations were complete, i.e., none were missing their distance or group size component. Thus, no replacements were necessary.

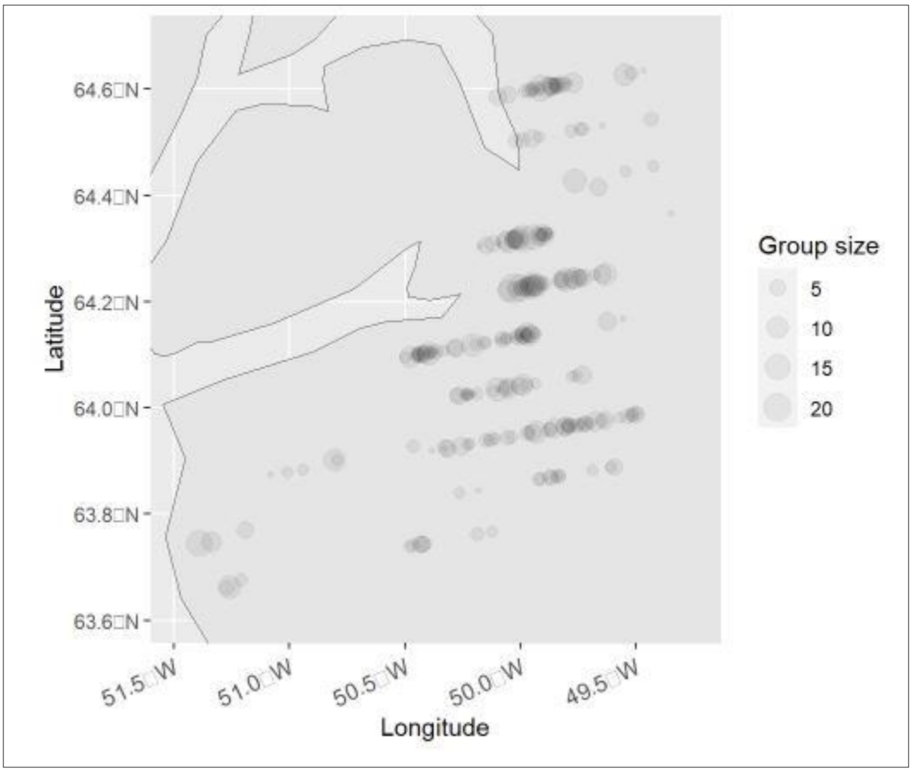

Figure 4. Location and group size of caribou detections (truncated data) observed along the line transects flown, 2019 survey of Ameralik caribou population.

Preliminary analysis distance sampling

For reliable estimates of abundance, Buckland et al. (2001) suggests that sample size is at least 60 to 80 observations and from a minimum of 10 to 20 replicate line transects. The 2019 caribou survey for the South region met these recommendations. For example, regarding observations (detections of groups of one or more caribou), the untruncated sample size was 231, while truncated was 228. Similarly, there were 25 parallel line transects separated by

10 or 20 km. Time required to complete a line transect depended on total length of line. The following are results for truncated data (n=228 detections).

Except for line 104, caribou were detected on every line transect in the 2019 survey. Of the three sub-areas, the Coastal Lowlands had the fewest detections, while the Xeric Inland sub-area dominated in observation frequency, i.e., number of detections (caribou groups) per sub-area (Fig. 4, 5). This dominance was expected because Xeric Inland was largest sub-area (ca. 3,006 km^2) and had the longest combined distance of line transects, relative to Coastal Lowland's and Glacial Mountains' smaller areas (ca. 499 and ca. 1,171 km^2, respectively) and shorter combined distance of line transects.

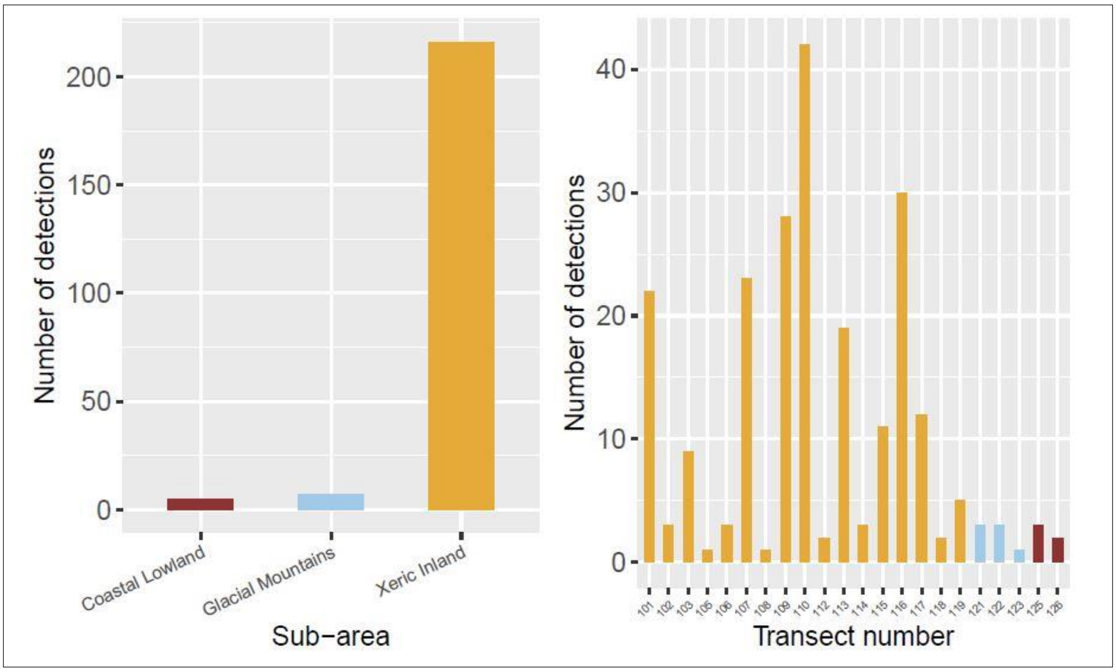

Figure 5. Exploratory analysis plots for the number of detections by sub-area (left), and number of detections per line transect by sub-area (right): Coastal Lowland (brown), Glacial Mountains (blue) and Xeric Inland (orange). Ameralik caribou population survey 2019.

The detected objects of interest, *i.e.*, caribou groups, typically included no more than six animals. The most observed group size was two animals (n = 49 observations) (Fig. 6). Groups consisting of less than five individuals made up 59% of the observations, while groups counting less than ten individuals made up 89%. Larger groups were scarce and typically observed at greater distances. For example, the largest caribou group size, observed once, had 23 caribou, and was detected at 0.4 km from the transect line. The helicopter's flight direction during the detections was not "even", with "West to East" direction being more than 3x more frequent than "East to West".

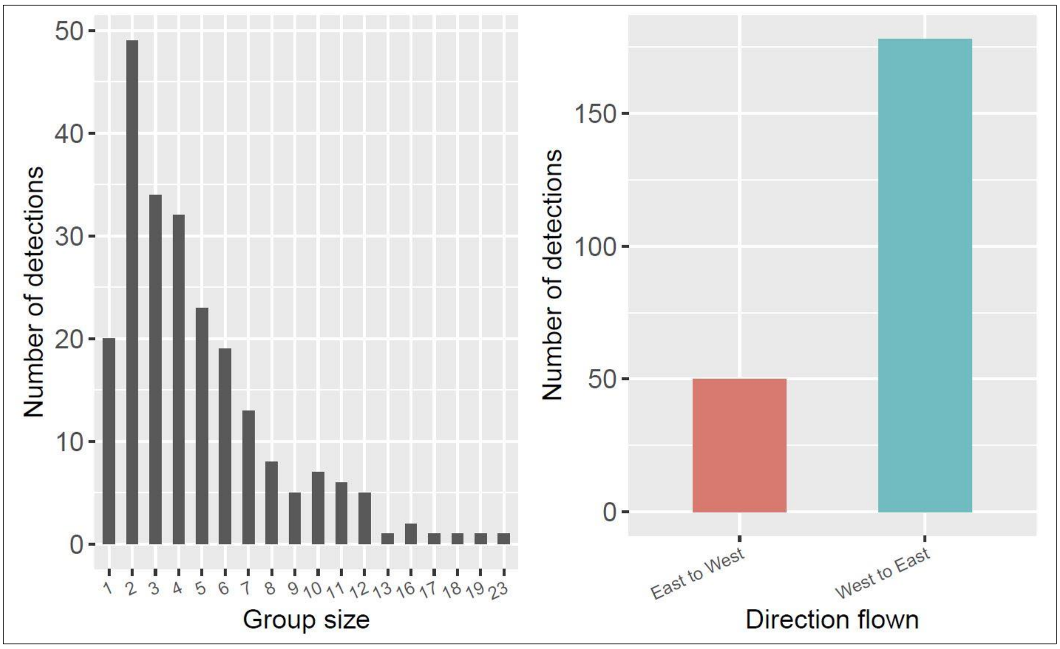

Figure 6. Exploratory analysis for caribou group size distribution among detections and for flight direction. Ameralik caribou population survey 2019.

The number of detections per unit transect length is the encounter rate. The Xeric Inland sub-area had the highest mean encounter rate at 0.58 caribou groups per km. Glacial Mountains and Coastal Lowland sub-areas had much lower means of 0.152 and 0.154, respectively (Fig. 7). The overall encounter rate was 0.486 caribou per km. Encounter rates, however, were highly variable for both Xeric Inland and Coastal Lowland sub-areas. This might lead to less precision in the final estimates.

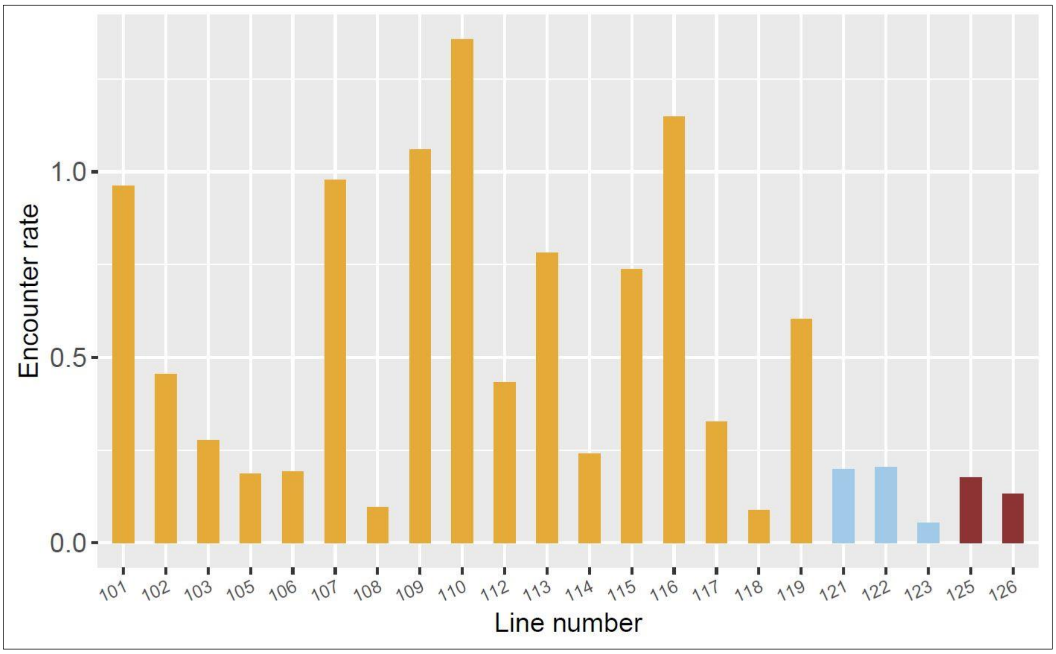

Figure 7. Exploratory analysis for caribou encounter rate (groups per km) per line transect and illustrating sub-area: Coastal Lowland (brown), Glacial Mountains (blue) and Xeric Inland (orange).

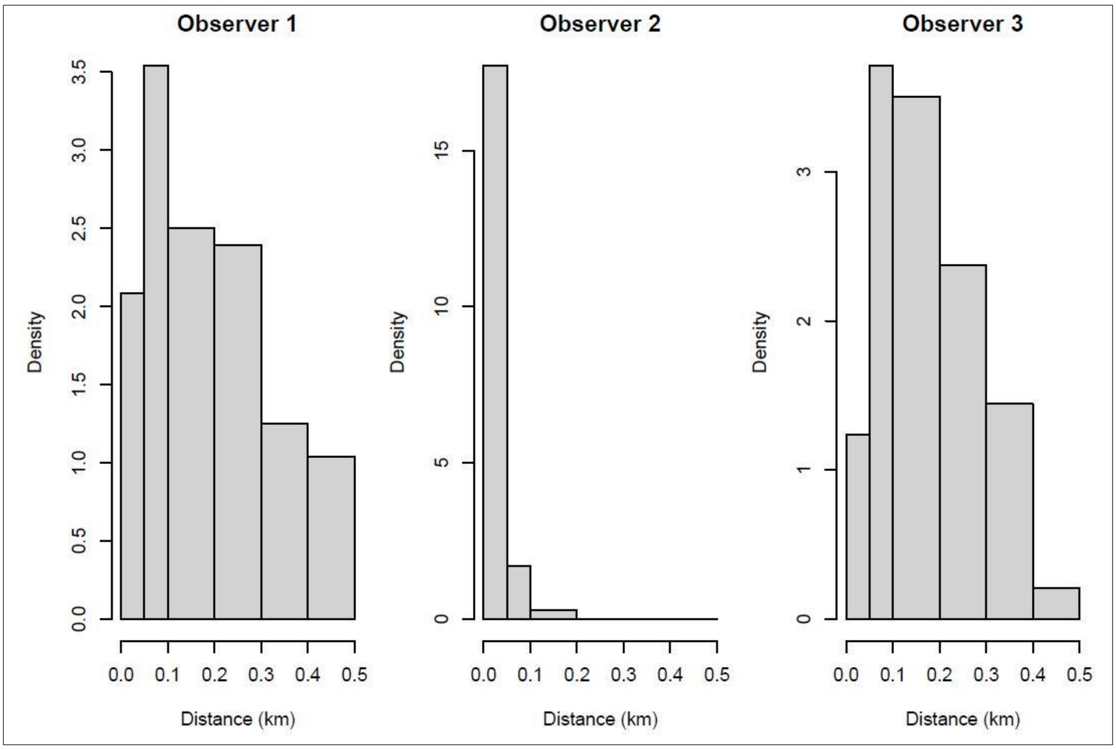

Figure 8. Observer effect: histograms illustrating detected distances for the three observers (a covariate with three levels). Density, y-axis, refers to the density of observations.

Histograms examining observer effects (Fig. 8) illustrate that Observers 1 and 3 had similar detection patterns and contributed little to explanations for detectability across distance. In contrast to Observers 1 and 3, Observer 2 focused attention on the center line and therefore had fewer detections, and these were concentrated on the center line.

As noted for all helicopter surveys since 2000, detecting well camouflaged caribou was again difficult owing to background conditions, which permitted some caribou to blend completely camouflaged into the terrain. Background conditions included incomplete or patchy snow cover, substrate (including grass, low vegetation, ground) poking or showing through thin snow layer, rocky terrain, and light/shadow conditions typical to latitudes of ca. 64°N in early March (Appendices 2, 6). Detecting caribou could be compromised by changing visibility (fog) the west-east orientation of the lines, which ensured that on the south-facing side of the helicopter in the absence of cloud cover, the sun reflected off the snow surface causing solar glare into the observer eyes. To compensate, the observers wore polarized sunglasses. Still, intense glare might reduce detectability of caribou. The flight altitude of 40 m reduced the amount of dead ground (land blocked from view by terrain features), which improved detectability. Sighting caribou could be made difficult as caribou groups often lacked movement despite helicopter fly-by.

Potential covariates covering the above (e.g., helicopter side, visibility, camouflage, vegetation/ground showing through snow surface, boulders showing through snow surface, solar glare reflected off snow surface, and dead ground) were available for most caribou detections and compared against number of caribou detections (Figs. 9, 10, 11).

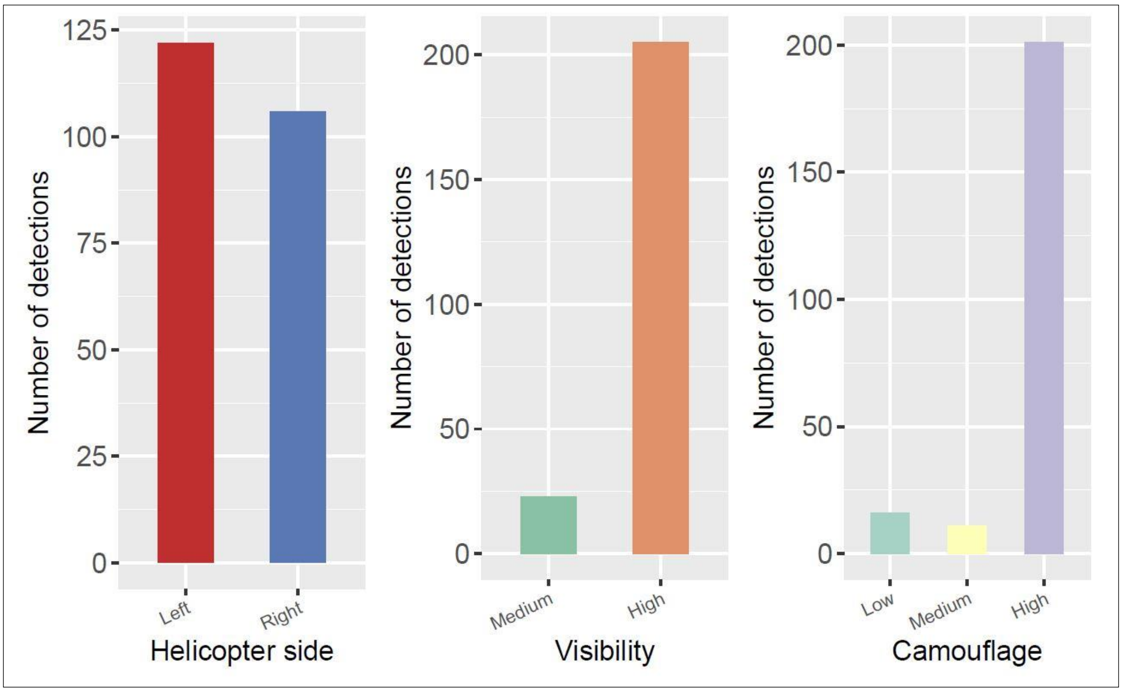

Figure. 9. Number of caribou detections per covariates: helicopter side, visibility, and camouflage (truncated data).

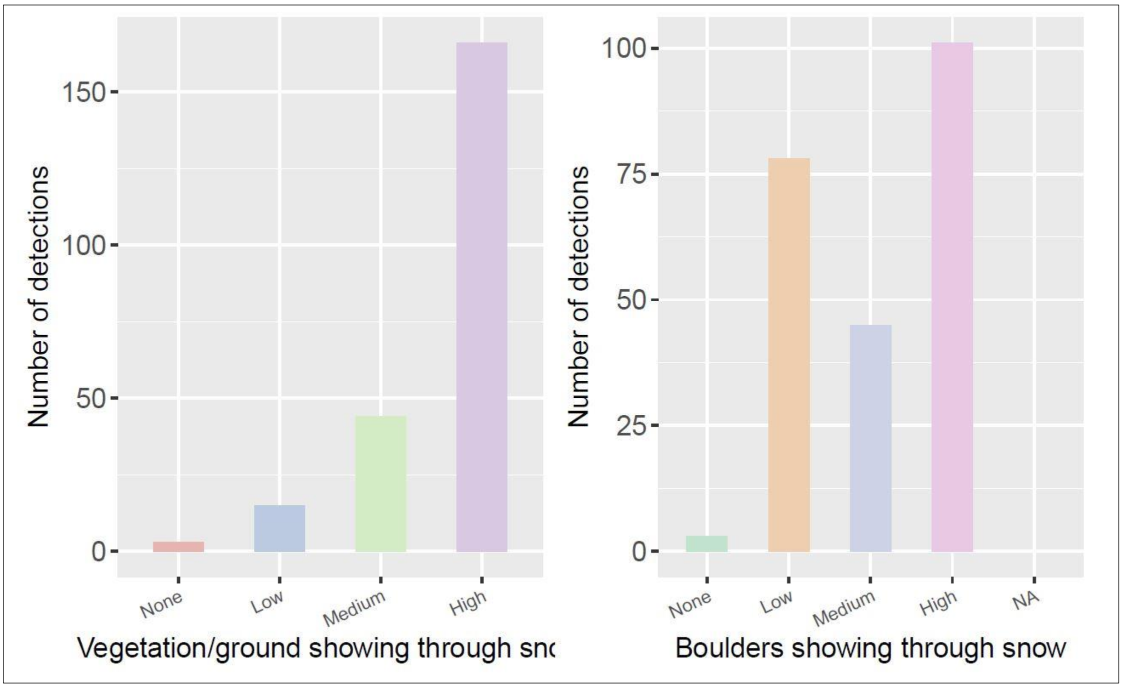

Figure. 10. Number of caribou detections per covariates: vegetation/ground or boulders showing through the snow surface (truncated data).

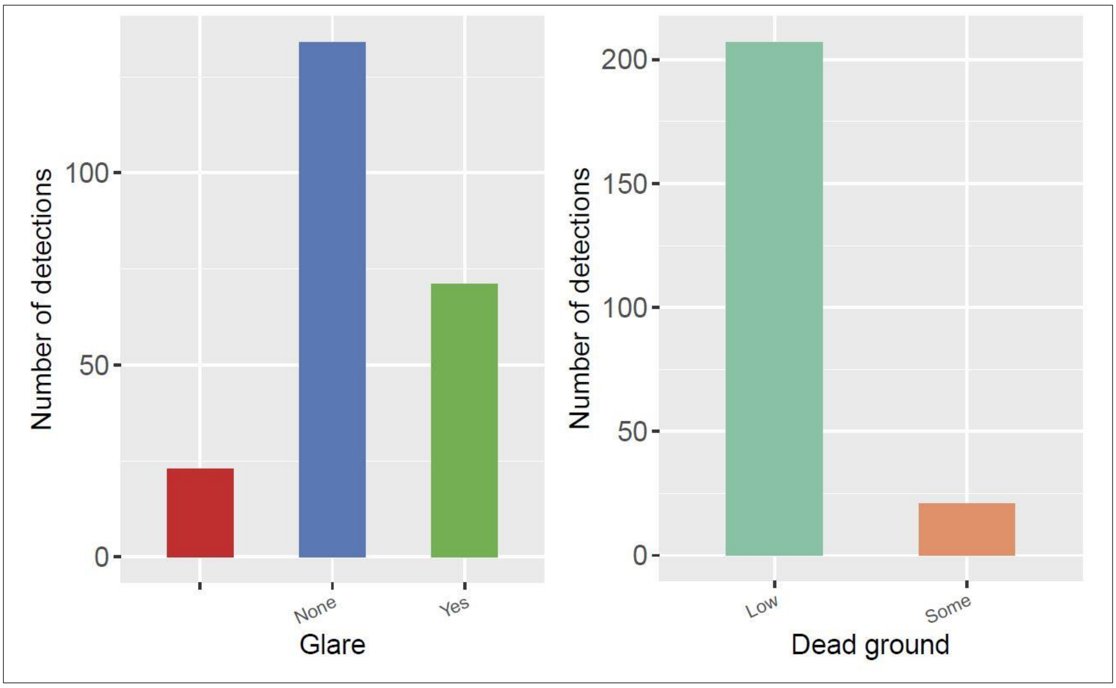

Figure. 11. Number of caribou detections per covariates: solar glare and dead ground (truncated data).

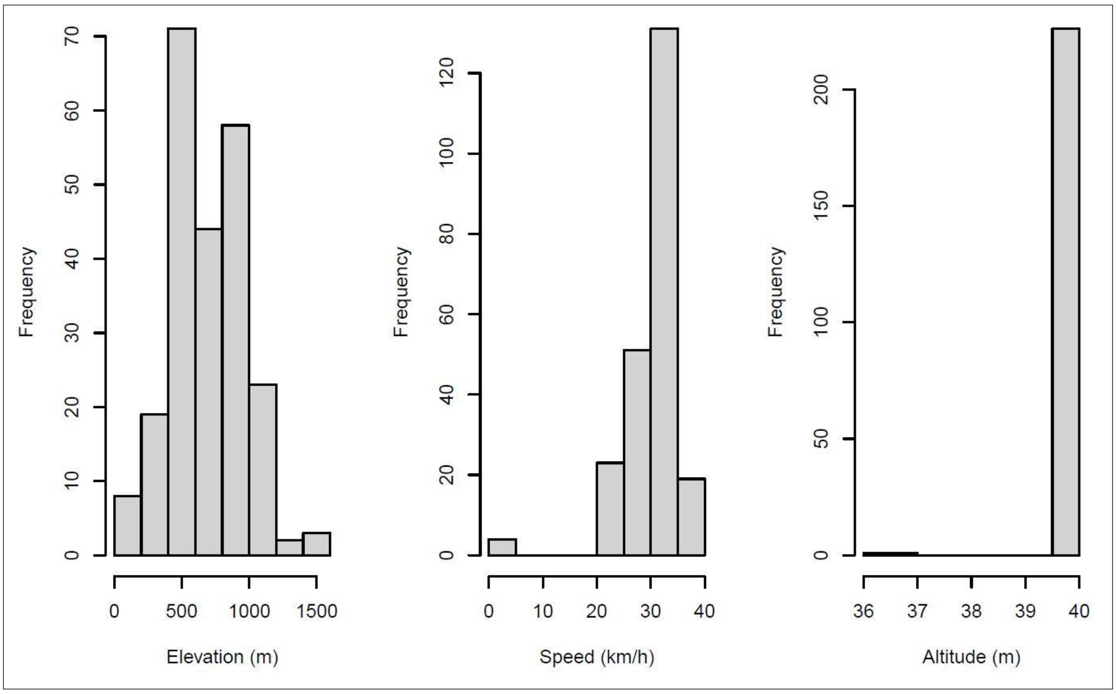

Figure. 12. Summary of the frequency of elevations flown as well as helicopter speed and altitude.

Elevations encountered while flying the line transects usually were between 500 and 1200 m. Helicopter flight speed was predominantly 40 knots, and a constant altitude of 40 m was maintained (Fig. 12).

Given the preliminary analysis we expect reasonable precision in further analyses of detections, because the information agreed well with anticipated a priori, e.g., Xeric Inland sub-area would have more caribou than the other two sub-areas.

Distance sampling analysis

Before conducting any modelling, an analysis of the observed distances was made to evaluate whether any major assumption violation occurred or other data-related issue, as stated in previous sections. The histogram of observed distances with no defined truncation distance was not typical of DS data, owing to the 0.5-0.6 km gap (Fig. 13). This likely occurred because observers tended to record some preferred values over others (Buckland et al. 2001). Given the histogram of binned distances, a strip half-width of w = 0.50 km was selected (i.e., all observations at distances beyond 500 meters were discarded). This truncation reduced the sample size from 231 to 228 caribou groups for the DS analysis. Data truncation is a common procedure because otherwise extra adjustment terms may be needed to fit the long tail of the detection function. For this study's analysis, little information is lost by truncation, since the few data observations (1.3% of caribou groups detected) located at > 0.50 km from each side of the line, make little contribution to the final abundance estimate.

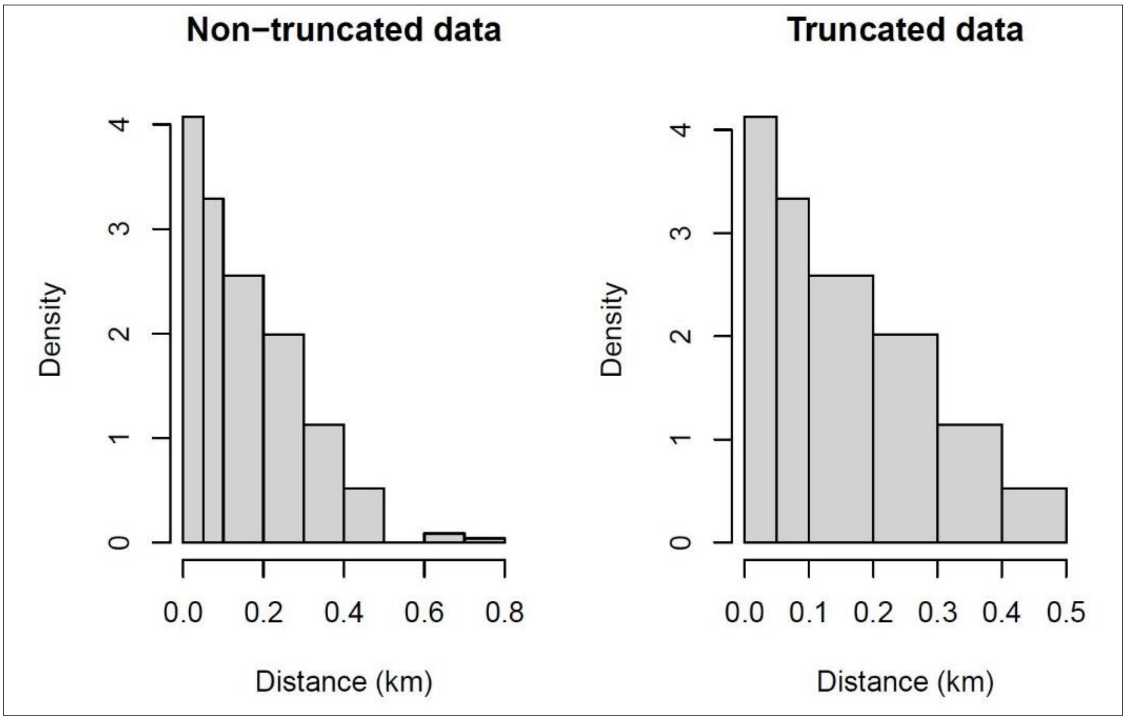

Figure 13. Histogram of observed caribou distances for non-truncated data (left), and truncated data (right). The area of the rectangles is proportional to the number of points within each bin.

Table 3. Model comparison across the three Conventional Distance Sampling models and models considering different covariates further explaining detection.

Key function	Formula (variable)	x^2 *p*-value	$\widehat{P}_a$	se ($\widehat{P}_a$)	AIC	ΔAIC
Hazard-rate	Observer	0.037	0.350	0.061	685.042	0.000
Hazard-rate	Group size + Observer	NA	0.354	0.058	685.178	0.136
Half-normal	Observer	0.061	0.326	0.030	689.524	4.482
Half-normal	Group size + Observer	0.018	0.326	0.030	691.036	5.994
Half-normal	Visibility	0.656	0.548	0.030	777.210	92.168
Half-normal	Helicopter side	0.648	0.550	0.031	777.700	92.658
Half-normal	1	0.788	0.554	0.031	778.664	93.622
Uniform with cosine adjustment term of order 1	NA	0.746	0.561	0.022	778.888	93.846
Half-normal	Camouflage	0.444	0.549	0.031	779.062	94.020
Half-normal	Solar glare	0.446	0.548	0.030	779.062	94.020
Hazard-rate	Boulders through snow	NA	0.582	0.043	779.360	94.318
Half-normal	Dead ground	0.638	0.553	0.031	779.881	94.839
Half-normal	Group size	0.634	0.554	0.031	780.582	95.540
Hazard-rate	Visibility	0.125	0.603	0.041	781.008	95.966
Uniform with simple polynomial adjustment terms of order 2,4	NA	0.521	0.574	0.035	781.171	96.129
Half-normal	Vegetation/Ground through snow	0.205	0.548	0.031	781.194	96.152
Hazard-rate with simple polynomial adjustment term of order 4	1	0.695	0.503	0.073	781.689	96.647
Hazard-rate with cosine adjustment term of order 2	1	0.556	0.357	0.136	782.076	97.034
Hazard-rate	Helicopter side	0.142	0.576	0.045	782.219	97.177
Hazard-rate with Hermite polynomial adjustment term of order 4	1	0.521	0.526	0.066	782.268	97.226
Hazard-rate	Solar glare	0.040	0.605	0.041	782.960	97.918
Hazard-rate	Camouflage	0.048	0.529	0.050	784.079	99.037
Hazard-rate	Group size	0.129	0.532	0.051	784.344	99.302
Hazard-rate	Dead ground	0.133	0.567	0.047	784.490	99.447
Hazard-rate	Vegetation/Ground through snow	NA	0.549	0.048	785.649	100.607
Uniform with Hermite polynomial adjustment terms of order 2,4	NA	0.0.043	0.664	0.051	786.815	101.773

Note: Formula = 1 for no covariates. NA is for Uniform Key. Under Chi-square *p*-value: NA = not enough degrees of freedom for GOF test, (Degrees of freedom calculated considering model parameters, these vary considering which key function used and how many/which explanatory variables considered.)

Detection function models were fitted to the truncated data, i.e., strip width w = 0. 50 km, to each side of the helicopter. For these models, every combination of key function and adjustment terms was tested (Appendix 7). Additional covariates assessed were Observer, Group size, Visibility, Helicopter side, Vegetation and Ground showing through the snow surface, Boulders showing through the snow surface, Camouflage, Dead ground, and Solar Glare. Group size, as covariate, did little to explain caribou detection. We did not convert Group size into a categorical variable (small, medium, large) because much information is lost to no advantage, and we can estimate a probability of detection for each group size when this covariate is included in model.

A summary of the information from each model fitted to the data (Table 3) provides a simple overview of the many models, and includes the respective key functions, adjustment terms, model formula, $\chi 2$ Goodness-of-Fit test p-value, estimates of the detection probability, respective standard error (se ($\hat{P}$a)), AIC, and ΔAIC comparison between each model and the model with the lowest AIC. The best model fitted to the data possesses the lowest change in AIC value (ΔAIC = 0).

For the 2019 survey data from Ameralik caribou population, this model has the hazard rate function as key function, no adjustment terms added and only Observer as covariate (AIC = 685.042). However, the models with Observer as covariate had very poor fits to the actual data (Appendix 7) and poor, or non-applicable, p-values. Although those were the models with lowest AIC's, the plots revealed that the estimated detection functions were nonsense. The next truncated model with the lowest AIC was the Half-normal with Visibility as covariate. The large p-value for $\chi 2$ Goodness of Fit Test (null hypothesis is "the model fits well to the data"), means this model fitted the data well (details page 76 this report).

Thus, we chose the model 'Half-normal with Visibility as covariate' (Fig. 14), which had an estimated probability of detection for the South region of $\hat{P}$a = 0.548 (se = 0.030, cv = 0.055). It is an averaged estimate since Visibility is included in the model. Consequently, each Visibility level has its separate detection function, corresponding to different estimates for the probability of detection (Fig. 15). When visibility was high, probability of detection was greater than when visibility was medium. Further, large group sizes, e.g., groups ≥ 12 caribou, were only detected when visibility was high.

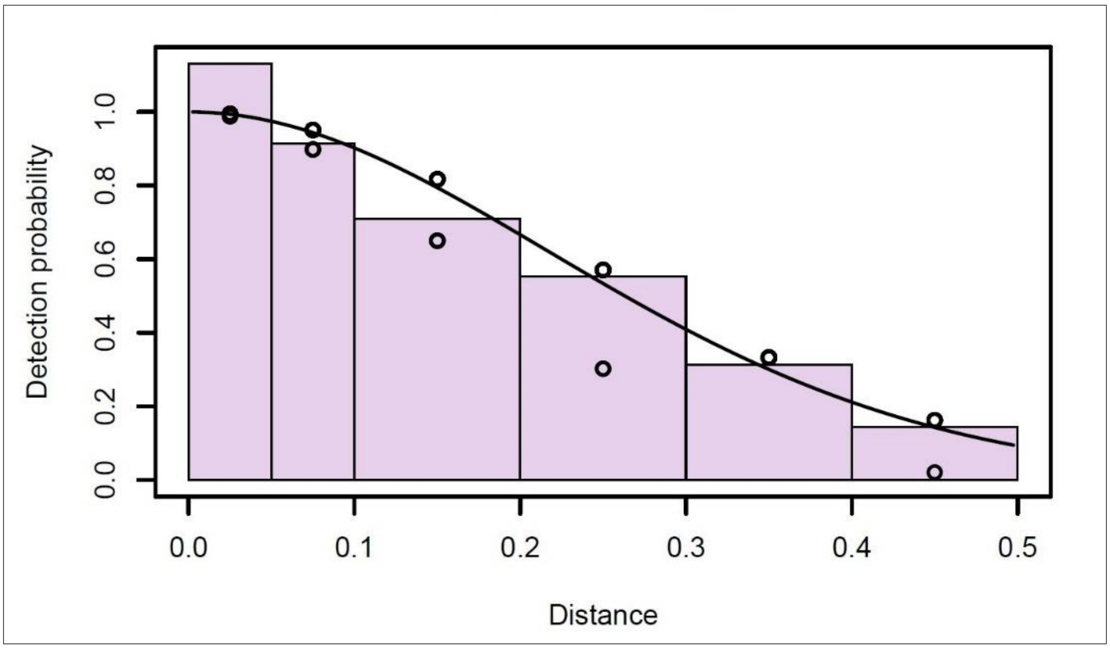

Figure 14. Histogram for Half-normal with Visibility as covariate of detected distances with the estimated detection function overlaid.

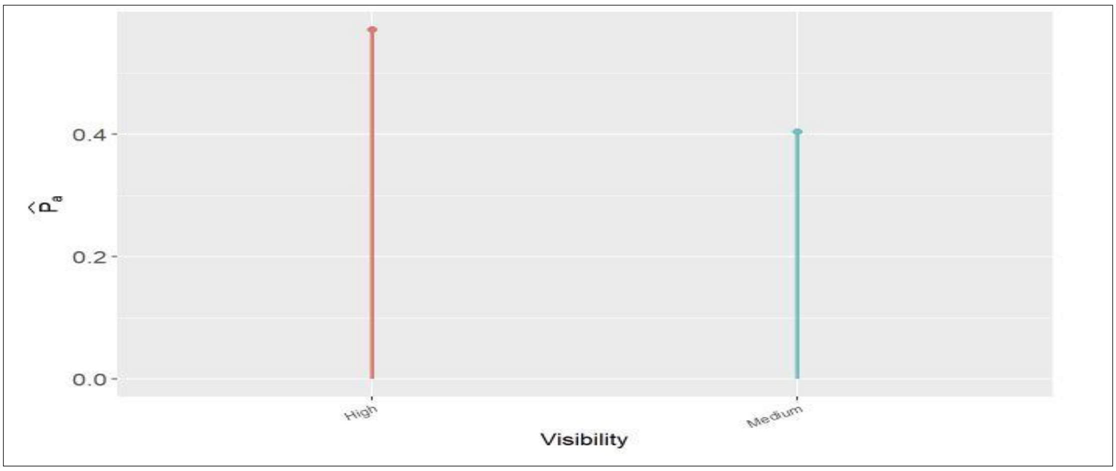

Figure 15. Estimated probabilities of detection as per Visibility (obtained with the fitted model, truncated data).

The estimates for encounter rates indicate that the Xeric Inland sub-area had the most caribou, since its estimate was larger than the other sub-areas (Table 4). Concerning the design-based estimates for caribou abundance and density, Xeric Inland is also the sub-area presenting more caribou (Tables 5, 6, Fig. 16).

In March 2019, the Ameralik portion of the South region had an estimated population size of 19,503 caribou (95% CI: 12,404 – 30,665). Sum of abundance estimates for each sub-area equals total estimated abundance for the region. CV of 0.219 (Table 5, Fig. 16) indicates good accuracy for Ameralik abundance estimate. Design-based density estimate for whole survey region was 4.17 caribou/km^2, with 95% CI: 2.653 – 6.558 (Table 6, Fig. 16).

Table 4. Encounter rate (ER) estimates per sub-area (stratum) for caribou groups of the Ameralik population, considering three strata, six bins, and a detection function fitted with Visibility as covariate.

Sub-area	Encounter rate	Standard Error (se)	Coefficient of Variation (cv)
Coastal Lowland	0.155	0.021	0.138
Glacial Mountains	0.144	0.052	0.362
Xeric Inland	0.666	0.121	0.182
TOTAL	**0.481**	**0.079**	**0.164**

Table 5. Estimates of abundance per sub-area (stratum) for the Ameralik caribou population in the South region, March 2019, considering three strata, six bins and a Half normal detection function with Visibility as a covariate.

Sub-area	Abundance Estimate	Standard Error (se)	Coefficient of Variation (cv)	95% Confidence Interval	
				Lower	Upper
Coastal Lowland	1221	340	0.278	74	21,127
Glacial Mountains	972	528	0.544	114	8,250
Xeric Inland	17,310	4192	0.242	10,479	28,595
TOTAL	**19,503**	**4268**	**0.219**	**12,404**	**30,665**

Table 6. Estimates of density per sub-area (stratum) for the Ameralik caribou population in the South region, March 2019, considering three strata, six bins and a Half normal detection function with Visibility as a covariate.

Sub-area	Density Estimate	Standard Error (se)	Coefficient of Variation (cv)	95% Confidence Interval	
				Lower	Upper
Coastal Lowland	2.447	0.680	0.278	0.148	40.335
Glacial Mountains	0.830	0.451	0.544	0.098	7.045
Xeric Inland	5.758	1.394	0.242	3.486	9.513
TOTAL	**4.171**	**0.913**	**0.219**	**2.653**	**6.558**

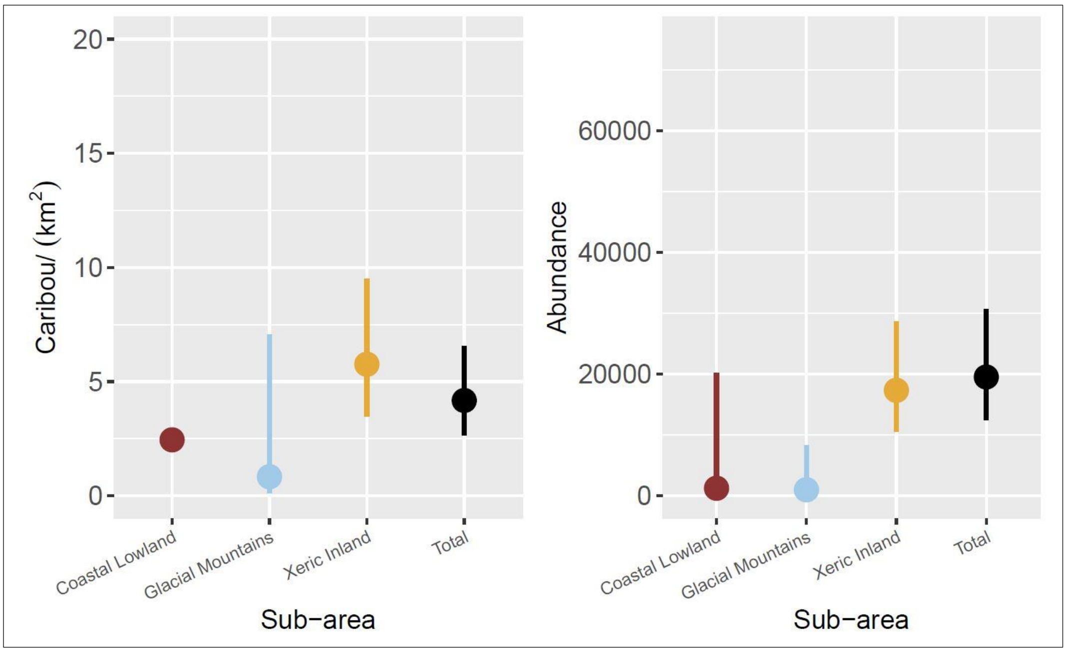

Figure 16. Estimates for caribou density (left) and abundance (right), with corresponding confidence intervals for three sub-areas, Coastal Lowlands, Glacial Mountains, and Xeric Inland, and finally for the South region (northern portion).

Caribou flight reaction or lack thereof

Like the North region survey of 2018 (Cuyler et al. 2021), the Ameralik caribou population survey of 2019 used digital audio recorders to collect observation data. The digital recorders permitted including in the dataset what, if any, was the behavioral reaction of the caribou group to the helicopter flying a line transect past or over them. Behavior could then be put in relation to group size and distance from the line transect.

Table 7. Movement or non-movement of caribou reacting to helicopter fly-by, March 2019. Dataset that included group size, distance from the line transect, and behavior was n=214.

Parameter	Ameralik caribou population		
	Movement	**Non-Movement**	***p* – value**
Number of groups	178	36	
% Group Observations	83.2%	16.8%	
GROUP SIZE			
Mean group size	5.02	4.31	0.341
Confidence Level (95%)	0.5462	1.4167	
Standard Error	0.2768	0.6979	
Median	4	3	
Mode	2	2	
Standard deviation	3.6929	4.1871	
Sample Variance	13.6379	17.5325	
Maximum	20	23	
Minimum	1	1	
Number of caribou involved	894	155	
DISTANCE [1]			
Mean distance	193.26 m	320.83 m	< 0.0001
Confidence Level (95%)	20.2487	47.3994	
Standard Error	10.2605	23.3482	
Median	200	300	
Mode	50	200	
Standard deviation	136.8927	140.0893	
Sample Variance	18739.6051	19625.0000	
Maximum	800	700	
Minimum	50	50	

[1] Distance from the line transect flown by helicopter.

There was no significant difference between the size of caribou groups that exhibited movement and those that did not, mean 5.0 for moving and 4.3 for non-moving (t Stat = -0.963; two-tailed testing P = 0.341, t = 2.012, df = 47). Non-moving caribou groups were ca. 128 m further away from the line transect flown by the helicopter than those caribou groups showing movement (Table 7). There was a significant difference between the mean distance for groups with movement, 193.26 m, relative to the groups lacking movement, 320.83 m (t Stat = 5.002; two-tailed testing $P < 0.0001$, t = 2.010, df = 49).

Caribou groups reacting to the helicopter fly-by with movement made up 83.2% of all observations for which behavior was reported. Conversely, 16.8% of those groups exhibited little or no movement. The results were similar when considering the absolute number of caribou involved (Table 7). Of 1050 individual caribou for which behavior was reported, 85.2% exhibited movement while 14.8% of lacked movement.

Table 8. Details for movement or non-movement of caribou reacting to helicopter fly-by, March 2019. Dataset of observations that included caribou group size, behavior, and distance from line transect, was n= 214 groups, which contained n = 1,050 individual caribou.

Ameralik caribou population				
Category	**Groups (n = 214)**	**%**	**Individuals (n = 1,050)**	**%**
Exhibiting Movement				
Running away	137	64.0	700	66.7
Running away high speed	14	6.5	65	6.2
Walking	11	5.1	50	4.8
Approach*	3	1.4	32	3.0
Confused, circling tightly	6	2.8	18	1.7
Running parallel to line transect	0	0,0	0	0.0
Running, later standing looking	3	1.4	17	1.6
Trotting away	3	1.4	10	1.0
Mixed: some moved, others did not [1]	1	0.5	3	0.3
TOTAL	**178**	**83.2**	**895**	**85.2**
Lacking Movement				
Standing still	35	16.4	153	14.6
Standing, later walking	0	0.0	0	0.0
Lying down	0	0.0	0	0.0
Lying down, later stood up	1	0.5	2	0.2
Some lying, others standing still	0	0.0	0	0.0
Lying down, later walking	0	0.0	0	0.0
TOTAL	**36**	**16.8**	**155**	**14.8**

*Approach movement (walking, trotting, running) was towards the helicopter while looking at helicopter.
[1]Mixed = different behavior by members within same group, e.g., some running towards others, which stood still and looked at the helicopter.

Among the 157 'running' groups (Table 8), 151 of those groups exhibited unabated flight, i.e., they never stopped while within view of the helicopter. Group composition (sex, age) was determined for 101 of those groups, of which 88 groups (87.1%) were composed of cows with calves. There were 10 adults only groups (9.9%) and three groups with only juveniles (3%).

Considering only the 47 caribou groups whose original position was on or within 50 m of the track line, 42 of those groups (91.3%) never stopped running away, three groups were confused circling tightly about (6.5%), and one group walked (2.2%). Meanwhile, 1 group lacked movement. This was an individual cow on the track line at 930 m elevation. The cow, which possessed both antlers, stood perfectly still facing the approaching helicopter in what appeared to be a defensive posture, even as we flew over her.

Demographics & recruitment

Sex, age, and late-winter calf recruitment data were collected in separate specific effort that was not part of the line transect DS dataset. On 14 March 2019, using just over 6 hours flight time, we sexed and aged 122 groups of caribou, for a total of 838 animals, in the Ameralik caribou population (Table 9). Cows were almost 58% of the population, bulls (age > 1-year) ca. 13% and calves ca. 30%.

Table 9. Demographics for Ameralik caribou population, South region, March 2019.

Parameter	Ameralik caribou population			
Number of groups observed	122			
GROUP SIZE				
Mean	6.87			
Confidence Interval (95%)	0.8735			
Standard Error	0.4412			
Standard Deviation	4.8735			
Sample Variance	23.7512			
Median	5			
Mode	3			
Maximum	25			
Minimum	1			
DEMOGRAPHIC	**Original data**		**Removed 19 orphan calves**	
Total individuals sexed & aged (*n*)	838	100 %	819	100 %
Cow (age > 1 year)	483	57.6 %	483	59.0 %
Calves from previous spring	248	29.6 %	229	28.0 %
	(140 females)	16.71 %	-	-
	(106 males)	12.65 %	-	-
	(2 unknown sex)	0.24 %	-	-
Bull (age > 1 year)	107	12.8 %	107	13.1 %
	(30 adults, age > 3)	3.6 %	(30 adults, age > 3)	3.7 %
	(77 juveniles, 1< age < 3)	9.2 %	(77 juveniles, 1< age < 3)	9.4 %
Recruitment (calves / 100 cows)	51.3		47.4	
Sex ratio (Bull age >3 year / Cow)	0.06		0.06	
Sex ratio (Bull age >1 year / Cow)	0.22		0.22	

Calf lacking their dam

During demographics data collection a total of 248 calves were observed (Table 9), of which two were 'true' orphan calves (0.8%), as they were in a single calf-only group (Table 10) with no cows nearby. The remaining 246 calves (99.2%) were in groups (n=96) that contained cows. However, for 11 of those groups, calf number exceeded the number of cows. In the extreme, one group contained a single cow accompanied by six calves. The five 'extra' calves present the possibility of five orphan calves. Those 11 groups contained a total of 65 caribou, whose composition was 18 cows, 37 calves, and 10 bulls (juveniles and/or adults occurred in four of the 10 groups). Among these, twice we observed possible twin calves following one dam/cow, as both calves were inseparable from the cow, i.e., both clung tightly to the cow's heels. In the nine other groups that contained more cows than calves. The 'extra' calf (or calves) was some distance from any cow and her 'clinging' calf. This separation was also evident during group flight away from the helicopter. The occurrence of twins aside, within those nine groups there were a possible 17 orphan calves. Adding the two calves in the calf-only group (above), brings the total to 19 orphan calves. Orphan calves (n=19) were 7.7% of all calves observed (n=248). No orphan calves were observed in bull-only groups.

If we assume the 19 orphan calves unlikely to survive their first winter, owing to higher mortality than calves with dams, and therefore remove these from the dataset, then the demographic becomes the following: cows 59%, bulls 13% and calves 28%, with a reduced calf recruitment of 47.4 calves per 100 cows (Table 9).

Group composition & group size

The sex and age composition of caribou groups seems to influence group size. Groups composed of a mix of cows, calves, and bulls (juvenile or adult) were the largest groups observed, mean 10.31 caribou (Table 10). This mix also had the maximum group size of 25 caribou. Groups composed of just cows and calves had the next highest mean, 6 caribou and a maximum group size of 20 caribou. There were only two groups containing just adult bulls (age > 3-years) each with three bulls. There were no groups containing just juvenile bulls. Juvenile bulls were always observed with older animals, which always included cows. Thus, there were no groups composed of a mix of juvenile and adult bulls. There were also no groups of bulls with calves. There was only one calf (age < 1-year) group of two calves, both males.

Out of the total 122 groups sexed, and aged, cow-calf pairs occurred in 95 of those groups, which involved 751 caribou (Table 10). Usually there were one or two cow-calf pairs within a group (Fig. 17), with the mean number of cow-calf pairs per group at 2.38 ±1.74 standard deviation. A few groups were notable for the large number of cow-calf pairs. One group of 19 caribou was composed of nine cow-calf pairs and one juvenile bull. A further three groups included seven cow-calf pairs, in addition to the other animals.

Table 10. Group size relative to group composition, Ameralik caribou population, South region, March 2019.

Parameter	Ameralik caribou population, group composition								
	Adult Bull	Juvenile Bull	Mixed Bull[1]	Bull[1] & Calf	Bull[1] & Cow	Bull[1], Cow & Calf	Cow	Cow & Calf	Calf
Number of caribou	6	0	0	0	38	433	41	318	2
Number of groups	2	0	0	0	8	42	16	53	1
GROUP SIZE									
Mean	3.00	-	-	-	4.75	10.31	2.56	6.00	-
CI (95%)	-	-	-	-	2.18	1.68	0.61	1.00	-
Standard Error	-	-	-	-	0.92	0.83	0.29	0.50	-
Standard Deviation	-	-	-	-	2.60	5.39	1.15	3.65	-
Sample Variance	-	-	-	-	6.78	29.05	1.33	13.31	-
Median	3	-	-	-	3.5	9.5	2.5	5	2
Mode	3	-	-	-	3	4	3	7	2
Maximum	3	-	-	-	9	25	5	20	2
Minimum	3	-	-	-	2	4	1	2	2

[1] Includes both juveniles (1-year < age < 3-year) and adults (age > 3 years).

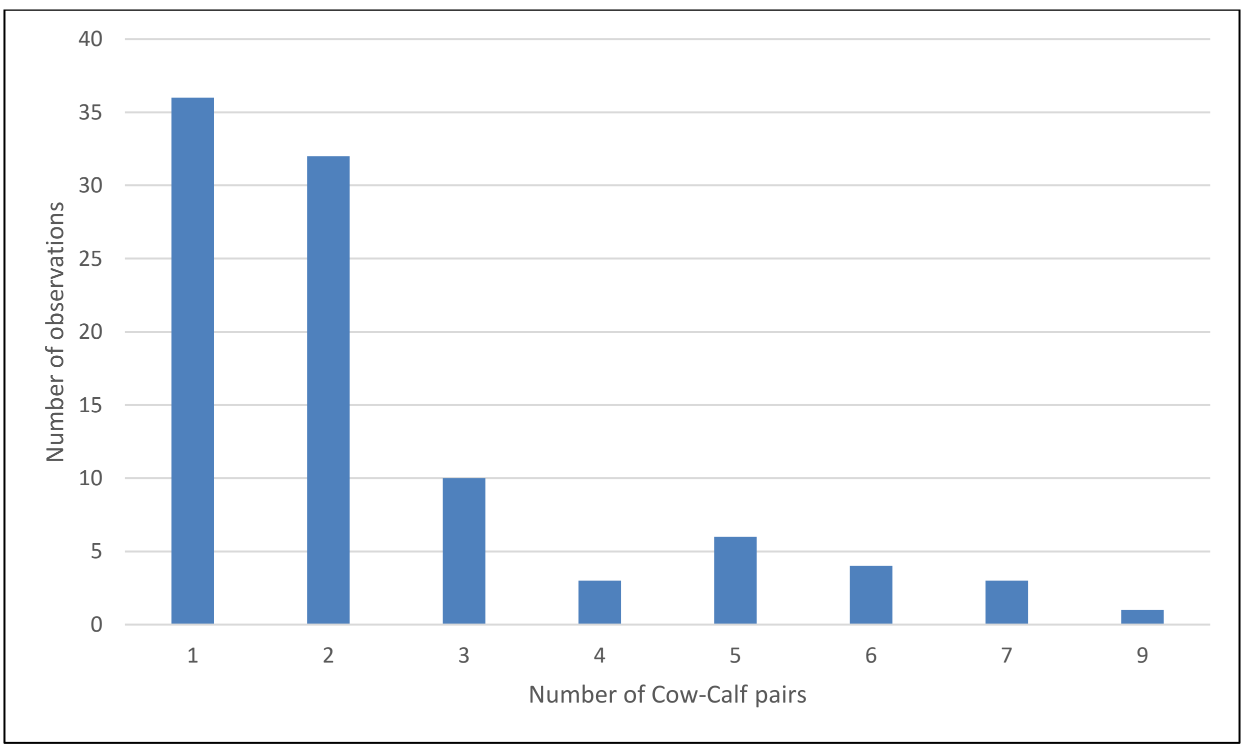

Figure 17. Observed frequency of cow-calf pairs for 95 groups for which demographics information was available.

Late-winter antler possession

The demographics dataset for the 838 sexed and aged caribou (Table 10) included antler possession for most observations. Adult (age > 3-years) bulls lacked antlers and were ca. 28% of all males observed for age > 1-year. Juvenile (age 1½-2½-years) bulls made up 72%. In contrast to adult bulls, 96.1% of juveniles possessed antlers from the previous autumn, two antlers 93.5%: one antler 2.6%), while 3,9% had no visible antlers. Meanwhile, adult cows possessing one or both antlers made up 91.9% of all females (two antlers 79.7%: one antler 12.2%). Polled (no antlers) cows were 8.1%. Antler possession was not recorded for three calves, one female and two males. Regarding female calves (n=139), 66.2% possessed one or both antlers (two antlers 42.4%: one antler 23.7%), while 33.8% of female calves were polled. Regarding male calves (n=104), 87.5% possessed antlers (two antlers 67.3%: one antler 20.2%), while 12.5% were polled.

Table 11. Approximate elevations for caribou groups observed: DS survey of the Ameralik caribou population by helicopter in the northern portion of South region, 08-12 March 2019.

Parameter	South region sub-area			Total South region
	Coastal Lowland	Glacial Mountains	Xeric Inland	
Sample size	5	7	219	**231**
ELEVATION				
Mean (m)	138	716	656	**647**
Standard Error (SE)	86.04	131.65	17.65	**17.93**
Median	80	620	646	**633**
Mode	N/A	N/A	898	**898**
Standard Deviation	± 192.4	± 348.3	± 261.1	**± 272.6**
Variance	37017.48	121324.67	68193.04	**74299.49**
Range	465	851	1455	**1459**
Minimum	12	300	16	**12**
Maximum	477	1151	1471	**1471**
Confidence Level (95%)	238.89	322.14	34.78	**35.34**

Elevations where caribou detected

All elevation results for observed caribou indicate only approximate values (Table 11). There were several sources of error on elevation values. The Greenland topography is mountainous and elevation changes can be abrupt, which could place the helicopter at a radically different elevation than the caribou observed. Matching the timestamps could create errors on caribou elevation when the digital recording was made before or after the helicopter passed the caribou location. Even caribou on the track line flown did not necessarily receive correct GPS positions. Owing to flight behavior, these caribou were often digitally recorded while still ahead of the helicopter's position. Additionally, caribou not on the track line flown could be in terrain at a higher or lower elevation than the helicopter. From the author's experience, most caribou observed would have been at elevations below that recorded for the helicopter, even after subtracting the flight altitude of 40 m. Further error arose from the GPS device itself. At the start of each survey day, the GPS device was manually synchronized to the Nuuk airport elevation, but commonly by the end of the day the GPS devise's value for Nuuk airport had changed somewhat. Meanwhile, of the 231 caribou groups detected, only 28 groups (12%) were observed at elevations over 1000 m. Most of these groups (n = 26) were in the Xeric Inland sub-area, and the remainder in the Glacial Mountains sub-area.

Estimated natural mortality

Using an assumed approximate natural adult mortality of 8-10% for caribou populations in West Greenland (Kingsley & Cuyler 2002) and the 2019 estimated population size (19,503), the calculated natural mortality for the Ameralik caribou population would be between ca. 1,560 and 1,950 caribou annually. The assumed approximate 8-10% natural mortality rate excludes catastrophic stochastic events (e.g., pathogen outbreak and extreme weather) as well as hunter harvest.

Miscellaneous observations

Other species observed included only ptarmigan (n=164), hare (n=44), sheep (n=12), arctic fox (n=4), and ringed seal (*Pusa hispida*, n=1). Although presence has been sporadically reported in the past, muskoxen were not observed during the early March 2019 survey of the South region (northern portion) in West Greenland.

We observed three lakes in the South region that appeared to have emptied (Appendix 8). Two were large lakes, one bordering the south side of the Narsap Sermia (glacial tongue) and the other bordering another tongue of the Greenland Ice Cap. Both seemed to have lost an enormous volume of water and likely prior to freeze-up winter 2018/2019. The first appeared to have emptied all-at-once. In contrast, the second and larger lake, had emptied by stages, i.e., in at least five events. The third 'lake' was the Austmanntjern, which likely had emptied recently. It was once pond-sized, was lake-sized in 2014, and in March 2019 was pond-sized again. (Appendix 8 includes a fourth such lake (tiny) located in the Central region).

Discussion

Ameralik population size & density

Currently, caribou populations elsewhere around the Arctic are typically declining, sometimes abruptly (Aronsson et al. 2021). Proposed causes are diverse, among them climate change, catastrophic weather events, pathogen outbreaks, and overharvest. The 2019 results for the Ameralik caribou population of West Greenland illustrating recent growth diverge sharply from the global situation (Figs. 18, 19).

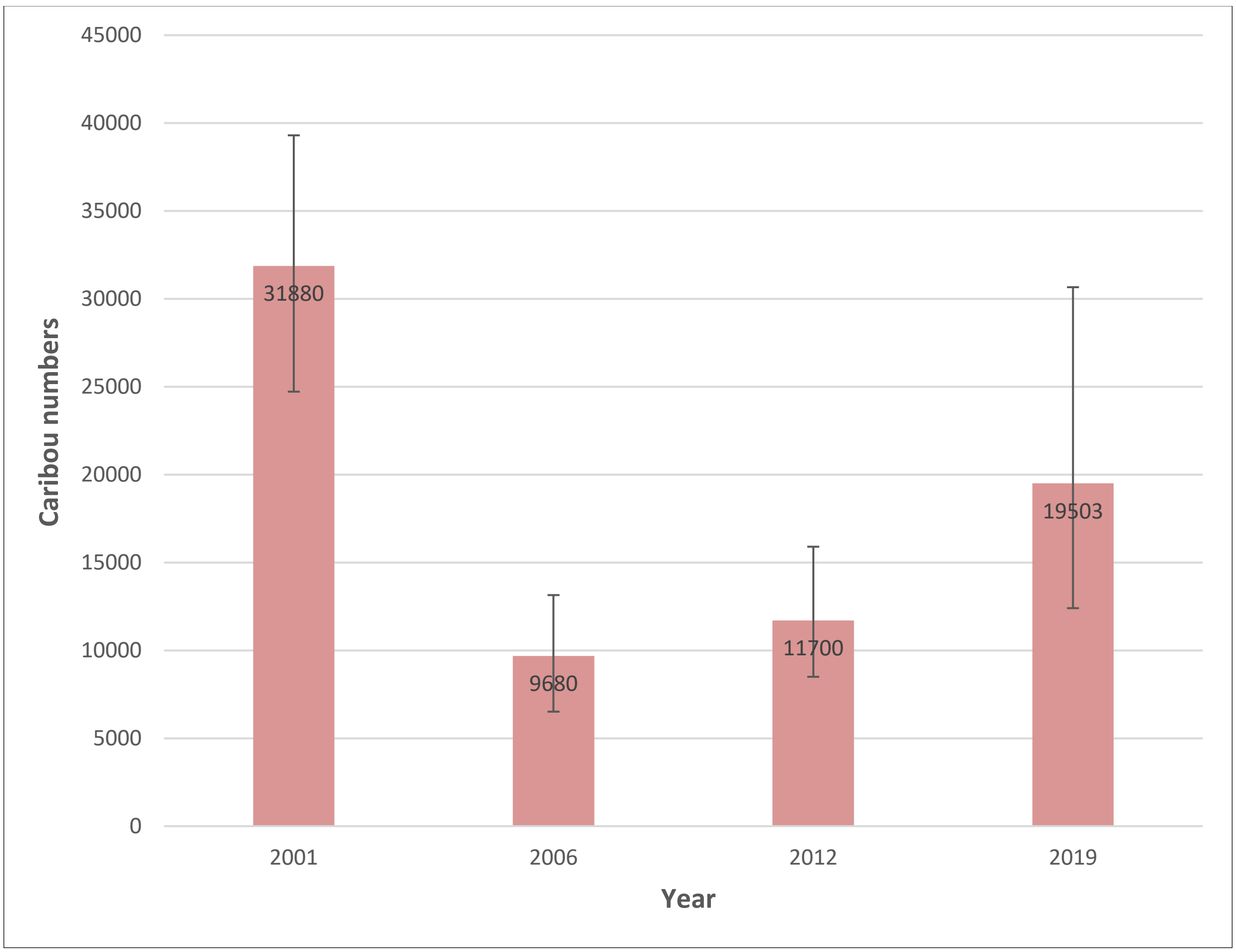

Figure 18. Past and present caribou population size estimates with confidence intervals for the Ameralik population. Confidence Interval varied being 80% in 2001, changing to 90% for 2006 and 2012, and finally was 95% for 2019.

In 2019, the Ameralik population size was large (Fig. 18), while density was the highest estimated since 2001 (Fig.19). This population has increased substantially since the last census of 2012 and likely steadily since 2006. The Ameralik population is located near the greatest concentration of commercial and recreational hunters in Greenland, i.e., Greenland's Capital city, Nuuk. Since 2006 caribou population growth occurred despite among other things unlimited harvesting, long hunting seasons, rising hunter numbers and ability to access the caribou (Cuyler et al. 2016). Albeit harvest magnitude is unknown, whatever its level, it has been insufficient to prevent the Ameralik population growth observed by 2019 aerial survey. This suggests hunter harvest is not a major factor regulating population size of the Ameralik population of caribou in West Greenland.

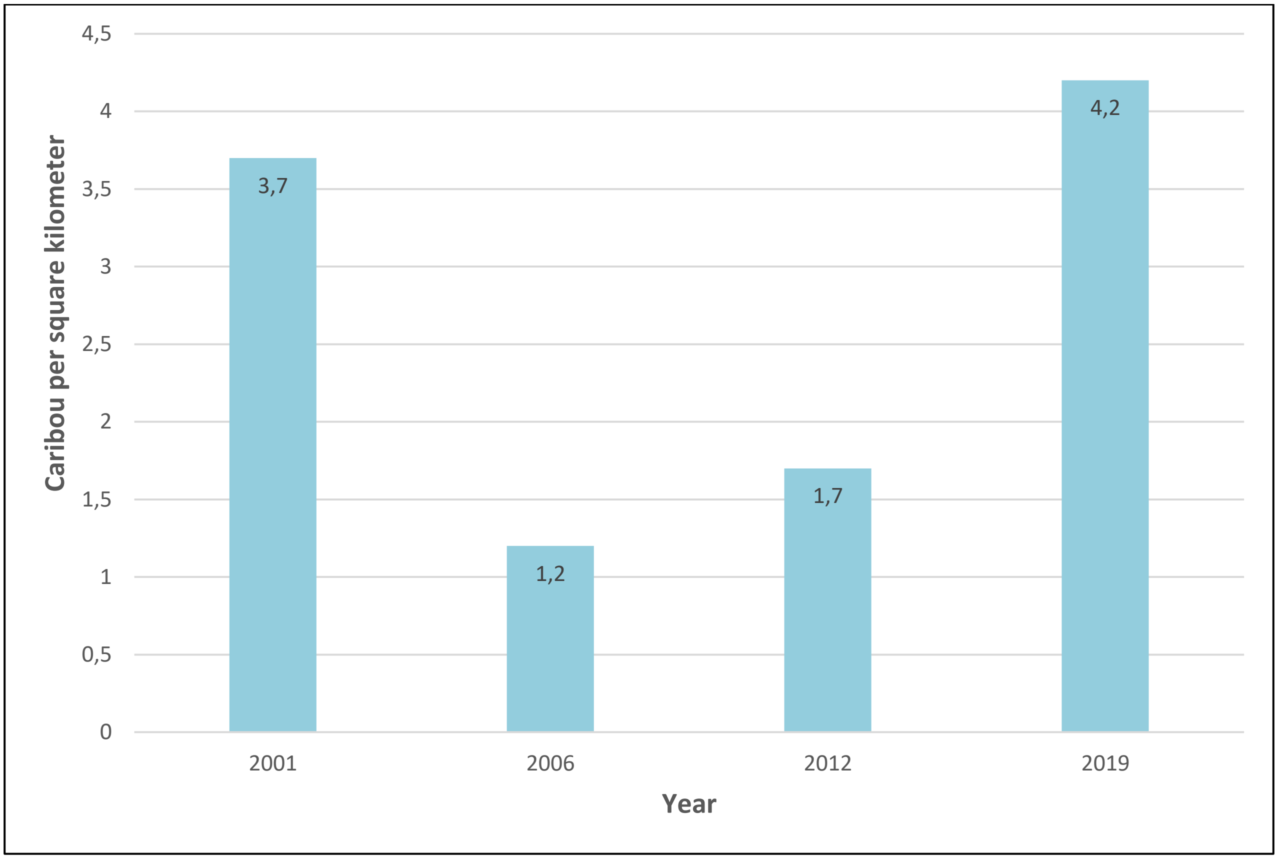

Figure 19. Past and present caribou density estimates for the Ameralik population, West Greenland.

The following support a conclusion that the Ameralik population size increased by 67% from 2012 to 2019. The 2019 Ameralik caribou population size and density estimates are of good accuracy since the Coefficient of Variation (CV) value was 0.22. Values of 0.20 are reasonable in Distance Sampling (DS) surveys for estimating abundance and density of wildlife populations (Pollock et al. 1990). Although the 95% CI is large for both population size and density in 2019, this can be explained by the uncertainty and variability caused by too few caribou detections in two of the three sub-areas surveyed. Regardless, there is little overlap in the Confidence Intervals for the 2012 and 2019 population estimates. Finally, the 2012 and 2019 surveys were similar in coverage and method. The jump in population size was surprising, since local knowledge, authors included, did not anticipate it. Perhaps the more than a decade of almost unlimited hunting, exerted selective harvest pressure on the unwary individuals in the population, resulting in fewer seen as remaining caribou appear to generally avoid the sight or sound of humans.

Caribou detection

Incomplete or patchy snow cover, substrates (including grass, bushes, ground) poking or showing through a thin snow layer, rocky terrain, light/shadow conditions, and occasionally fog, whether alone or in combinations are normal during aerial survey in West Greenland (Cuyler et al. 2005, 2007, 2011, 2016, 2021, 2023). Conditions were similar in 2019 and as usual made the well camouflaged caribou a challenge to detect. Stationary caribou exacerbated the detection difficulty. The almost west-east orientation of the line transects used in 2019 meant that in sunny conditions solar glare in the eyes of the observer on the south-facing side of the helicopter required polarized sunglasses. Despite the use of polarized sunglasses, detectability of caribou may have been reduced (Fig. 11).

We recommend that future DS surveys combine all covariates contributing to the caribou becoming camouflaged into the terrain (e.g., Figs. 9, 10, 11), into a single index, camouflage (extreme, high, medium, low, none). We expect this pooling will improve how caribou "invisibility" interacts with Key Functions to model the detection function. Regardless, given robust DS data, the influence of covariates on detectability is small and unlikely to significantly alter final abundance and density estimates.

Caribou behaviour – flight response of caribou groups

It is reasonable to expect that any survey for caribou would have some proportion of non-moving caribou present in the surveyed area of the line transects. Since flight responses by the caribou may influence whether an observer detects them, in 2019 the line transect data included whether the helicopter fly-by elicited a flight movement response from the caribou group or whether they were stationary.

While flying line transects for Distance Sampling (DS) survey of the Ameralik area, 16.8% of the caribou groups did not exhibit movement. This was fewer than observed for either aerial survey of the Akia-Maniitsoq or Kangerlussuaq-Sisimiut populations, 25% and xx%, respectively (Cuyler et al., 2021, 2023). These results suggest that on any given caribou survey in West Greenland, from 17% to 31% of all caribou groups will remain stationary as the aircraft passes them. Thus, detecting non-moving caribou is essential to avoiding underestimating population size and density and to facilitate accuracy of final estimates. As per Greenland caribou surveys since 2000, skilled observers and flying low & slow are both important and necessary.

Although non-moving groups had somewhat lower mean group size than moving groups, the difference was not significant ($p = 0.341$), indicating that group size had little influence on flight behavior. However, non-moving groups were significantly ($p < 0.0001$) further distant from the helicopter line transect, 130 m, than moving groups. As with previous aerial surveys, this attests to exceptional observer ability to detect caribou despite behavior displayed. Explanations for lack of movement among caribou further away from the helicopter would include the likelihood of less fear, since at greater distances the helicopter may be perceived as less threatening. Additionally, group composition may be involved. During the DS survey, cows with calves generally fled from the helicopter. Out of 157 moving groups, 151 of those groups exhibited unabated flight behavior (running away, never stopping) and 88% of those groups involved cows with calves.

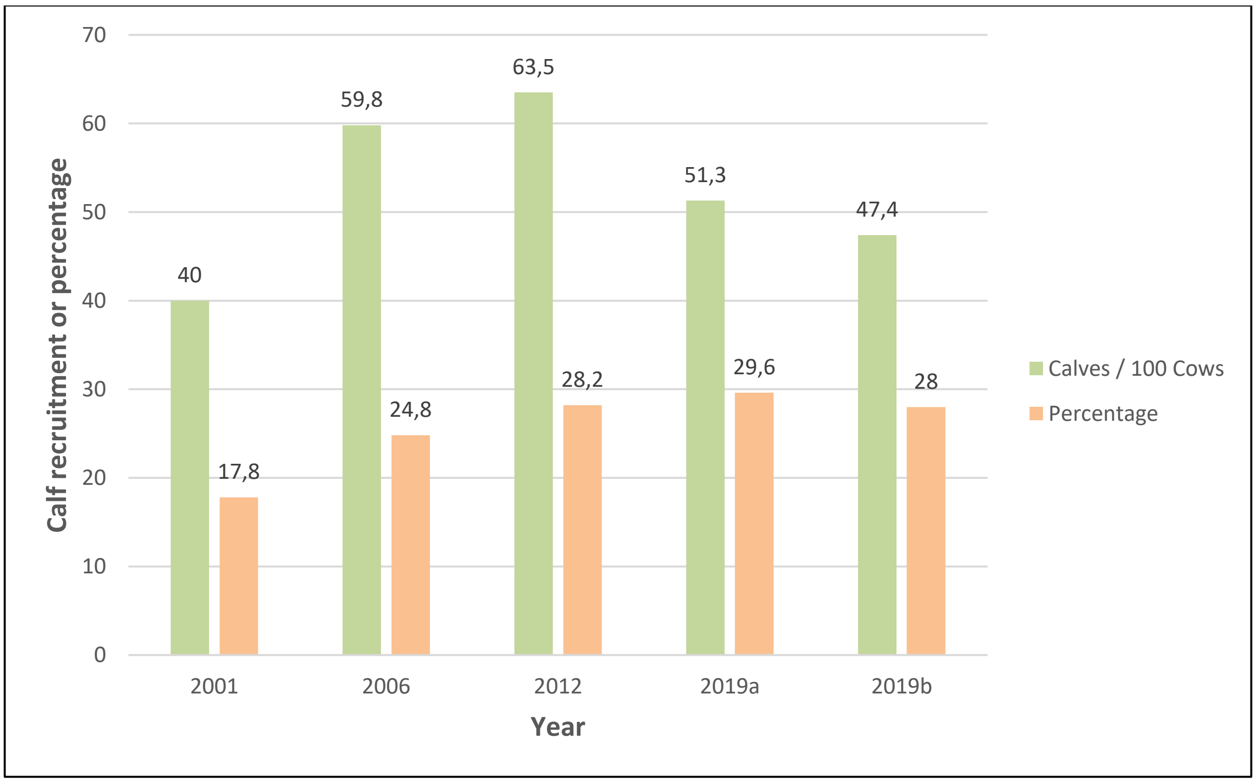

Figure 20. Past and present late winter calf (age 10-month) recruitment (number calves per 100 cows) and calf percentage for the Ameralik caribou population. Column 2019a included all calves observed, while 2019b removed all orphan calves.

Demographics

Regarding the March late winter period, the percentage of calves in the Ameralik population has remained relatively stable from 2012 to 2019 (Fig. 20). In contrast, calf recruitment (number calves per 100 cows) peaked in 2012 and decreased by 2019. The drop was acerbated by the number of orphan calves (n = 19) in 2019. When orphans were removed from the calculation, late winter recruitment fell below 50, albeit still a good value. Diverse factors affect recruitment, among them the bull to cow ratio (Fig. 21), which being poor in 2019 may have played a negative role. Nevertheless, 2019 late winter calf (age 10-month) recruitment suggests continued relatively good recruitment to the Ameralik population, which might lead to growth in abundance, albeit notwithstanding future catastrophic stochastic events, including pathogen outbreaks and extreme weather.

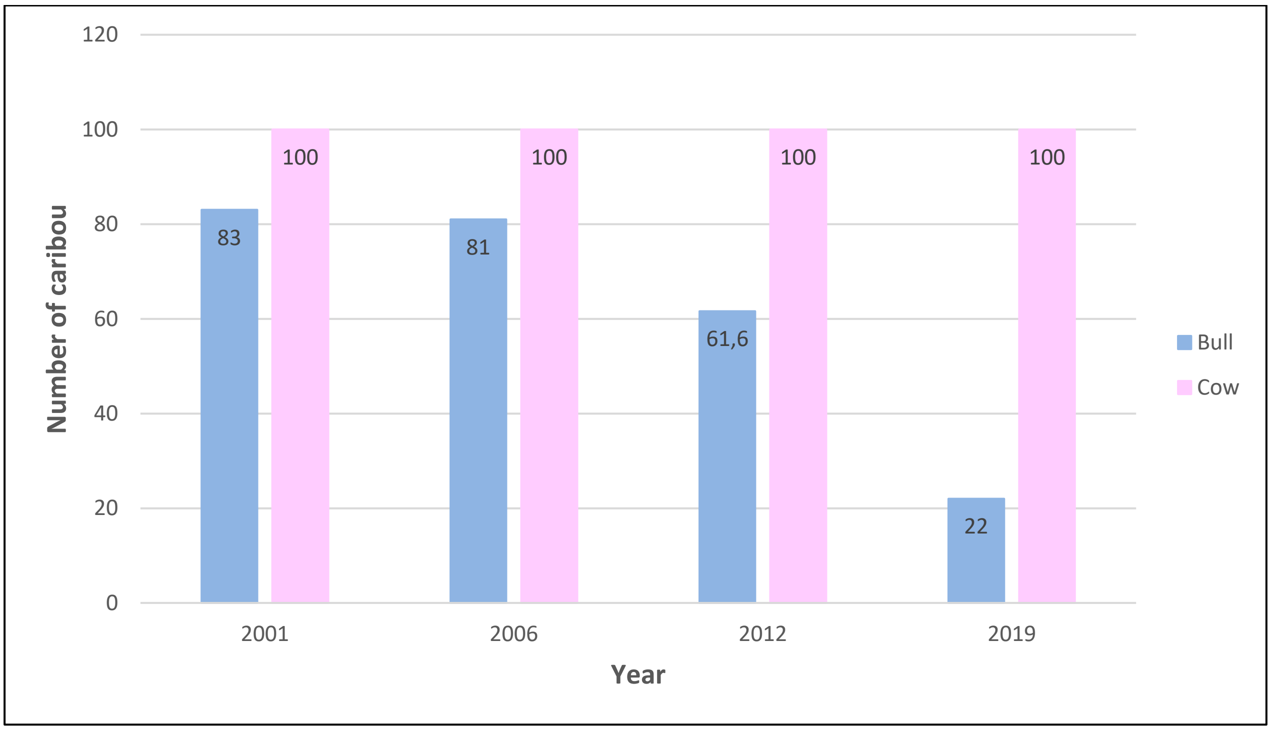

Figure 21. Past and present late winter bull to cow ratios for the Ameralik caribou population. Bull classification includes both juveniles, 1-year < age < 3-year, and adults, age > 3 years.

Since 2001, the bull to cow ratio has decreased. The extremely low value for 2019 suggests two possibilities. First, it is well known that caribou/reindeer generally demonstrate a high degree of sexual segregation, breeding period excepted (Cameron & Whitten 1979, Jakimchuk et el. 1987, Skogland 1989). The 2019 value may be incorrect because bull groups were elsewhere than where the demographics data was collected, i.e., we missed the bulls. Secondly, there truly were two few bulls relative to cows. If true, this could lead to poor calf production. Decreased 2019 calf recruitment supports the second possibility.

Elevation

Albeit elevation data was only approximate given the limitations of the GPS device and mismatch between helicopter and caribou positions, during the 2019 aerial survey, caribou of the Ameralik population were observed at elevations of mean 647 m ±273 with the mode being 898 m. The relatively high elevations where caribou were observed in 2019 is similar to elevation use observed during the 2012 survey (mean elevation 599 m ±280; Cuyler et al. 2016). It may only be coincidence, but both surveys were preceded by a winter hunting season. In 2012, the season ended the day before, while in 2019 hunting ended 2-weeks prior, i.e., winter 2019 caribou hunting season for the South region was 01-15 February, with a quota of 100 Ameralik caribou (Naalakkersuisut 2019).

Explanations for the relatively high elevation use in late winter by the Ameralik caribou would include that there are relatively limited lowlands in the South region (Figs. 1, 12) and most caribou observed were inland, where elevations are mostly >200 m. Explanations would also include possible better forage availability at higher elevations in this region. Albeit, given the latitude (ca. 64°N), at the 500-800 m elevations used by the Ameralik caribou population, available winter forage could be assumed inferior and less plentiful than that found in lowland valleys (Körner 2007). Another possibility would be caribou are avoiding hunters present at low elevations. Snowmobile use may also have influenced caribou choice of relatively high elevations in winter (Cuyler et al. 2016). Specifically, the South region is readily accessible by boat and by snowmobile. Use of snowmobiles is permitted over much of the Ameralik caribou population's range, popularity of recreational use is increasing, and the village of Kapisillit may facilitate snowmobile access even to the Xeric Inland sub-area. Elsewhere, caribou avoid areas of snowmobile use, becoming displaced from, and even abandoning, high-quality habitat (Simpson 1987, Seip et al. 2007).

The Ameralik caribou population used elevations that averaged ca. 300 m higher than elevations used by the Akia-Maniitsoq caribou population, which were also surveyed in March 2019 (Cuyler et al. 2023). Explanations would include, most Ameralik caribou were in the Xeric Inland sub-area, which lacks extensive lowland areas. Given current easy access to the region's lowlands, human disturbance may also be a contributing factor to high elevation use by Ameralik caribou.

Almost two decades ago, Ameralik caribou made extensive use of the Coastal Lowland sub-area, which is all <200 m elevation. According to Körner (2007) lowland habitat should be highly preferred by caribou. This supposition was confirmed in March 2001, when 115 caribou were detected on 28 km of lines flown in the Coastal Lowland sub-area (Cuyler et el. 2003). However, thereafter winter hunting was permitted and the number of caribou using the Coastal Lowland sub-area dwindled markedly. In March 2006, just 29 caribou were seen on the same 28 km of lines flown. Further, in the same area, snowmobiles were used (illegally) to hunt down caribou (Cuyler et el. 2007). In March 2012, placement of line transects changed and only one line transected the Coastal Lowland sub-area. It was 13.5 km in length and only seven caribou were seen (Cuyler et el. 2016). In 2019 the number and length of line transects increased. Although now 60 km of lines, we still only detected 45 caribou. Thus, the observed 4.1 caribou per km flown in 2001, dropped 75% to 1 caribou/km in 2006 and decreased further to 0.5 in 2012 and remained low, 0.7, for this study. Late winter use of the Coastal Lowland sub-area by the Ameralik caribou population was high in 2001 and then dropped. Other than the opening of winter hunting season and use of snowmobiles, there has been no change to the sub-area in the 2001-2019 period, e.g., no unusual late winter weather events, no new roads or infrastructure, etc. This suggests human disturbance is the important factor influencing late winter elevation use by Ameralik caribou in the South region. While the Akia-Maniitsoq caribou had alternate remote lowland areas to use (Cuyler et al. 2023) it appears high elevation was the only option available for Ameralik caribou avoiding human disturbance in lowlands, and specifically the Coastal Lowland sub-area.

Late-winter antler possession

Bulls

As expected for caribou populations, adult (age > 3-years) bulls from the Ameralik population lacked antlers in early March, while most, 96%, juvenile bulls retained one or both their antlers from the previous autumn. Thus, late-winter antler possession among bulls age > 1 year of the Ameralik population is similar to bulls in both the Kangerlussuaq-Sisimiut and Akia-Maniitsoq caribou populations (Cuyler et al. 2021, 2023). Among late-winter male calves (age < 1-year) antler possession varied for those same three populations. Antler possession was common and similar in male calves for the Ameralik and Kangerlussuaq-Sisimiut populations at 87.5% and 86.2%, respectively. In contrast, in the Akia-Maniitsoq population just 40% of male calves possessed antlers (Cuyler et al. 2021, 2023).

Cows

Although among wild caribou populations in North America, 98% of cows have antlers in late winter (Kelsall 1968, Reimers 1993, Bergerud et al. 2008), antler possession among cows in caribou populations of West Greenland is highly variable and often exhibits a high percentage of polled cows, i.e., no antlers (Thing et al. 1986, Cuyler et al. 2002). In North America, decline in the percentage of antlered cows has been attributed to overgrazed range, because that is a major factor causing poor cow body condition, which precludes antler growth (Gaare & Skogland 1980, Reimers 1983, Thing et al. 1986, Bergerud et al. 2008). In West Greenland, range condition is not the major factor influencing the number of polled cows (Cuyler et al. 2021).

In the Ameralik caribou population, 92% of cows had antlers, and most possessed both antlers (80%) rather than just one (12%). This was also reflected in antler possession or absence among female calves, and to a lesser extent even male calves. The 2019 results for antler possession and absence among Ameralik cows is supported by the 2012 survey, which percentage for antlered Ameralik cows was 86% (Cuyler et al. 2016). The greater percentage of antlered cows in 2019 relative to 2012, suggests that summer/autumn 2018 range conditions were not adversely affecting antler growth among Ameralik cows.

At 92% antler possession, more Ameralik cows have antlers then cows from either of the other two large caribou populations (Akia-Maniitsoq and Kangerlussuaq-Sisimiut) surveyed in West Greenland. For example, in 2019, just 8% of Ameralik cows were polled, which contrasts sharply with 68% polled Akia-Maniitsoq cows (Cuyler et al. 2023) and the 46% polled Kangerlussuaq-Sisimiut cows in 2018 (Cuyler et al. 2021). Polled cows are common among caribou populations in West Greenland.

Specifically, the Ameralik caribou population has a strong semi-domestic reindeer (*R. t. tarandus*) heritage (Thing et al. 1986, Jepsen et al. 2002), which stems from the Itivnera semi-domestic reindeer herd that went feral in this region during the 1970's (Cuyler 1999). Since semi-domestic reindeer cows usually have antlers in late winter (Skjenneberg & Slagsvold 1968), we suspect the greater antler possession among cows of the Ameralik, relative to other West Greenland populations, is likely due to this genetic heritage.

Other species observed

During the early March 2019 survey species other than caribou were observed. These included only ptarmigan, hares, fox, and feral sheep. There were no avian predators observed. Although local knowledge (Cuyler et al. 2016) has reported muskox presence in the South region of West Greenland, like all previous aerial surveys of this region, no muskoxen were observed during the early March 2019 survey.

There were two aerial surveys conducted in early March 2019, i.e., this study's South region and another in the Central region (Cuyler et al. 2023). Although the surveys occurred almost simultaneously, in the South region, excepting feral sheep, there were fewer of each observed species (Cuyler et al. 2023).

Still, the South region's area of survey effort (Table 2) was 2.4 times below that for the Central region (Cuyler et al. 2023). This partially explains the lower number of observations. However, it remains that the South region had fewer ptarmigan and foxes as well as no avian predators. Compared to the Central region, late winter 2019 habitat conditions in the South region appeared unable to support the same abundance of those species.

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Appendix 1

Place names for the South region

Figure 22. Place names used regarding the northern portion of the South region (ca. 63°30′–64°30′°N; 49°–51°40′W), which is inhabited by the Ameralik caribou population.

Appendix 2
Photos of camouflaged caribou (and fox) observed March 2019.

Figure 23. Six caribou, of which five are readily visible. All are within 75 m of the helicopter. Photo A. Jensen.

Figure 24. Six camouflaged caribou. Some are visible on a snow patch, but others are difficult to spot when among mix of thin snow, bare ground, and flat light (lack of shadows). All are within ca. 100 m of the helicopter. Photo C. Cuyler.

Camouflaged caribou

Figure 25. Seven camouflaged caribou. None are readily visible against the mix of thin snow, boulders, and bare ground. All are within ca. 100 m of the helicopter. Photo A. Jensen.

Figure 26. Three camouflaged caribou. Despite full sunshine, none are readily visible against the mix of patchy snow cover, boulders, bare ground, and willows. All are within 100-150 m of the helicopter. Photo C. Cuyler.

Camouflaged caribou

Figure 27. 11 camouflaged caribou. Few are readily visible against the mix of thin snow cover, boulders, bare ground, and the flat-light (lack of shadows). All are within ca. 150 m of the helicopter. Used as cover photo. Photo C. Cuyler.

Figure 28. 35 camouflaged caribou. None are readily visible against the mix of thin snow cover with vegetation poking through the snow surface. All are within 500 m of the helicopter Photo C. Cuyler.

Camouflaged caribou

Figure 29. 15 camouflaged caribou. Despite full sunshine, none are readily visible against the mix of thin snow cover with vegetation poking through the snow surface. All are within 300 m of the helicopter. Photo C. Cuyler.

Figure 30. 31 camouflaged caribou. None are readily visible against the mix of thin snow cover with vegetation poking through the snow surface. All are within 300 m of the helicopter. Photo C. Cuyler.

Camouflaged caribou

Figure 31. 17 camouflaged caribou. None are readily visible against the mix of thin snow cover with vegetation poking through the snow surface. All are within 500 m of the helicopter. Photo C. Cuyler.

Figure 32. Seven camouflaged caribou. Given the strong sunshine causing deep shadows, none are readily visible against the mix of thin snow cover with vegetation poking through the snow surface. All are within 250 m of the helicopter. Photo C. Cuyler.

Camouflaged caribou

Figure 33. Six camouflaged caribou at the south end of the lake, Isortuarsuk. Despite sunshine, none of the caribou are readily visible against the mix of thin snow depth with vegetation poking through the snow surface. All are within 300 m of the helicopter. Photo C. Cuyler.

Figure 34. Two groups camouflaged caribou (n= 3 + 17), south end of lake, Isortuarsuk. Despite sunshine, only group of three is readily visible because they presented broadside view, which the group of 17 did not. All are within 200 m of helicopter. Photo C. Cuyler.

Camouflaged caribou

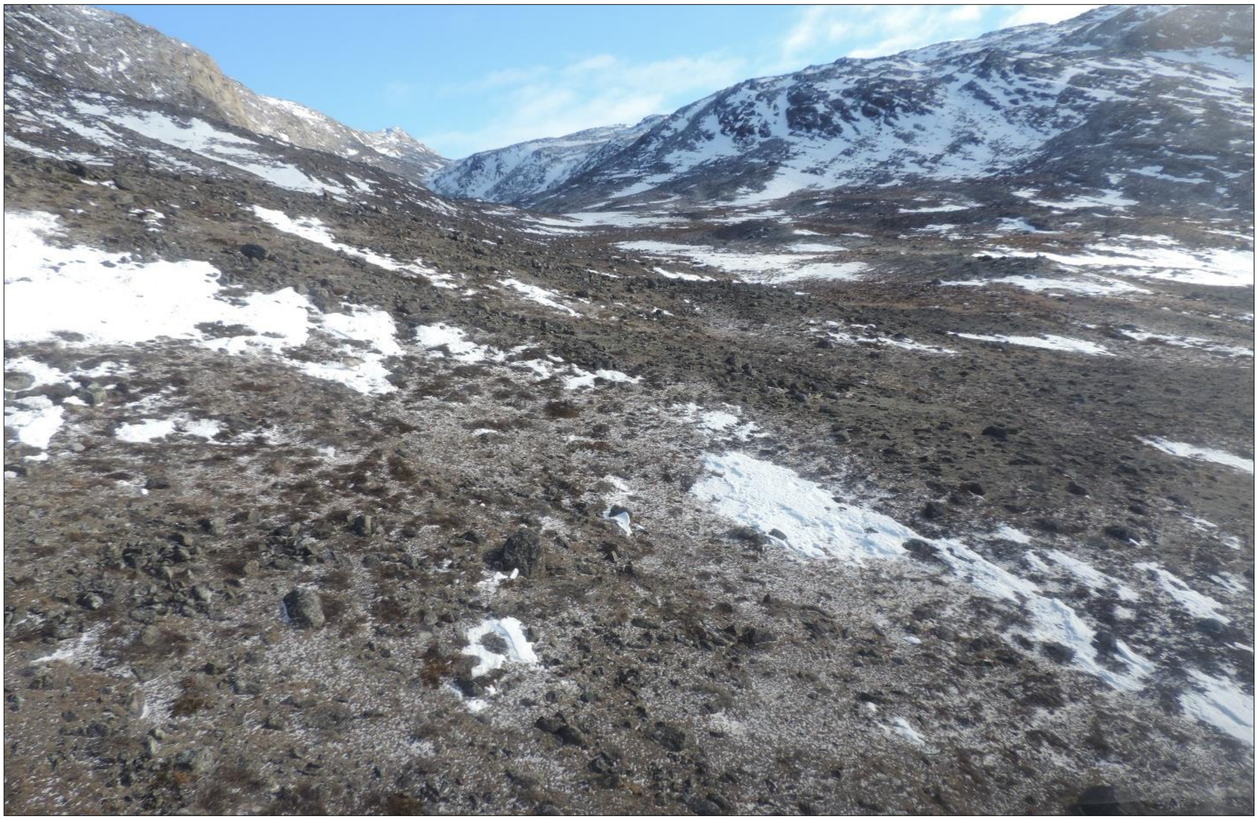

Figure 35. Five camouflaged caribou, south end of lake, Isortuarsuk. Despite sunshine and broadside presentation, none are readily visible. All are within 100 m of helicopter. Photo C. Cuyler.

Figure 36. Twelve camouflaged caribou, east side of lake, Isortuarsuk. Despite sunshine, none are readily visible. All are within 200 m of helicopter. Photo C. Cuyler.

Camouflaged caribou

Figure 37. Nine camouflaged caribou among dwarf shrub, east side of lake, Isortuarsuk. Despite sunshine, none are readily visible. All are within 100 m of helicopter. Photo C. Cuyler.

Figure 38. Five camouflaged caribou, east side of lake, Isortuarsuk. Despite sunshine, none are readily visible. All are within 200 m of helicopter. Photo C. Cuyler.

Camouflaged arctic fox

Figure 39. Xeric inland sub-area, illustrating vegetation poking through thin snow layer. This camouflaged one arctic fox (blue phase) curled in a ball in response to helicopter at 75-100 m. Photo C. Cuyler.

Figure 40. Location of arctic fox (blue phase) indicated by blue circle. Photo C. Cuyler.

Appendix 3
Feral sheep (Ovis aries) near Kuussuaq (Austmannadalen), 14 March 2019

Figure 41. One camouflaged feral sheep in the foreground just left and below center, within 100 m of the helicopter. The mix of bare ground, rocks, and thin snow cover with vegetation poking through the snow surface make detection difficult. This one feral sheep was associated with eleven others (not in photo). Photo C. Cuyler.

Figure 42. One feral sheep observed just north of the mouth of the Austmannadalen valley on willow covered peninsula. It was associated with eleven other feral sheep. Photos A. Jensen.

Appendix 4

Statistical methods behind Distance Sampling

This appendix presents the basic building blocks and reasoning behind Distance Sampling (DS) methods, followed by some details. This summary of statistical methods is from Correia (2020).

Fundamental concepts

Before entering into the detailed theory behind the DS methodology, we present a simpler design, which is quadrat or plot sampling (Buckland et al. 2001; Marques, 2009).

In plot sampling, a region of interest with total area A, is divided into small plots of area a_{plot} (Fig. 43). Some of these small plots are randomly chosen for sampling and the total number of individuals within these, n_{plot}, is recorded.

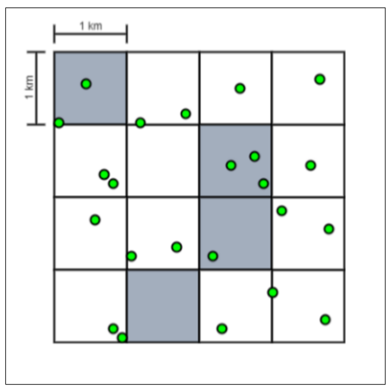

Figure 43. Plot sampling grid example of total area A divided into smaller plots of area a_{plot}.

The density within each plot, D_{plot}, is the number of individuals per unit area for the respective plot so, by definition, it is given by

$$\widehat{D}_{plot} = \frac{n_{plot}}{a}, \qquad \text{Equation (1)}$$

where a is the total area sampled within A. (i.e., $a = 4 \cdot a_{plot} = 4km^2$ for Fig. 43) Since a random design was used, the density is a representative estimate, by design, for the total area A. Hence, an estimate for the abundance, $\hat{N}$, can be obtained by simply multiplying $\hat{D}_{plot}$ by the total area A,

$$\widehat{N} = A \cdot \widehat{D}_{plot} = A \cdot \frac{n_{plot}}{a}. \qquad \text{Equation (2)}$$

The DS methodology is an extension of quadrat-based sampling methods. The detail that creates the bridge from one methodology to the other is the fact that the method described above assumes that every individual of interest is detected (Miller et al. 2016). Frequently, this assumption cannot be met, specifically if among the individuals of interest there are animals impossible to observe owing to low sightability. Several factors cause low sightability,including topographical barriers, weather conditions, ground surface conditions and many others related to observer training and survey design. The proportion of individuals that werenot detected can be estimated using the detection function fitted to the observed distances (Thomas et al. 2002). Once this proportion is estimated, it can be considered to obtain more accurate estimates and then, an extrapolation for a wider region can be done similarly as shown in Equation (2).

In DS, this proportion of detected objects in the area a is defined as the probability of detection, P_a. Therefore, a density estimate can be obtained as per Equation(1) by adjusting n_{plot} by P_a, i.e., by correcting the detections for those that were missed. Since the latter cannot be known, in general, an estimate must be also obtained, thus

$$\widehat{D} = \frac{\frac{n_{plot}}{\widehat{P}_a}}{a} = \frac{n_{plot}}{2wL\widehat{P}_a}, \qquad \text{Equation (3)}$$

where $\hat{P}_a$ is an estimate of P_a obtained from the distance data, and a is the area of the sampled region. Usually $a = 2wL$, with w as the truncation distance, for both sides of the track line, and the total transect length $L = \sum_{j=1}^{k} l_j$, where l is the length of transect j. Abundance can be determined using a reasoning analogous to that above (Equation 2). The truncation distance is defined as the distance beyond which distances are not recorded. This can be defined in the field or at the analysis stage.

The coefficient of variation of $\widehat{D}$, $cv(\widehat{D})$, is related with two random components referred above, encounter rate (n_{plot}/L), and $\hat{P}_a$, plus a third one that is the estimate of the expected size of detected clusters ($\hat{E}(s)$). Assuming independence between these, the former is given by

$$(cv(\widehat{D}))^2 = \left(\frac{se(\widehat{D})}{\widehat{D}}\right)^2 = (cv(n_{plot}/L))^2 + (cv(\widehat{E}(s)))^2 + (cv(\widehat{P}_a))^2. \qquad \text{Equation (4)}$$

An approximation of the standard error of $\widehat{D}$, $se(\widehat{D})$, is defined as

$$se(\widehat{D}) = \widehat{D} \cdot \sqrt{(cv(n_{plot}/L))^2 + (cv(\widehat{E}(s)))^2 + (cv(\widehat{P}_a))^2}. \qquad \text{Equation (5)}$$

Once these are obtained, an approximate $100(1-\alpha)\%$ confidence interval (CI) can be determined by

$$\widehat{D} \pm z_{1-\frac{\alpha}{2}} \cdot se(\widehat{D}), \qquad \text{Equation (6)}$$

Where $z_{1-\frac{\alpha}{2}}$ is the quantile of the $N(0,1)$ distribution $(z_{1-\frac{\alpha}{2}} = z_{1-\frac{0.05}{2}} = z_{0.975} = 1.96$ for a 95% confidence interval). However, the distribution of the $\widehat{D}$ is positively skewed, thus an interval assuming that $\widehat{D}$ is log-normally distributed has better coverage. According with Buckland et al. (2015), a 100(1-alpha)% confidence interval can be given by

$$\left(\widehat{D}/C, \widehat{D} \cdot C\right), \qquad \text{Equation (7)}$$

where

$$C = \exp\left\{z_{1-\frac{\alpha}{2}} \cdot se[\log_e(\widehat{D})]\right\} \qquad \text{Equation (8)}$$

and

$$se[\log_e(\widehat{D})] = \sqrt{\log_e\left[1 + \left(cv(\widehat{D})\right)^2\right]}. \qquad \text{Equation (9)}$$

For further details see Buckland et al. (2001) and Buckland et al. (2015).

Probability of detection

Given the above, the probability of detecting an object, giving that it is within the area covered by the transects, $\widehat{P}_a$, needs to be estimated. For this project, the object of interest consists in caribou groups.

To illustrate the importance of this probability, consider that an observer walks across a large patch of tundra and detects 8 caribou (Fig. 44). While discussing with the local biologist, and considering the biologist's experience, he/she will state that, on average, only one third of all caribou present are detected (i.e., $\widehat{P}_a = 1/3$) meaning that probably there were around 24 caribou within that patch of tundra and 16 have been missed. That is where DS is useful, since it allows a rigorous framework for the estimation of P_a and then an estimate of abundance can be obtained as shown in Equation (3).

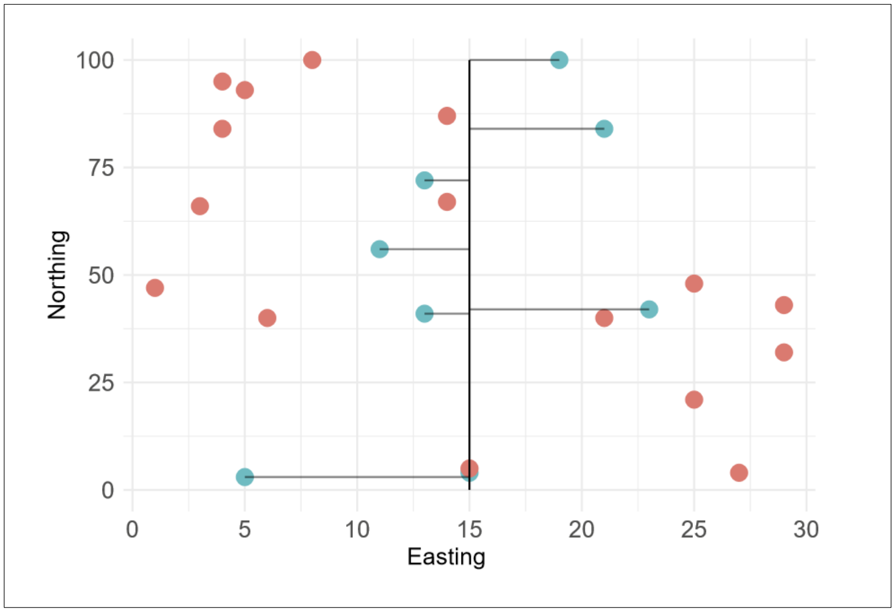

Figure 44. Example of a patch of tundra with the transect in the middle. Blue dots represent eight observed caribou, while orange dots represent the 16 undetected ones. The lines perpendicular to the transect represent the recorded distances.

Distance Sampling methods

The detection function, $g(y)$, describes the probability of detecting an object of interest given that it is at a distance y, from the track line (also known as 0-line), thus being a non-increasing function of y (Buckland et al. 2015).

For line transects, y is the perpendicular distance from the 0-line to the detected object. Within DS methods, the probability of detection is explained recurring to these observed distances (Buckland et al. 2001). Sometimes covariates may be added to explain their relationship with the detection probability. In this situation, we are within the Multiple Covariate Distance Sampling (MCDS) framework (Buckland et al. 2001).

Conventional Distance Sampling

Conventional Distance Sampling (CDS) occurs when no additional covariates are added to the model. Once the detection function is estimated, $\hat{P}_a$ can be obtained via the following equation

$$\widehat{P}_a = \int_0^w \hat{g}(y) \cdot \pi(y) dy, \qquad \text{Equation (10)}$$

where $\pi(y) = \frac{1}{\omega}$ and, therefore, used to estimate density using Equation (3). For $g(y)$ it is also specified a flexible semi-parametric model, composed by a key function and some additional series expansions, known as adjustment terms, and their parameters are estimated (Marques et al. 2007).

To obtain robust estimates of density, flexible models for $g(y)$ are needed with the form (Buckland et al. 2001)

$$g(y) = \frac{k(y) \cdot [1 + s(y)]}{k(0) \cdot [1 + s(0)]}, \qquad \text{Equation (11)}$$

where $k(y)$ is the parametric key function and $s(y)$ represents the additional adjustment terms (Table 12).

Table 12. Commonly used key functions and series expansions for the detection function. Adapted from Buckland (2001).

Key function		Series expansion	
Uniform	$1/w$	Cosine	$\sum_{m=2}^{M} a_m cos(m\pi y_s)$
Half-normal	$\exp[-y^2/2\sigma^2]$	Simple Polynomial	$\sum_{m=2}^{M} a_m (y_s)^{2m}$
Hazard-rate	$1 - \exp[-(y/\sigma)^{-b}]$	Hermite	$\sum_{m=2}^{M} a_m H_{2m}(y_s)$

Note: If Uniform key, $m = 1, ..., M$. $H(x)$ denotes Hermite function.

The uniform key function has no parameters, while the half-normal and the hazard-rate functions include a scale parameter, σ, which determines the rate at which the function decreases with increasing distance (Fig. 45). Furthermore, the hazard-rate function also includes a shape parameter, b, that provides greater flexibility to this function comparing to the others (Buckland et al. 2001).

It is not always necessary to include adjustment terms, and, in such cases, these models are referred to as “key only” models. When the key functions are not enough for fitting $g(y)$, some series expansions terms may be added to modify its shape (Fig. 46). These terms can be either cosine, simple polynomial or Hermite polynomial (Table 12).

It is important to note that these adjustment terms do not depend directly on y but on y_s which is a scaled value of y, where $y_s = \frac{y}{\omega}$ with ω being the truncation distance. This allows independence between the shape of the series expansion and the units used for y (Marques et al. 2007).

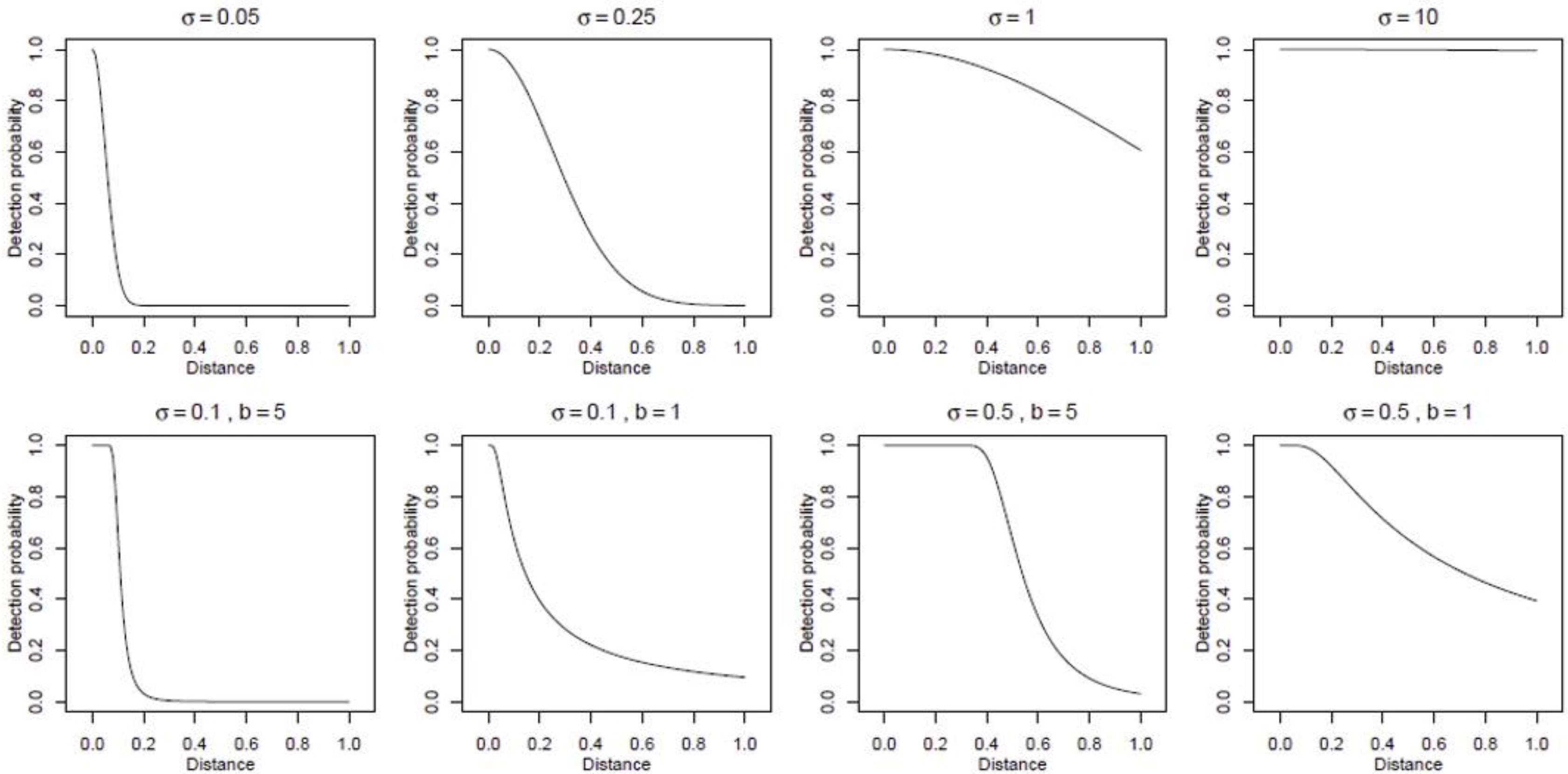

Figure 45. Half-normal (top row) and hazard-rate (bottom row) detection functions without adjustments, varying scale (σ) and, only for hazard-rate, shape (b) parameters. Values tested are presented above the plots. On the top row from left to right, the study species becomes more detectable (higher probability of detection at larger distances). The bottom rows show the hazard-rate model's more pronounced shoulder. Adapted from Buckland et al. (2001).

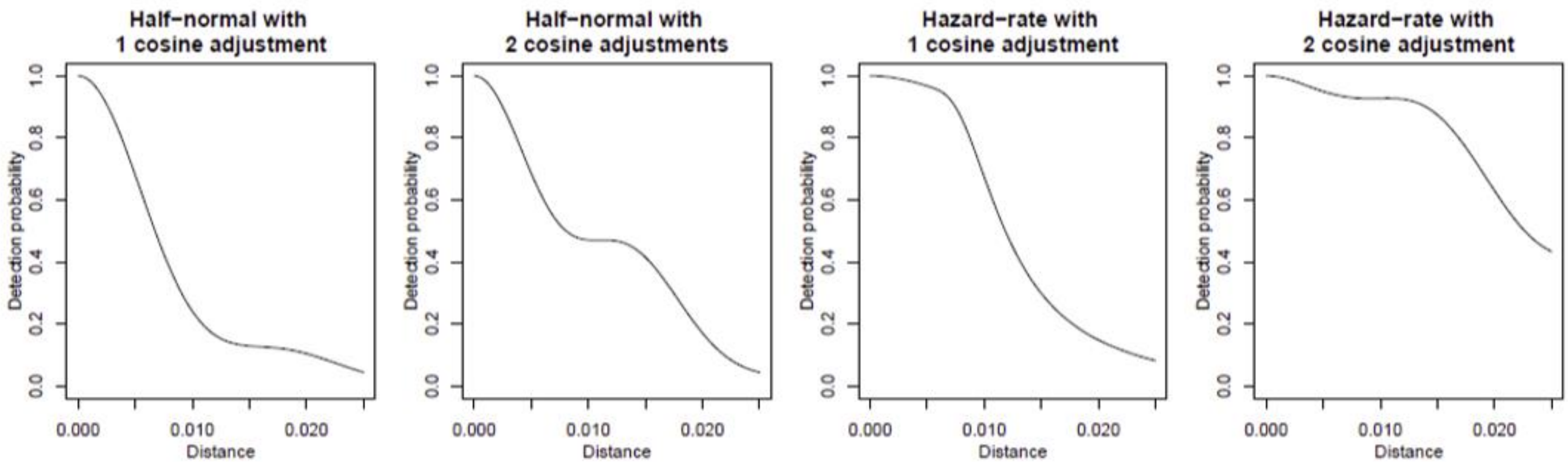

Figure 46. Possible shapes for the detection function when cosine adjustments are included for half-normal and hazard-rate models. Adapted from Buckland et al. (2001).

Right truncation of the data, or the removal of the largest distances, is a common procedure that aids model fitting. Some precision might be lost with truncation; however, it is usually slight. On the other hand, precision is increased since the data is easier to model and, consequently, fewer parameters and adjustment terms are required to model the detection function (Couturier et al. 2018).

Multiple Covariate Distance Sampling

CDS methods can be extended to MCDS, so that $g(y)$ is modelled as a function not only of distance, but also of a vector of J additional covariates for each of the n objects of interest, $\mathbf{z_i} = z_{i1}, ..., z_{iJ}$, $i = 1, ..., n$. Accordingly, the function that describes the probability of detection at a given distance, is represented by $g(y, \mathbf{z})$. These additional covariates caneither be discrete or continuous, such as observer and group size, and are assumed to affect only the scale, σ, of the detection function (Marques et al. 2007; Miller et al. 2016). For line transects, $P(\mathbf{z_i})$, i.e., the probability of detecting the i-th object of interest given its respective vector of covariates $\mathbf{z_i}$ can be estimated using the formula presented in Equation (12).

$$\widehat{P}(\mathbf{z_i}) = \int_0^w \hat{g}(y, \mathbf{z_i}) \cdot \pi(y) dy, \qquad \text{Equation (12)}$$

with $\pi(y) = \frac{1}{\omega}$. Considering the three key functions previously presented, only the uniform key is excluded from MCDS since it does not have a scale parameter. Half-normal and hazard-rate functions can have their scale parameter written as a function of the covariate values as

$$\sigma(\mathbf{z_i}) = \exp\left(\beta_0 + \sum_{j=1}^{J} \beta_j z_{ij}\right), \qquad \text{Equation (13)}$$

Where $\beta_0$and all the β_j's are the $J + 1$ coefficients to be estimated with J being the total number of covariates. The estimation of the parameters for both CDS and MCDS is typically done via maximum likelihood (Marques et al. 2007).

Once the detection function is estimated, according with (Buckland et al. 2004), density can be estimated as

$$\widehat{D} = \frac{1}{a} \sum_{i=1}^{n} \frac{1}{\widehat{P}(\mathbf{z_i})}, \qquad \text{Equation (14)}$$

where a is the total area surveyed, $\hat{P}(\mathbf{z_i})$ is the estimated probability of detecting the i-th object of interest given its respective vector of covariates $\mathbf{z_i}$.

Finally, Marques et al. (2007) states that MCDS methods potentially offer improved inference in four situations, when comparing to CDS methods:

1. when a subset of data is used to estimate density, e.g., by strata, where this information can be introduced as a factor covariate. In CDS, the strategy is more complex, either to estimate P_a for each stratum and thus, stratum-level estimates for density or to usea global estimate for the probability of detection, but this second introduces bias, for example, if one stratum favours the animals when compared to other strata which uses fewer parameters than a fully stratified detection function model;
2. where pooling robustness does not hold for CDS analyses, e.g., when survey intensity varies according with pre-defined strata to increase efficiency, or when the detection probability faces extreme heterogeneity due to different object habitats or behaviors, for example, showy males contrasting with cryptic females in animal surveys;
3. reduces the variance of density estimates by modelling the heterogeneity in the detection function;
4. if there are covariates of interest to be included in the model.

Model selection

Since the estimator of density is closely linked to the detection function, it is of critical importance to select models for the detection function carefully. Three properties desired for a model for $g(y)$ are, in order of importance, *model robustness*, a *shape criterion* and *estimator efficiency* (Buckland et al. 2001, 2015; Miller et al. 2016).

The most important property of a model for the detection function is model robustness. According with Buckland et al. (2001, 2015), this means that the model is a general, flexible function that can take a variety of plausible shapes for the detection function. The concept of pooling robustness is also included here. Models of $g(y)$ are pooling robust if the data can be pooled over many factors that affect detection probability and still yield a reliable estimate of density. A model is pooling robust if, for example, a stratified estimation for density, $\widehat{D}_{st}$, and a pooled estimation for density, $\widehat{D}_p$, are approximately the same. In the first scenario, the data is stratified by factors, such as observer or habitat type, and an estimate for density in each stratum is made. Then these estimates are combined into $\widehat{D}_{av}$, an average density estimate. In the second scenario, all data could be pooled, regardless of any stratification, and a single estimate computed, $\widehat{D}_p$. A model is pooling robust if $\widehat{D}_{av} \approx \widehat{D}_p$.

According to Buckland et al. (2001), the shape criterion consists in the fact that the detection function should have a 'shoulder' near the line (Fig. 47), i.e., detection remains nearly certain at small distances from the sampling unit's track line ($g'(0) = 0$). This allows the reliable estimation of object density (Thomas et al. 2002). Generally, good models for $g(y)$ will satisfy the shape criterion near the track line (0-line, zero-line), which is especially important in the analysis of data where some heaping at zero distance is suspected.

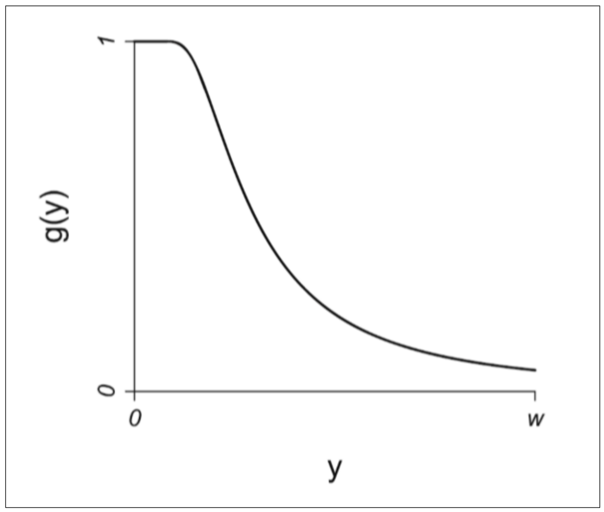

Figure 47. A good model for the detection function should have a shoulder, with probability of detection staying at or close to one at short distances from the track line or point. At larger distances, it should fall away smoothly. The truncation distance ω corresponds to the strip half-width (for Line Transect DS). Adapted from Buckland et al. (2001).

Estimator efficiency is the third most important property (Buckland et al. 2001), which means that it is desirable to select a model that provides estimates that are relatively precise, i.e., that have small variance. This property is of benefit only for models that are model robust and have a shoulder near zero distance, otherwise the estimation might be precise but biased.

Besides these three criteria, the model should be a monotonic function of distance from the line, that is, the probability of detection at a given distance cannot be greater than the probability of detection at any smaller distance (Fig. 47) (Buckland et al. 2001).

There is no fixed standard method to select the best fitting model, i.e., choosing the most appropriate key function and series expansion (Marques et al. 2007). It is usually done by applying the Akaike's Information Criterion (AIC), Kolmogorov-Smirnov test, Cramér-von Mises test and the χ^2 Goodness-of-Fit test (GOF test). The likelihood ratio test can also be used but, since it is only applicable for nested models, AIC is the recommended method

(Marques et al. 2007). A proper model should be simple with an adequate fit without overfitting the data.

Akaike Information Criterion

The relative fit of alternative models may be evaluated recurring to AIC, or AICc, in case of small samples, providing a small sample bias correction (Buckland et al. 2001). These criteria can be determined as follows

$$AIC = -2 \cdot \ln(\mathcal{L}) + 2q, \text{ and} \quad \text{Equation (15)}$$

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$$AICc = AIC + \frac{2q(q+1)}{n-q-1}, \quad \text{Equation (16)}$$

where $\mathcal{L}$ is the likelihood function, q is the number of estimated parameters in the model, and n is the sample size. This measure provides a trade-off between bias and variance. AIC includes two terms, one related with the fitted model, and the other working as a penalty considering the excess of parameters in the model (Brewer et al. 2016).

Kolmogorov-Smirnov test

The Kolmogorov–Smirnov test is one of the tests that can be applied to the detection function to assess model fit (Buckland et al. 2004). This test is only applicable for continuous data, being preferable to the χ^2 GOF test for MCDS methods.

Considering the cumulative distribution function (c.d.f.) $F(x) = P(X \leq x)$ and the empirical c.d.f. (e.d.f.) $S(x)$, the null hypothesis to be tested is $H_0 : F(x) = F_0(x), \forall x$. The alternative hypothesis states that both functions differ for at least some value of x. In practice, $F(x)$is replaced by its estimate, and H_0 states that the assumed model is the true model for the data (Buckland et al. 2004). The largest absolute difference between $\hat{F}(x)$ and $S(x)$, denoted D_n, is the test statistic (Gibbons and Chakraborti 2011). The corresponding p-value can be approximated by

$$p = 2 \cdot \sum_{i=1}^{\infty} (-1)^{i-1} \exp(-2ni^2 D_n^2). \quad \text{Equation (17)}$$

Cramér-von Mises test

Similarly to the Kolmogorov-Smirnov test, the Cramér-von Mises test shares the same null hypothesis and basis on differences between c.d.f. and e.d.f.. However, instead of considering only the largest difference between the two functions, this test is based on their entire range (Buckland et al. 2004). The test statistic can be given by

$$W^2 = \frac{1}{12n} + \sum_{i=1}^{n} \left[\widehat{F}(x_{(i)}) - \frac{i-0.5}{n} \right]^2. \qquad \text{Equation (18)}$$

Chi-square Goodness-of-Fit test

The χ^2 Goodness-of-Fit test (Buckland et al. 2001, 2015) compares the observed frequencies, n_i, with the expected frequencies under the model $E(n_i)$ and it is given by

$$X_{obs}^2 = \sum_{i=1}^{n} \frac{\left[n_i - E(n_i)\right]^2}{E(n_i)} \sim \chi^2_{(u-q-1)}, \qquad \text{Equation (19)}$$

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under the null hypothesis (H_0) of good model fitting, i.e., the difference between the observed (n_i) and expected ($E(n_i)$) counts is close to zero. In Equation (19), n is the total number of observations, u is the number of groups (or bins) within the distance data, and q is the number of model parameters estimated. Reject H_0 if $X_{obs}^2 > X_{1-\alpha;(u-q-1)}^2$, with the latter representing the 1–α quantile from a χ^2 distribution with u - q - 1 degrees of freedom.

As the number of parameters of the fitted model increases, the bias decreases, but the sampling variance increases (Buckland et al. 2001). While the Goodness-of-Fit test results should be considered in the analysis of distance data, they will be of limited value in selecting a model since these tests are sensitive to heaping. Therefore, care is needed in choosing suitable distance intervals.

If data are collected with no fixed ω, it is possible that a few extreme outliers will be recorded. These values are not useful, and the data should therefore be truncated. This can be checked using the distances' histogram, and whether there is evidence of heaping or not (Buckland et al. 2001; Couturier et al. 2018).

Goodness-of-Fit tests allow formal testing of whether a detection function model provides an adequate fit to the data. Since the GOF test cannot be used on continuous data, unless grouped, it is of limited use for testing MCDS models (Buckland et al. 2015), being useful for testing models using CDS methods. However, if distances are not grouped, they must first be categorized into groups to allow the test to be conducted. Thus, there is a subjective aspect to the test, and different analysts, using different group cut points, may reach different conclusions about the model adequacy. In contrast, the Kolmogorov–Smirnov and Cramér–von Mises tests can only be applied to continuous data (Buckland et al. 2015).

Appendix 5

Distance Sampling Assumptions – short summary

Line transect DS assumptions and design are described in Buckland et al. (1993) and a summary of the assumptions in relation to caribou survey in Greenland provided below are from Cuyler et al. (2016).

1. All caribou on the 0-line are detected. This is critical and must be true.
2. Caribou are randomly distributed. (Lacking this will not bias abundance estimates if the line transects are randomly placed, which they were.)
3. Detection of caribou is independent. (Although detection was dependent in our survey, the lines had random start-end points, so this assumption is not violated).
4. No caribou movement prior to detection. The method is a 'snapshot' method. In practice this assumption is not violated if the observer moves faster than the animal, e.g., if movement of caribou to the next line transect to be surveyed is rendered impossible, which it was.
5. Distance measurements are exact. Provided distance measurements are approximately unbiased, bias in line transect estimates tends to be small in the presence of measurement errors. In our survey we binned the observations into distance intervals which decreases measurement error.
6. Clusters (caribou groups) close to the 0-line are accurately sized.
7. Other assumptions include those for other survey types, e.g., that each population is closed, being confined within a clearly defined area.

Appendix 6
Photos, South region aerial survey conditions for census of the Ameralik caribou population, March 2019

Figure 48. Coastal Lowlands sub-area in background beyond the mouth of Buksefjord, which crosses the middle of this photo, view is south. Line transect 125 parallels Busksefjord. Photo C. Cuyler.

Figure 49. Coastal Lowlands sub-area, view east towards bordering mountains. Photo A. Jensen.

Figure 50. Coastal Lowlands sub-area, west end line transect 127, view is north. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 51. Glacial Mountains sub-area, Itoqqarmiut Kangerluarsunnguat (Buksefjord) and Hydro Power station located at the bottom of fjord. Line transect 121 was flown over the area left of center, view is southwest. Photo A. Jensen.

Figure 52. Glacial Mountains sub-area, south of line transect 122 and west of 117, illustrating the mountains and glaciers typical to this sub-area, view is southwest. Photo A. Jensen.

South region aerial survey conditions, March 2019

Figure 53. Glacial Mountains sub-area, middle portion of line transect 123, view is northeast up the lake, Sangujaat Tasersuat. Photo A. Jensen.

Figure 54. Glacial Mountains sub-area, river valley, Qoorusussuaq, which is just east of line transect 123, view is north. Photo A. Jensen.

South region aerial survey conditions, March 2019

Figure 55. Glacial Mountains sub-area, east end of line transect 123, illustrating one of several glaciers in this sub-area, view is south. Photo A. Jensen.

Figure 56. Glacial Mountains sub-area, the valley and lake, Eqaluit, an area atypical amongst the mountains and glaciers common to this sub-area, view is southwest. Photo A. Jensen.

South region aerial survey conditions, March 2019

Figure 57. Xeric inland sub-area, line transect 101, view east, note thin snow layer. Photo C. Cuyler.

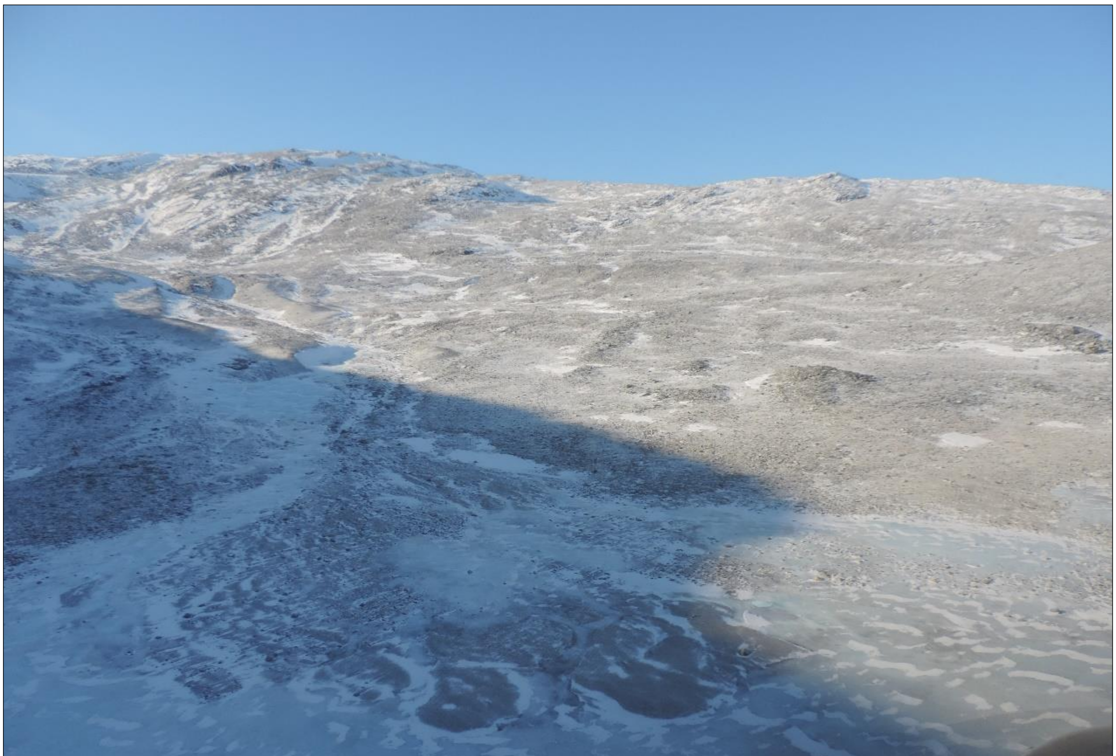


Figure 58. Xeric inland sub-area, line transect 102, view west, note thin snow layer. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 59. Xeric Inland sub-area, approaching east end line transect 103, view east. Photo C. Cuyler.

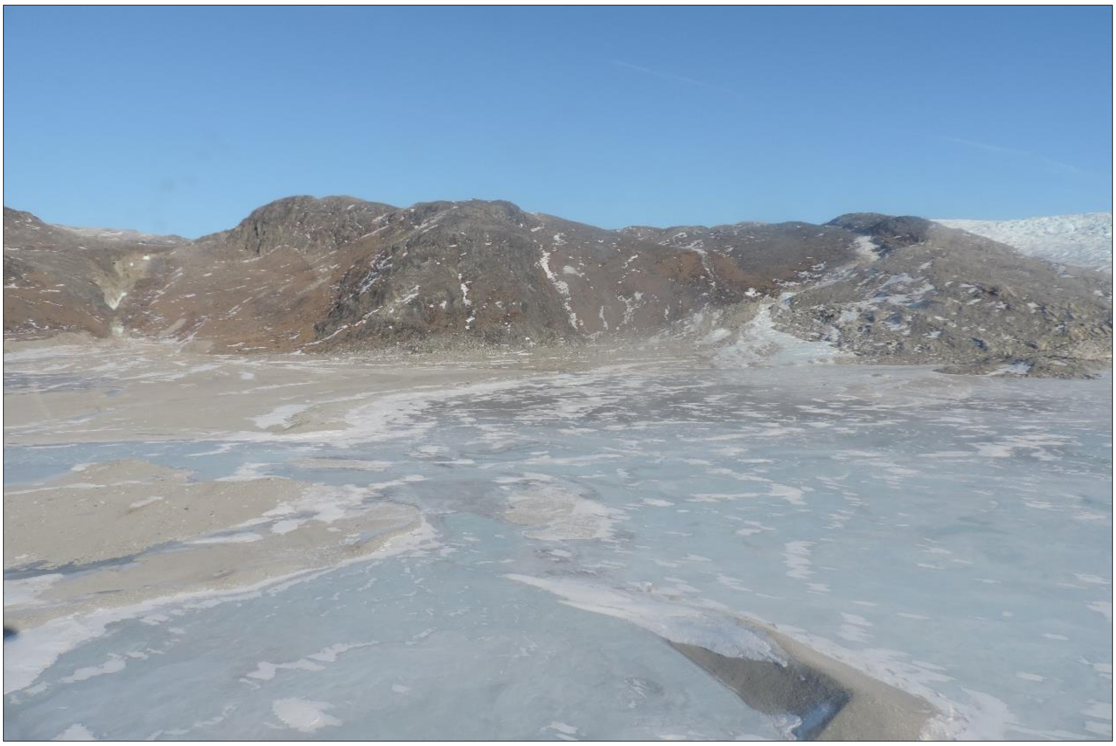


Figure 60. Xeric Inland sub-area, east end line transect 103, view north. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 61. Xeric inland sub-area, line transect 104, south of Kapisillit, view is south. Photo C. Cuyler.

Figure 62. Xeric Inland sub-area, view north illustrating mouth of broad braided river valley, Sarqarssuaq, which is sandwiched between Akullersuaq to the north (background) and Nunatarssuaq to the south (foreground), Kangersuneq fjord far left. Line transect 105 ran from inner braided river along far mountainside of Akullersuaq and out to the shores of Kangersuneq. Photos C. Cuyler.

South region aerial survey conditions, March 2019

Figure 63. Xeric Inland sub-area, east end of line transect 106, view west across Akullersuaq. Note the amount of bare ground with no snow layer. Photo A Jensen.

Figure 64. Xeric Inland sub-area, line transect 107, view east, note thin snow layer and presence of 16 caribou. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 65. Xeric Inland sub-area, view northeast over Nunataarsuk and area of line transect 108, Akullersuup Sermia far left. Note, thin snow permits ground to show through. Photo C. Cuyler.

Figure 66. Xeric Inland sub-area, line transect 108, Nunataarsuk, view east. Note, thin layer of snow permits ground to show through it. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 67. Xeric Inland sub-area, around the west end of line transect 110, four caribou, view NNE. There is a mixture of almost bare ground and windblown snow of varying depth. Photo A. Jensen.

Figure 68. Xeric Inland sub-area, around the east end of line transect 110, two groups of caribou, four (upper left) and two (bottom right), view east. The snow layer is generally thin, although thicker patches occur where snow has been windblown into drifts. Photo A. Jensen.

South region aerial survey conditions, March 2019

Figure 69. Xeric inland sub-area just north of line transect 112 and in proximity to the Kangiata Nuuaata Sermia (to right but not in photo). View is west towards Kuussuaq (Austmannadalen), which is dark sided valley in distant background, center. Photo C. Cuyler.

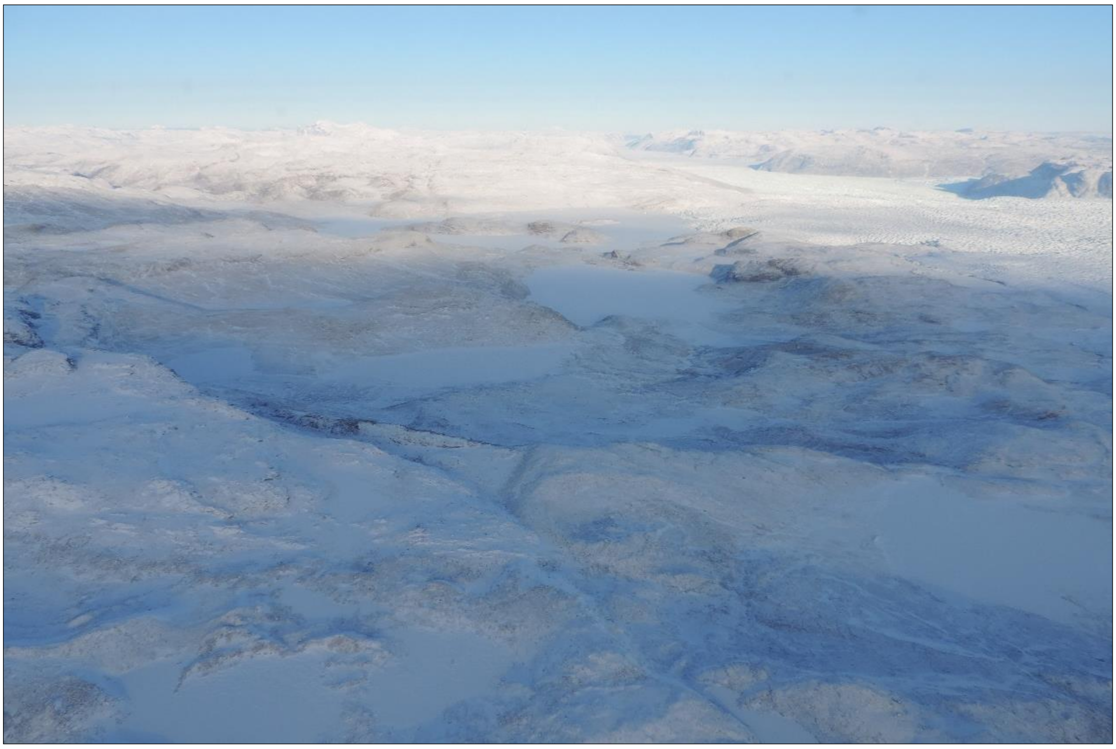


Figure 70. Xeric Inland sub-area, view north over the landscape and conditions on eastern portion of line transect 112. Note snow cover is a thin layer. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 71. Xeric Inland sub-area, around the middle of line transect 113, seven caribou, view west. Most of the ground has only a thin snow layer with sporadic deeper snow in patches. Photo A. Jensen.

Figure 72. Xeric Inland sub-area, valley at east end of line transect 113, ten caribou are almost invisible in vegetation poking through thin snow layer, view southeast to Isortuarsuk. Photo A. Jensen.

South region aerial survey conditions, March 2019

Figure 73. Xeric inland sub-area, line transect 114, east of lake, Isortuarsuk, view northeast, illustrating vegetation poking through the thin snow layer. Photo C. Cuyler.

Figure 74. Xeric inland sub-area, east end of line transect 114, view north, illustrating thin snow layer and Kangaarsuup Sermia and Greenland Ice Cap in background. Photo C. Cuyler.

South region aerial survey conditions, March 2019

Figure 75. Xeric Inland sub-area, while flying line transect 116. Above illustrates the approach to the south end of the lake, Isortuarsuk. Below, Isortuarsuk is just visible in background (left), view to ENE. Photos C. Cuyler.

South region aerial survey conditions, March 2019

Figure 76. Xeric inland sub-area, east end line transect 117, at the Greenland Ice Cap, ground view looking west. Photo C. Cuyler.

Figure 77. Xeric inland sub-area, line transect 117, at lake that emptied, view north. Photo A Jensen.

South region aerial survey conditions, March 2019

Figure 78. Xeric inland sub-area, illustrating condition on the line transect 118, which was flown from right to left (east to west) across the middle of this photo, view is south. Photo A. Jensen.

Figure 79. 'Finding Waldo' *camouflage conditions, Xeric inland sub-area, east end line transect 118 approaching the Greenland Ice Cap, view is east. Photo C. Cuyler.*

South region aerial survey conditions, March 2019

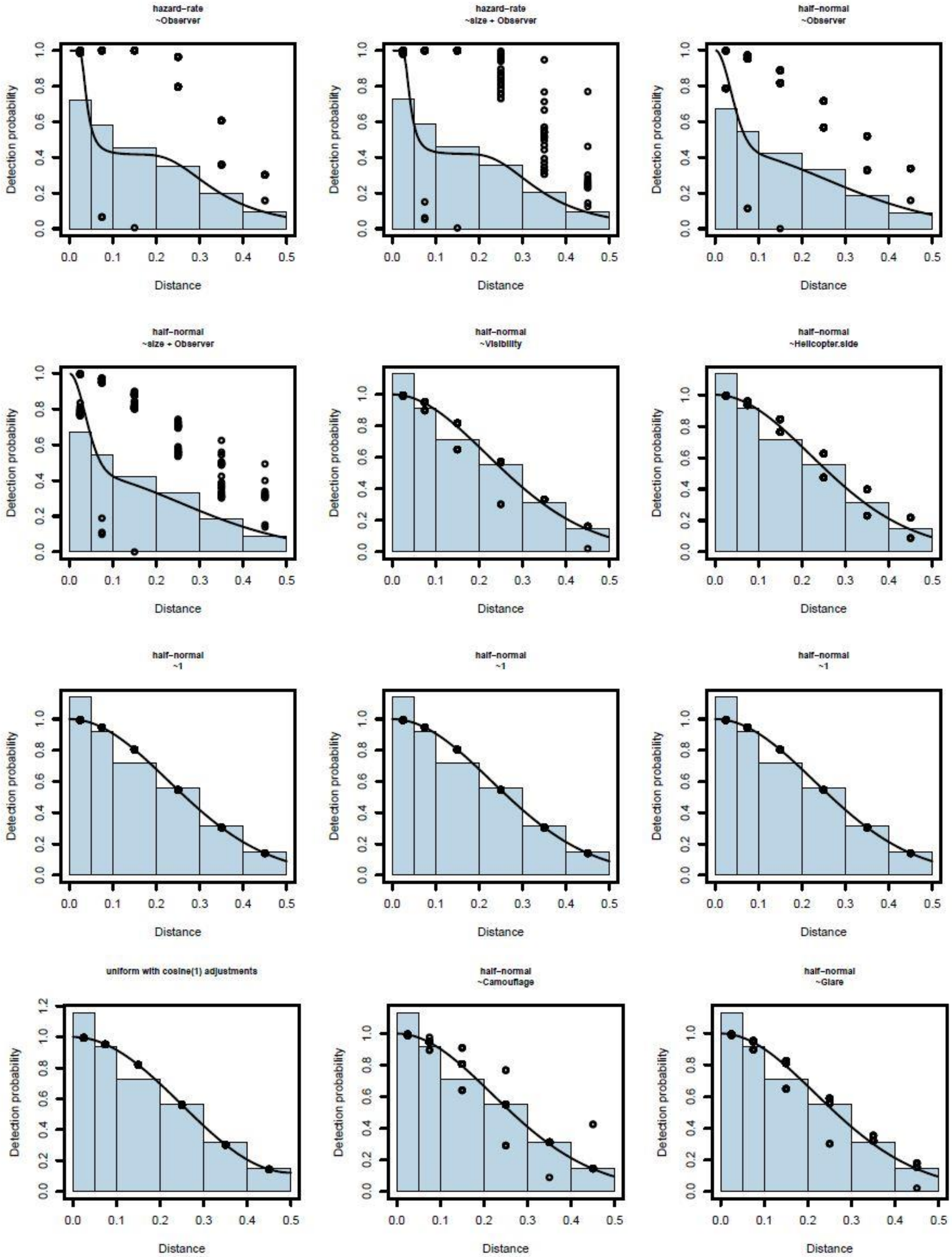
Figure 80. Xeric inland sub-area, east end line transect 119 at shore of lake, Ilulialik, view is northeast from southwest end of the lake. Photo A. Jensen.

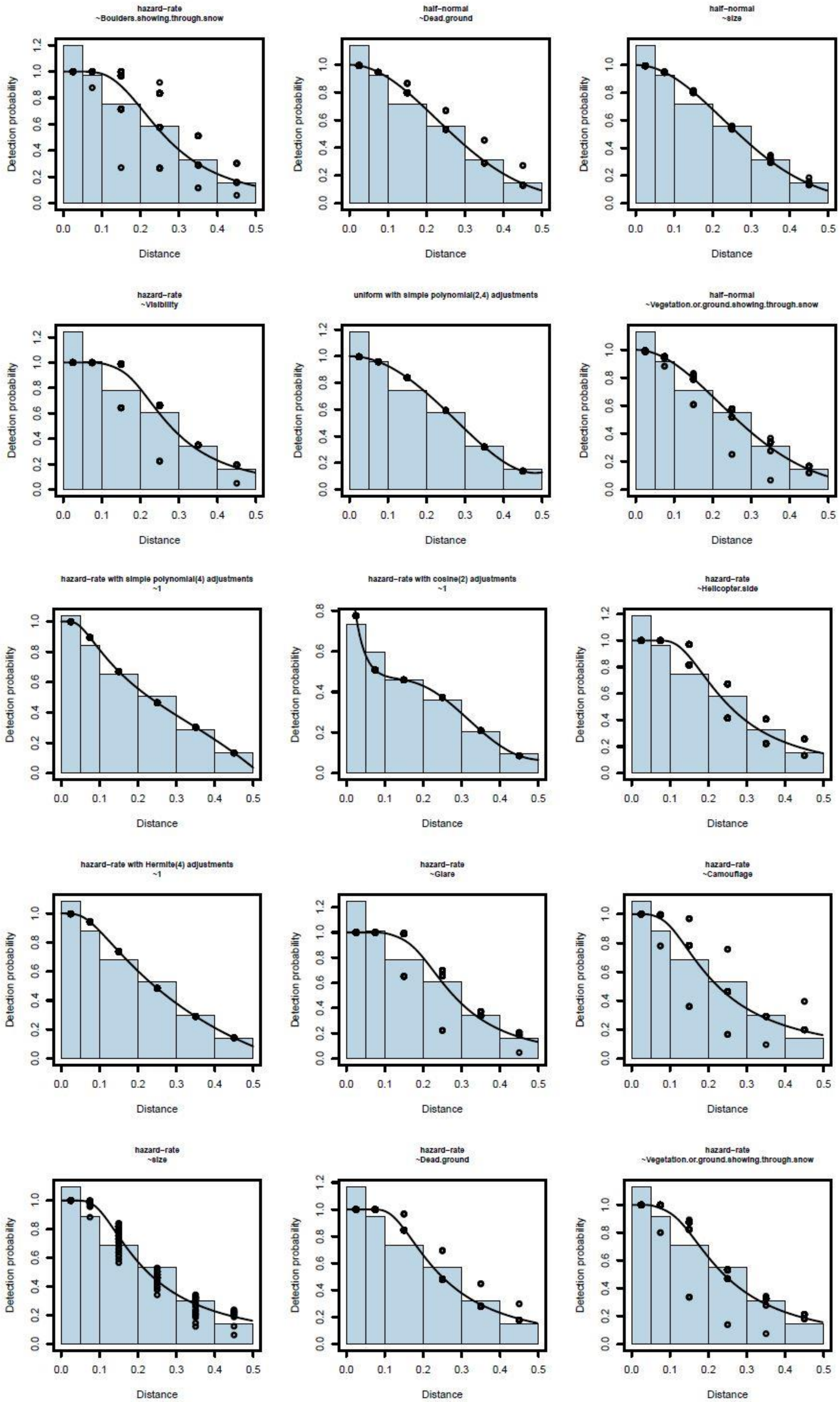
Figure 81. Xeric inland sub-area, view to SW end of the lake, Ilulialik and the east end point of line transect 119 at lakeshore. Line transect 119 came down off the highlands to the right. Photo A. Jensen.

Appendix 7

Histograms for detected distances

Histograms for detected distances superimposed with estimated detection functions for all truncated fitted models, presented order as in Table 3




hazard-rate
~Boulders.showing.through.snow
half-normal
~Dead.ground
half-normal
~size
hazard-rate
~Visibility
uniform with simple polynomial(2,4) adjustments
half-normal
~Vegetation.or.ground.showing.through.snow
hazard-rate with simple polynomial(4) adjustments
~1
hazard-rate with cosine(2) adjustments
~1
hazard-rate
~Helicopter.side
hazard-rate with Hermite(4) adjustments
~1
hazard-rate
~Glare
hazard-rate
~Camouflage
hazard-rate
~size
hazard-rate
~Dead.ground
hazard-rate
~Vegetation.or.ground.showing.through.snow
Detection probability
Distance

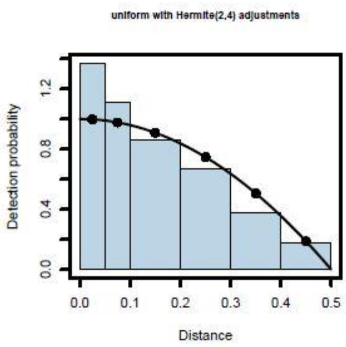


Figure 82. Histograms for detected distances superimposed with estimated detection functions for all truncated fitted models.

The parameter estimates and variability associated with them (Table 13), essentially illustrates that the "Medium" visibility has a lower detection probability estimate than the "High" visibility (as also shown in Fig. 15).

Table 13. Detection function parameters' estimates.

	Estimate	Standard Error
Intercept	-1.444	0.074
Visibility Medium	-0.378	0.156

Note: Estimates are on log scale.

Appendix 8

Glacier bounded lakes that recently emptied, March 2019

While flying the 2019 aerial surveys (Central and South regions), we observed four lakes that had emptied recently (Figs. 83-87). All had connections to the Greenland Ice Cap or to glacial tongues. Likely more such lakes exist but were not detected because observations were limited to the apriori line transects flown.

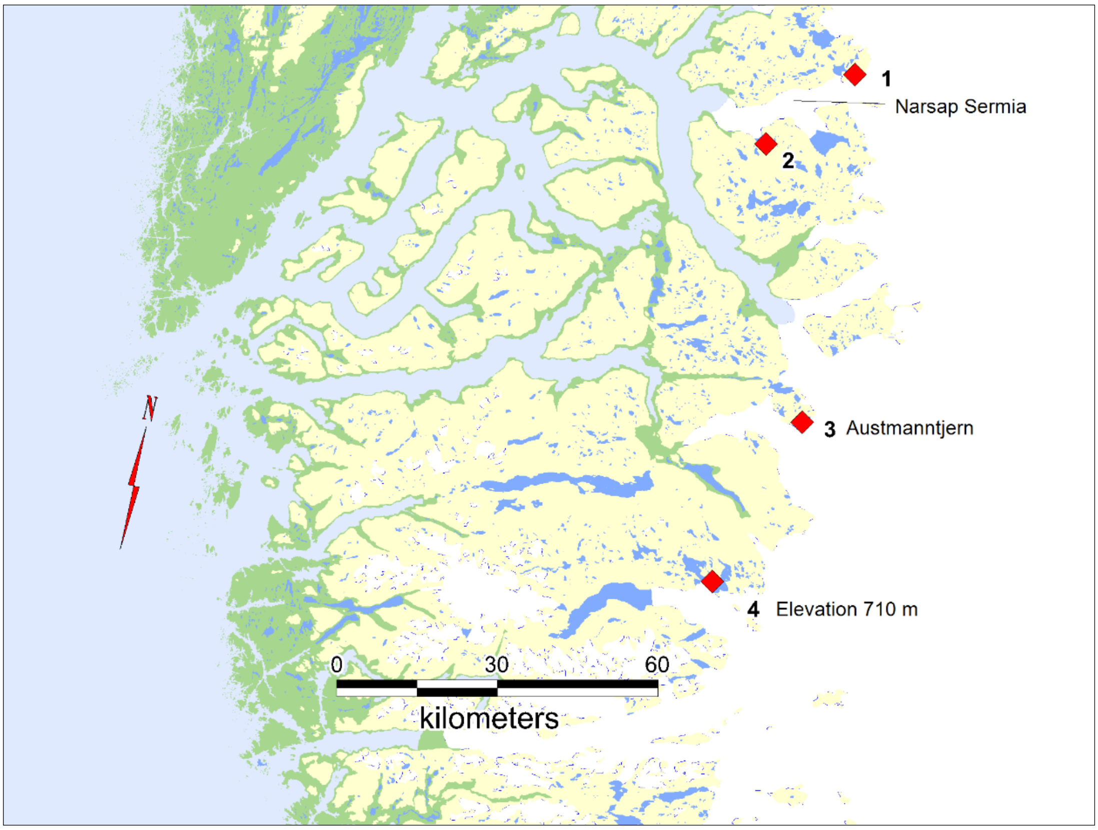


Figure 83. Locations of the four lakes observed to have recently emptied, before March 2019.

Glacier bounded lakes that recently emptied, March 2019

Figure 84. Small lake in Central region, Ujarassuit sub-area, that recently emptied in what appears to have been an all-at-once event, e.g., surface lake ice remains strewn on mountainside. Highwater line is indicated by thin ice-foot (right of center) running along mountainside. A previous highwater mark is suggested by the light-grey bare rock above the recent highwater ice-foot. This lake borders the north side of Narsap Sermia (Narsap Glacier), and line transect 27. (Fig. 83, Number 1). Photo C. Cuyler.

Figure 85. Emptied large lake in South region, Xeric Inland sub-area, illustrating marked highwater line on mountainside. Lake size and height of highwater line compared to current elevation of lake surface suggests an enormous water volume was involved in the emptying event, which may have been prior to freeze up winter 2018/2019, since there is no visible disturbance to surface ice along the lake shore. This lake borders the south side of the Narsap Sermia (Narsap Glacier), and line transect 101. (Fig. 83, Number 2). Photo C. Cuyler.

Glacier bounded lakes that recently emptied, March 2019

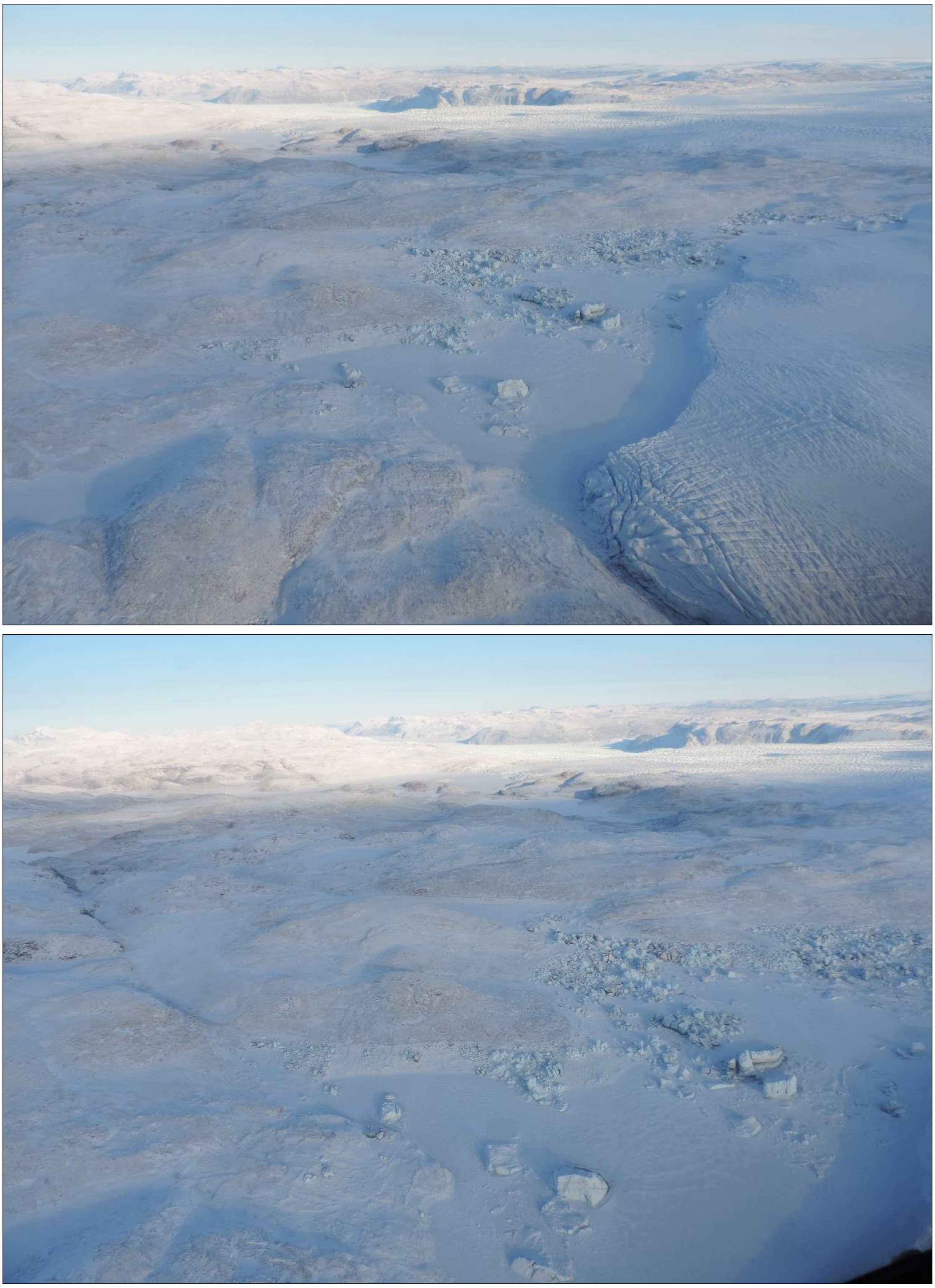


Figure 86. Recently emptied pond, Austmanntjern, near east end of line transect 112, at Greenland Ice Cap, Xeric Inland sub-area, South region. Google Earth Pro image (taken 2014) shows Austmanntjern much enlarged, while by March 2019 it had emptied. Strewn placement of ice chunks suggests emptying occurred post summer 2018 and all-at-once. Above view is to the north, below is to northwest. (Fig. 83, Number 3). Photos C. Cuyler.

Glacier bounded lakes that recently emptied, March 2019

Figure 87. Large unnamed lake in South region, Xeric Inland sub-area, on the north side of line transect 117. This lake borders the north side of a Greenland Ice Cap glacial tongue There were at least five highwater lines on the black mountainside (right side of bottom photo). This suggests the lake has emptied to its present surface level in five stages. While the timing of those events is unknown, the most recent may have been prior to freeze up winter 2018/2019, since there is no visible disturbance to surface ice along the lake shore. Previous lake surface elevation from standard maps was 710 m. Emptying water would pass through the lake, Isortuarsuup Tasia. The Alanngorlia fjord is known for abrupt rises in sea level owing to lake emptying. (Fig. 83, Number 4). Photo A. Jensen.

Appendix 9
Recommendations for improving future surveys

Aerial survey methods & design

The 9.7% survey coverage for the 2019 Distance Sampling (DS) survey of the Ameralik caribou population, promotes accuracy of abundance estimates and should be maintained or improved in the future to permit evaluating population trends. When flying line transects, distance and other factors often make identification of calves impossible, resulting in an underestimate of calf number. Demographic (sex, age, calf recruitment) data must continue to be collected in efforts separate from flying the line transects for DS.

Flight altitudes from 30 to 40 m permit scanning the landscape for caribou even out to 1000-1500m from the track line without dead-ground interfering. Just be aware the degree to which the caribou are extremely camouflaged against the typical backgrounds. This can cause observer fatigue, mental exhaustion, even at the relatively slow speeds flown (60-70 km/hour). Any 'dead' ground causing caribou detections to be missed, will likely be mitigated by the DS analysis.

Training and testing, observer ability to judge correct distance bin is necessary for improvement of this important variable. It is the author's experience that without practice people commonly misjudge distance. Looking down from above can exacerbate this tendency. Flat terrain may provide a more (normal) horizontal line-of-sight to the animals, which may increase binning accuracy. However, terrain that slopes away, either up or down, confuses observers' ability to judge distance from track line to animals. The steeper the slope, the greater the errors.

The timing for aerial surveys could remain early March because that coincides with annual minimum caribou movement (avoids double counting), and enough day length for flying the pilot maximum of 7-hours per day. Experience from eight surveys since 2000 has illustrated that snow cover and depth is variable regardless of the winter period chosen.

In Greenland, helicopters are seldom available at short notice. Book about 3-5 months ahead and reaffirm booking several times thereafter. For estimating the necessary window (dates) that helicopter is booked for survey, first calculate the number of days required for survey. Then, add days to allow for several non-flying days owing to pilot flying hours going over weekly limit, airport closures on Sundays, and poor weather. For the latter a minimum 3-4 days should be allocated.

Book survey observers early (Fig. 88), about six months in advance, to ensure the probability of obtaining the observers you require. Attributes would include previous experience detecting superbly camouflaged caribou, and proven lack of nausea, e.g., on ships at sea or in helicopters. Even the usually sedate helicopter maneuvers for line transects can illicit nausea in some. Meanwhile, the non-stop abrupt flying maneuvers required to obtain caribou demographics cause nausea in most persons.
Note: Previous helicopter experience, including animal live capture, does not guarantee lack of nausea during sharp the maneuvers specific to caribou demographics work.

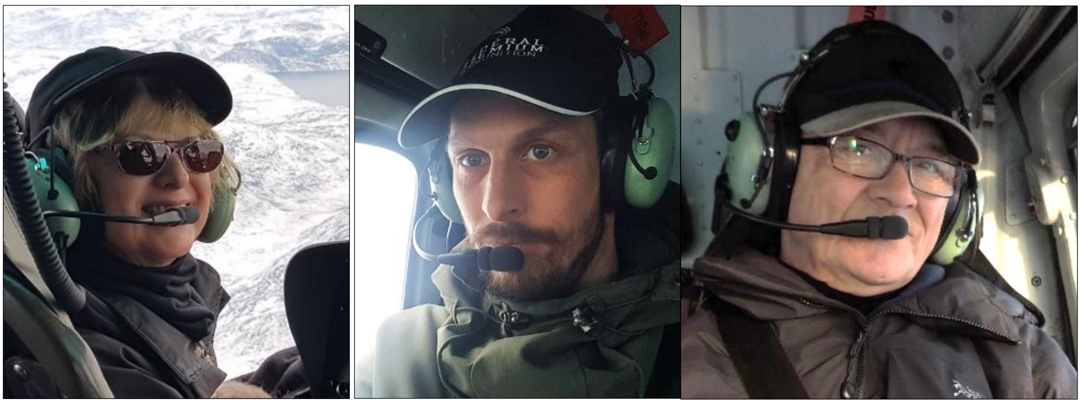


Figure 88. The three observers, Dr. Christine Cuyler, scientific leader (left), Aslak Jensen, commercial hunter (center), and Hans Mølgaard, Sisimiut hunting officer (right).

Standardization of data collection regarding surface conditions
Prior to 2019, the covariates (including degree of camouflage, % snow cover, snow depth, icing, visibility, lighting (e.g., flat light, shadow), presence of boulders and their size, vegetation poking through snow layers, etc.) were recorded without standardization and often ad hoc. In contrast the 2019 survey used specific standardized qualitative terms to make the covariates available for analyses. Evaluations for all environmental covariates were standardized to just five easy qualitative terms: Zero, Low, Medium, High, and Extreme. However, there were too many covariates to permit recording each with every detection of the object-of-interest (caribou).

If the covariates are to be useful in analyses, an evaluation must be assigned for most caribou detections, ideally for all. However, this is usually impossible with current methods, given groups often appear in rapid succession, which leaves little time to record the survey's prerequisite data. The three prerequisites (species, distance, group size) must be recorded accurately or the survey analyses cannot estimate population density and size. To date, behavior has also been recorded for those caribou detections where time permitted it. Under current methods (including using one recorder/line observer and two side observers), to add the recording of several covariates for each caribou detection might compromise the three prerequisite data collected.

Thus, we recommend that future DS surveys combine all the covariates that contribute to caribou becoming difficult to detect in the terrain into a single covariate. For example, combine the covariates camouflage, vegetation/ground showing through the snow surface and boulders of the same, flat light, snow cover, etc., into a single umbrella covariate named "camo" with qualitative index: Zero, Low, Medium, High, and Extreme. A single umbrella covariate incorporating all environmental factors will improve how caribou "invisibility" interacts with Key Functions to model the detection function.

Figure 89. AS350 Helicopter viewing windows for the left and right sides, illustrating small rear window size and the numerous impediments obstructing viewing.

Logistics
Check if other helicopter options are available. To date, the smallest helicopter available is the AS350 from Air Greenland, Charter Department. Although AS350 engine capacity is excellent for handling adverse weather, the side windows limit vision for rear observers owing to small window size, and several bar/struts (Fig. 89). Further, under cold ambient temperatures all windows typically fog with ice-frost. These factors reduce overall vision.

Although normal to reconfirm booking several times with the helicopter charter company in the months leading up to survey, i.e., both helicopter and pilot(s) are available for entire survey period and from the specific airport from which the survey will be operating and based in. Despite these precautions, three days were truncated from 2019 survey period owing to charter company mistake, which allocated all pilots to obligatory training in another region. Thus, reconfirmation is also recommended during the survey period itself.

Appendix 10

Recent caribou population estimates & minimum counts for West Greenland

Table 14. *Population estimates and minimum counts of caribou populations in West Greenland, 2000-2019, given in order from north to south.*

Caribou Population	Caribou Region Name	Caribou Hunting Area	2000	2001	2002	2005	2006	2010	2012	2018	2019
Naternaq	Naternaq	1	-	-	-	-	-	-	-	-	-
Kangerlussuaq-Sisimiut	North	2	51,600[2]	-	-	90,464[2]	-	98,300		60,469* (73,895[3])	
Akia-Maniitsoq	Central	3	-	46,236	-	35,807		24,000			48,941
Ameralik	South	4	-	31,880	-	-	9,680	-	11,700*		19,503
Qeqertarsuatsiaat	South	5	-	5,372	-	-	5,224	-	4,800*		
Qassit	Paamiut	6	196**	-	-	-	-	-			
Neria	Paamiut	7	1,600 (332**)	-	-	-	-	-			
Total Greenland Estimate			-	**140,000[1]**	-	-	**141,000[1a]**	-	**139,000[1b]**	**103,000[1c]**	**134,000[1d]**

*Estimates for the 2012 survey of South region and 2018 survey of North region used DS survey methods as compared to the random strip survey methods of 2001, 2006 and 2010.
** Minimum count.
[1] Rough sum of population estimates obtained in 1999 (not shown), 2000 and 2001.
[1a] Rough sum of population estimates obtained in 2005 and 2006.
[1b] Rough sum of population estimates obtained in 2010 and 2012.
[1c] Rough sum of population estimates obtained in 2018 and those for most recent estimate from other populations.
[1d] Rough sum of population estimates obtained in 2019 and those for most recent estimate from other populations.
[2] Kangerlussuaq-Sisimiut estimates from 2000 and 2005 were obtained using somewhat dissimilar methods, i.e., the 2005 survey reduced flight altitude by 85 m, speed by *ca.* 45 km/hr, and strip width by 400 m. The two estimates are therefore not assumed readily comparable and should not be interpreted as indicating population trend for this population for the period 2000-2005.
[3] Model-based population estimate (Correia 2020).
Sources: Cuyler et al. 2002, 2003, 2004, 2005, 2007, 2011, 2016, 2021, 2023 and current study.

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