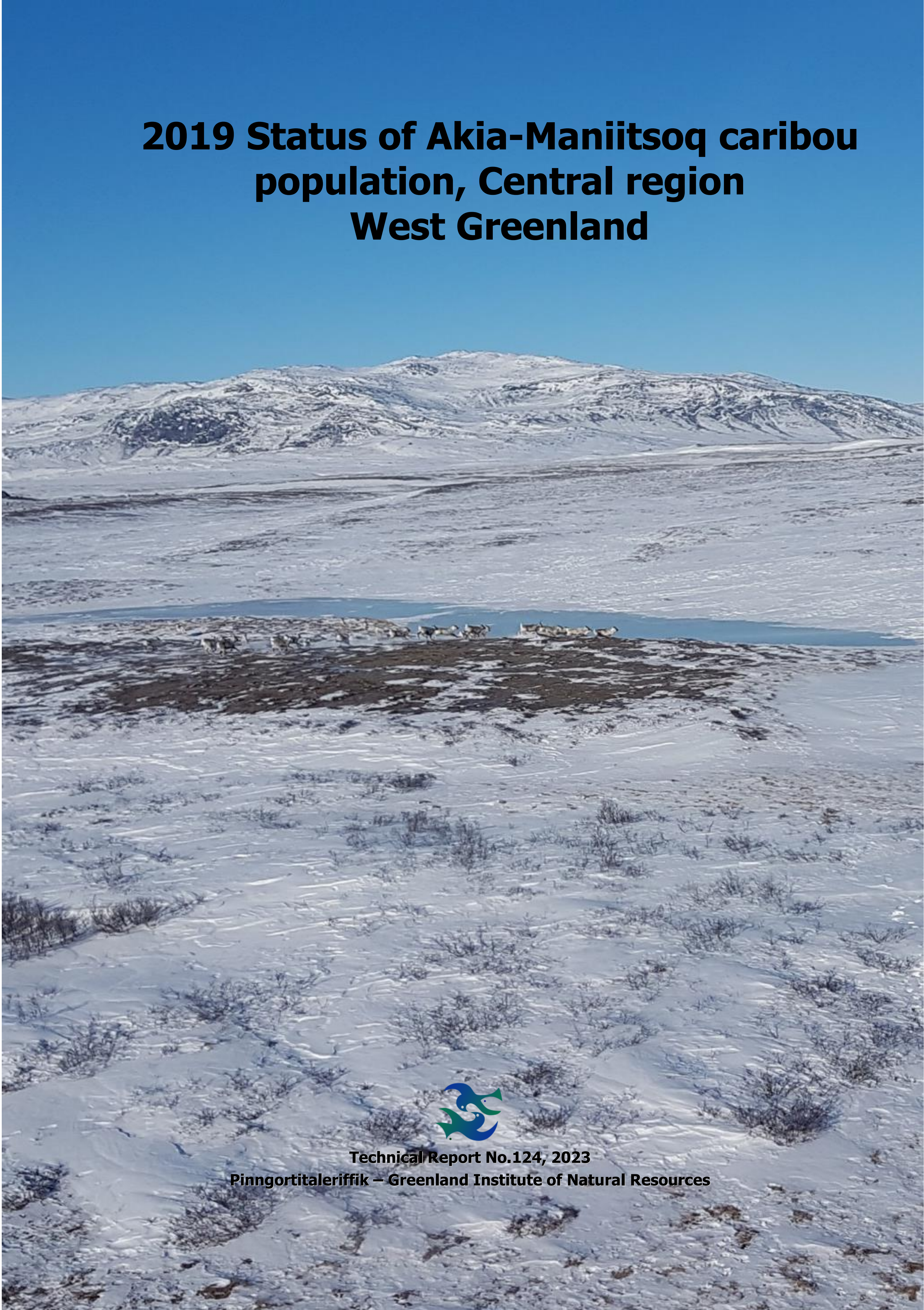
2019 Status of Akia-Maniitsoq caribou population, Central region West Greenland



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Cover photo: Aslak Jensen: One of many large caribou groups for the Akia-Maniitsoq population, Narssarssuaq valley, Central region.

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2019 Status of Akia-Maniitsoq caribou population, Central region, West Greenland

By

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Raw data may be accessed by contacting Pinngortitaleriffik – Greenland Institute of Natural Resources, Department of Mammals and Birds.

Summary (English)

This report presents results from the aerial survey carried out by helicopter in early March 2019, for the Akia-Maniitsoq caribou population inhabiting the Central region in West Greenland. This population was last surveyed in March 2010. New estimates of abundance were overdue. Helicopter surveys in 2001, 2005 and 2010 used strip transect counts. The March 2019 helicopter survey, however, used Distance Sampling methods.

For March 2019, the Akia-Maniitsoq caribou population abundance was estimated at 48,941 caribou (95% CI: 37,612 – 63,682; CV = 0.131; SE = 6390), with a density of 4.2 ± 0.5 caribou/km^2 (95% CI: 3.2–5.5). The distance sampling estimate was precise given the excellent CV value (0.13). Survey coverage was 9.6% (truncated data), which is a ca. five-fold improvement from the 2001, 2005, 2010 strip transect count surveys, where coverage was always below 2%.

Despite 18 years of harvest management aimed at controlling caribou abundance and density, by March 2019 Akia-Maniitsoq caribou population size was double what it was in 2010. Confidence Intervals for the 2010 and 2019 survey estimates do not overlap, therefore we conclude the Akia-Maniitsoq population size truly doubled over the nine-year period, 2010-2019.

The overall density estimate for the Akia-Maniitsoq population was 4.2 caribou per km^2. This value is much greater than the management recommended target of 1.2 caribou per km^2 (Kingsley & Cuyler 2002, Cuyler et al. 2007). Further, density in the Akia sub-area averaged 6.6 caribou per km^2. Exceeding the target caribou density is assumed to raise the risk of overgrazing and thus decline in caribou abundance.

The late-winter calf percentage and calf recruitment were the highest ever recorded from helicopter surveys. Values remained high even after the unusually high number of orphan calves (n = 83) were removed from the calculations. The 2019 ratio of 49 bulls to 100 cows, reversed the downward trend (from 58 to 38 bulls per 100 cows) in 2001-2010 period for animals age > 1-year. We conclude the 2019 demographics of the Akia-Maniitsoq population provides potential for further growth in abundance, albeit notwithstanding 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 helicopters low and slow were critical factors permitting detection of caribou, specifically because 25% of all groups remained stationary.

Beyond population parameters, results of interest included relatively low elevations, mean 351 m, used by the Akia-Maniitsoq caribou population in early March. Among other things, this reflects the relative abundance of low elevations in the region. Further, although antlers are typical on female caribou, few (32%) cows possessed antlers in the Akia-Maniitsoq population.

Eqikkaaneq (kalaallisut)

Uani nalunaarusiami saqqummiunneqarput nunap immikkoortuani tuttutassiissutinik aqutsiviusuni qulimiguulik atorlugu Martsip aallartilaarnerani 2019-imi tuttunik kisitsinernit inernerit. Tuttut taakku pineqartut nunaatta kitaata qiterpasissuaniipput. Tuttutoqatigiiaat kingullermik kisitsivigineqarput martsimi 2010-mi. Taamanikkut tuttut amerlassusiisa missiliorneqarneranni amerlanaagaapput. Qulimiigulik atorlugu 2001-imi, 2005-imi, 2010-milu kisitsinerni periuseq atorneqartoq tassaavoq, qulimiguulimmit takusat aalajangersimasumik kisitseriaaseq, taaguuteqartinneqartoq Distance Sampling methods.

Akia-Maniitsumi tuttut marts 2019 48,941-nik (95% CI: 37,612 – 63,682; CV = 0.131; SE = 6390) amerlassuseqarnissaat missiliuunneqarpoq, naatsorsuinertigullu tuttut kvadratkilometer-imut, km^2-imut, eqimassuseqarnissaat 4.2 ± 0.5 tuttut/km^2 (95% CI: 3.2–5.5) aalajangiunneqarpoq. The distance sampling missiliussineq, CV-kisitsit ajunngilluinnartoq (0.13-ulluni). Nuna kisitsiviusoq qulangiuaarneqartorlu 9.6%-iuvoq (truncated data), tassuunalu takuneqarpoq tuttut 2001-imi, 2005-imi 2010-milu kisinneqarneranni tallimariaammik amerleriarsimasut, kisitseriaaseq taannarpiaq atorlugu, kisiannili nunap kisitsivigineqartup angissusia tamatigut 2 % ataattarsimagaa.

Naak ukiuni 18-ini tuttut ikilisarniarlugit kiisalu amerlassusiisigut eqimassusiisa aqussinnaalernissaat anguniarlugu aqutsisoqarsimagaluartoq, taamaattoq marts 2019-imi 2010-mut sanilliullugu marloriaammik amerlassuseqalersimapput. CI (confidence interval, tassa kisitsisit tutsuiginaataasa naatsorsuusiortunit %-lerneqarnerat) taamanernitsat imminnut qalleraatinngillat. Taamaattumik inerniliilluta naggasiivugut, Akia-Maniitsumi tuttut ukiut qulingiluat ingerlanerini, 2010-miit 2019-p tungaanut, marloriaammik amerleriarsimasut.

Kisitsisit tamakkiisumik isiginiarlugit tuttoqassutsip Akia-Maniitsumi eqimassusia kvadratkilometer-imut 4, 2-uvoq. Kisitsit taanna aqutsinikkut anguniagaasumit tuttut kvadratkilometer-imut 1,2 eqimassuseqarnissaannik (Kingsley & Cuyler 2002, Cuyler et al. 2007) anguniagaasumit qaffasinnipilussuuvoq. Nunallu immikkoortuata ilaanni allaat agguaqatigiissillugu 6.6 -inik eqimassuseqalersimanerat anguneqarsimalluni. Eqimassutsit qaffasippallaartut tuttut nerisassaalatsilernerannik naggataagullu allaat tuttuisatsinnerulerneranik kinguneqalersinnaanera ilimagineqarpoq.

Ukiuunerani, kingusissukkut, piaqqiaasartut aammalu tuttoqassutsip piaqqanik pilersorneqarnera qulimiguulimmik kisitsisoqartalermalli aatsaat taamak amerlatigalutik qaffasitsigipput. Kisitsisit qaffasippallaaqimmata piaqqat qaqutigoortumik kisimiittut amerlasuut (n=83) naatsorsuusiornernit peerneqarput. Tuttut inersimasut nikingassutaat 2019-imi arnavissat 100-gaangata angutivissat 49-t, angutivissat 2001-miit 2010-p tungaanut ikiliartuleraluarnerannik mumisitsivortaaq (imaakkaluarmatami arnavissat 100-ppata, 58-it arnaviaassapput angutivissat 38-ullutik), taakkunani tuttut ukioq ataasileereersimasut isiginiarneqarsimallutik. Taamaammat naggasiivugut 2009-mi tuttut agguataarsimanerat eqqarsaatigalugu Akia-Maniitsumi tuttut amerleriaqqinnissaminnut periarfissagissaarput; ukiarlussuimmi akiugassaarpianngitsut takuppallaartassanngippata aammalu tuttut nappaalavallaassanngippata.

Avatangiisitigut atugassarititaasut 2019-imi eqqarsaatigalugit, tuttut kisitsinerup nalaani aatsaat taama nunamut ilassuunnissaminnut periarfissagissaartigipput. Kisitsiniarneq erloqinaraluaqisoq, taamaattoq pikkorissunik kisitsisoqarnitta tuttut takusinnaatissimavai, qulimiguulillu kigaatsumik appasissumillu ingerlaarmat tamarmik iluaqutaasimapput. Taamaanneralu pingaaruteqarsimavoq, kisitsinerummi nalaani tuttut aqupisimasut sisamararterutaasa, 25 %it, missaanniissimagamik.

Tuttunut tunngasorpiaat saniatigut misissuinerit takutippaat, Akia-Maniitsumi tuttoqatigiiaat immamiit agguaqatigiissillugu 351 m missaanni qatsissusilik angullugu martsip aallartilaarnerani appasissutsiniissimapput, appasissuniinniarsimapput. Aamma kulavaat 32 %-ii taamaallaat Akia-Maniitsumi nassunissimapput.

Tuttunut tunngasorpiaat tunulaassagaanni misisissuinerup takutippaa Aqutsiveqarfimmi Akia-Maniitsumi tuttut appasingaatsiartuni inissisimasimasut (agguaqatigiissillugu immamiit 351 m), tassa martsip aallartinnerani. Tamatumalu takutippaa nunap immikkoortuani tamaani nuna pukkikajaartuusoq. Aammalu tuttut arnavissat akornanni nassoqartarneq nalinginnaagaluartoq, kulavaat ikittuinnaat misissuinerup nalaani nassunis-simammata (32 % miss.).

Resumé (dansk)

Denne rapport omhandler resultater fra helikoptertællingen af rensdyr i Akia-Maniitsoq-bestanden i det centrale Vestgrønland foretaget i begyndelsen af marts 2019. Bestanden blev sidst optalt i marts 2010. Helikoptertællingerne i 2001, 2005 og 2010 blev udført som transekt-tællinger. Helikoptertællingen i marts 2019 blev udført ved hjælp af "Distance Sampling" (DS).

Akia-Maniitsoq-bestanden blev i marts 2019 anslået til 48.941 rensdyr (95 %-konfidensinterval: 37.612-63.682; variationskoefficient = 0,131; standardafvigelse = 6390), med en tæthed på 4,2 ± 0,5 rensdyr/km^2 (95 %-konfidensinterval = 3,2–5,5). Transekterne der blev fløjet dækkede 9,6 % af det totale areal, hvilket er ca. en femdobling i forhold til transekt-tællingerne fra 2001, 2005 og 2010, hvor dækningen var under 2 %.

På trods af, at man i 18 år har forsøgt at regulere bestandsstørrelsen og bestandstætheden, var Akia-Maniitsoq-bestanden i marts 2019 dobbelt stå stor som i 2010. Konfidensintervallerne for tællingerne i 2010 og 2019 overlapper ikke, dermed vores konklusion er, at Akia-Maniitsoq-bestanden reelt er fordoblet i løbet af den niårige periode (2010-2019).

Akia-Maniitsoq-bestandens tæthed var 4,2 rensdyr pr. km^2. Dette er langt højere end de anbefalede 1,2 rensdyr pr. km^2 (Kingsley & Cuyler 2002, Cuyler et al. 2007). Desuden var bestandstætheden i Akia-delområdet på gennemsnitligt 6,6 rensdyr pr. km^2. En overskridelse af den anbefalede bestandstæthed formodes at øge risikoen for overgræsning og dermed risikoen for nedgang i rensdyrbestanden.

Andelen af kalve sidst på vinteren og kalverekrutteringen viste de højeste værdier, der nogensinde er registreret ved helikoptertællinger. Værdierne forblev høje, selv efter at et usædvanligt højt antal moderløse kalve (n = 83) blev taget ud af beregningerne. Forholdet mellem hanner (tyre) og hunner (simler) i 2019 på 49:100 vendte den nedadgående tendens (fra 58:100 til 38:100) i perioden 2001-2010 for dyr ældre end 1 år. Vores konklusion er, at demografien i 2019 i Akia-Maniitsoq-bestanden kan være tegn på, at bestanden kan vokse yderligere, forudsat at der ikke opstår uforudsigelige og tilfældige katastrofale vejrforhold eller patogen udbrud i fremtiden.

Vejrforholdene under 2019-optællingen gjorde, at rensdyr var ekstra camouflerede. Ved at samle vejrmæssige kovarianter i et enkelt camouflage-indeks forbedredes ”detection function modelling” (en proces i DS-udregningerne). Det var muligt at spotte rensdyr, fordi der blev anvendt dygtige observatører, og helikopteren fløj langsomt og lavt. Det var især vigtigt, fordi 25 % af alle rensdyrflokkene stod stille.

Ud over at give bestandsparametre viste undersøgelsen, at Akia-Maniitsoq-bestanden opholdt sig i relativt lavtliggende områder (i gennemsnit 351 m over havets overflade) i begyndelsen af marts. Dette afspejler bl.a., at der er relativt mange lavtliggende områder i regionen. Desuden, selv om gevirer er typiske på rensdyr simler (hunkøn), var der kun få (32 %) af simlerne i Akia-Maniitsoq-bestanden der havde gevirer.

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 Central region (Fig. 1), which contains the caribou population named Akia-Maniitsoq and corresponds with the Government of Greenland's caribou management hunting area 3, shared by two Kommunia (municipalities), Nuuk and Qeqqata.

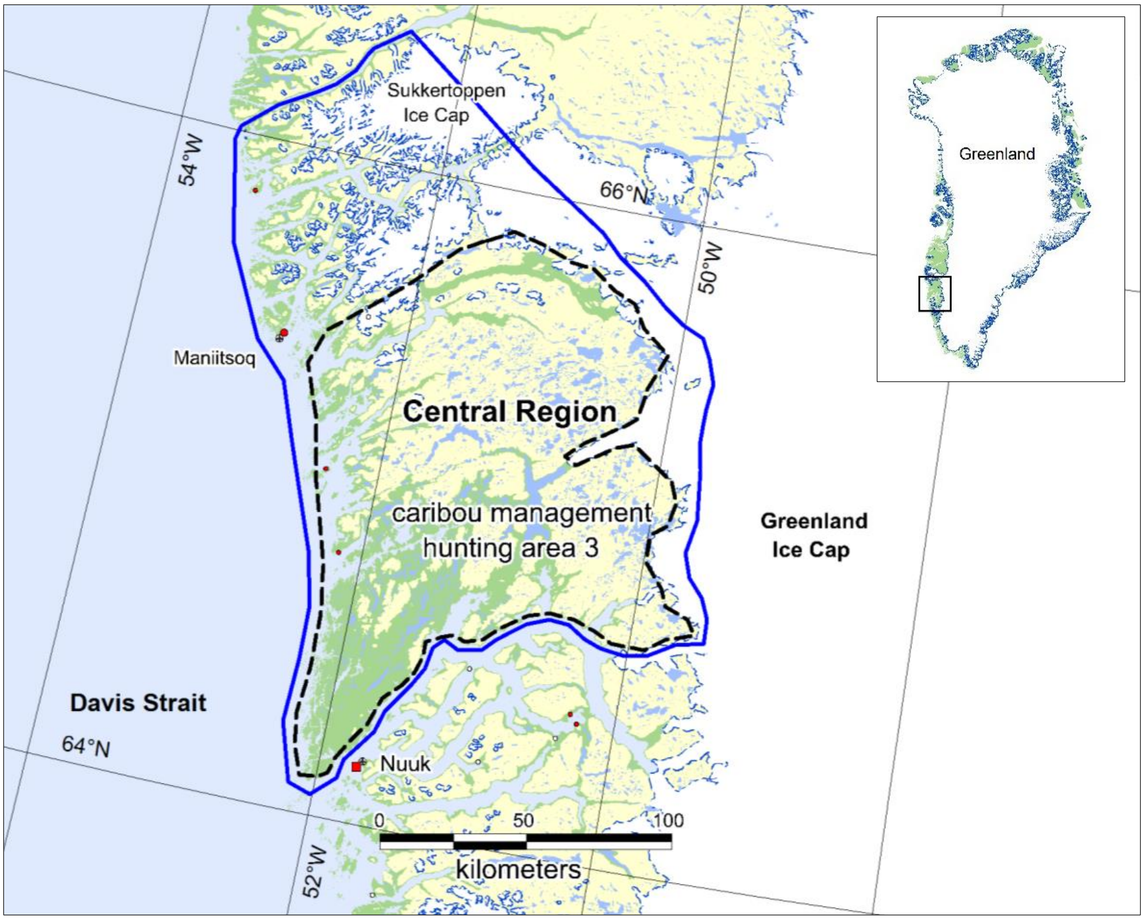

*Figure 1. Border of the Central region (blue), which corresponds with the Government of Greenland caribou management hunting area 3 and contains the Akia-Maniitsoq caribou population. Area of survey effort is outlined by dashes (**black**). Elevations below 200m are green and above 200m are light yellow.*

Survey methodology for Akia-Maniitsoq caribou population remained the same from 2001 to 2010 (Cuyler et al. 2011). All used similar strip transect counts, which makes it likely the resulting estimates indicate population trend for abundance within that period, i.e., abundance and density seemingly declined (Table 1). Meanwhile, in the period 1998-2005, calf percentage and recruitment were initially high and then decreased but seemed to stabilize for the 2005-2010 period, albeit at a low value that suggested population decline was possible. The number of bulls to cows was initially high in 1998-2000 period and declined thereafter, which also suggested population decline was possible.

Table 1. Late winter population parameters, Akia-Maniitsoq caribou population of Central region, West Greenland, taken from 1998 and 2000 ground (snowmobile) surveys for demographics (Cuyler unpublished) and the 2001, 2005, and 2010 aerial (helicopter) strip transect count surveys (Cuyler et al. 2003, 2005, 2011).

Parameter	**1998**	**2000**	**2001**	**2005**	**2010**
Population size estimate	-	-	46,236	35,807	23,989
90% Confidence Interval (CI) – lower	-	-	37,115*	24,474	16,667
90% Confidence Interval (CI) – upper	-	-	55,808*	44,720	31,311
Coefficient of Variation (CV)	-	-	-	-	0.18
Standard Error (SE)	-	-	-	-	-
Density per sq km	-	-	1.1 to 4.0[a]	1 to 3[a]	1.5 to 1.6[a]
Mean group size ± SD	6.4	3.6	3.2	4.3 ± 2.9	4.81 ± 4.14
Max group size	36	17	18	17	31
Calf percentage **	25 %	20	17 %	14 %	14.4 %
Recruitment (Calf /100 Cow) **	65	49	31	24	23.2
Sex ratio adults (Bull /100 Cow) **	92	100	58	45	38

*80% CI

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

[a] Low to High density strata

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 Akia-Maniitsoq caribou population was in March 2010. Since then, there have been long and unlimited autumn harvests, and, albeit short, often winter hunting seasons. The winter 2019 caribou hunting season for the Central region lasted two weeks, 01-15 February, with a quota of 200 caribou for Akia-Maniitsoq (Naalakkersuisut 2019). In early March 2019, the Greenland Institute of Natural Resources (GINR) again examined by aerial helicopter survey the Akia-Maniitsoq caribou population in the Central region (hunting area 3) of West Greenland.

The 2019 survey used systematic line transects and Conventional Distance Sampling (CDS), i.e., 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 first-time systematic line transects and CDS were applied to survey the Akia-Maniitsoq caribou population to obtain estimates of abundance and density. Previously (2001, 2005 and 2010) was surveyed using multiple short length random line transect strips. 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 Akia-Maniitsoq population in the Central region. Initially, we use DS analyses to present pre-calving estimates for 2019 abundance and density of the Akia-Maniitsoq 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 areas

Common to West Greenland, the Central 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 (Appendix 1, Figs. 31-34, 37-46).

In addition to caribou, there are just three wild mammals present in the Central region: arctic hare (*Lepus arcticus* Rhoads), arctic fox (*Vulpes lagopus* Linnaeus), and since ca. 1998, muskoxen (*Ovibos moschatus* Zimmermann) (Cuyler et al. 2016, Cuyler 2020). The arctic fox is the only terrestrial mammalian predator, as large mammalian predators are absent. By natural emigration, muskoxen inhabiting the North region (ca. 66°–67°45′N; 49°30′–54°W) expanded southward into the Central region (Cuyler unpublished). Regional borders are semi-permeable permitting limited animal movement between adjacent regions. Nevertheless, borders are likely effective barriers preventing mass animal movements (Linnell et al. 2000).

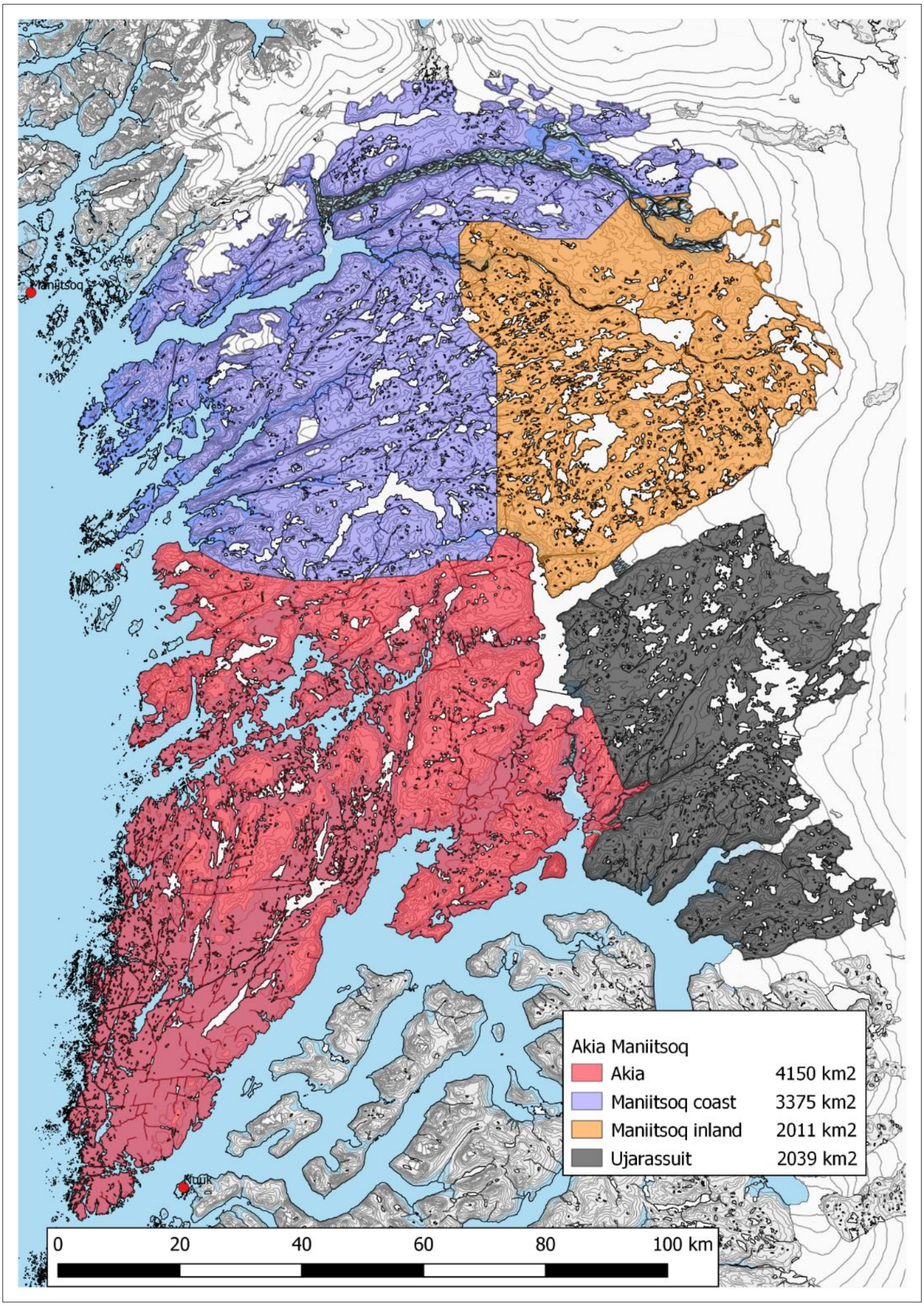

Figure 2. Area covered by the 2019 survey of the Central region (11,575 km²), which is inhabited by the Akia-Maniitsoq caribou population. Four different colours illustrate the four sub-areas, designated as Akia, Maniitsoq coast, Maniitsoq inland, and Ujarassuit. Greenland's capital city, Nuuk, is the red diamond on the tip of grey peninsula arm in bottom left corner.

The Central region (ca. 64°/64°45′–66°N; 50°–53°W) is shared by the Qeqqata and Nuuk Kommunia. The only large settlement, which is situated on an island, is the coastal city of Maniitsoq with ca. 2,534 inhabitants. Otherwise, there are three small villages, also coastal, which combined contain a further ca. 650 people. In 2019, use of snowmobiles was still prohibited beyond settlement boundaries. See Appendix 2 for place name details.

The Central region is seasonally ice-free and covers an area of 11,575 km^2, (excluding lakes, rivers, sand, glaciers, and islands) (Fig. 2). Previous surveys reported a less precise larger land area of ca. 15,362 km^2, which included lakes, rivers, and islands (Cuyler et al. 2003, 2005, 2011). The northern border is formed by two ice caps (i.e., Kangaamiut Sermiat (Sukkertoppen Ice Cap) and Tasersiap Sermia) and the western portion of the Kangerlussuaq Fjord. The southern border is framed by the Nuuk fjord (Godthåbsfjord), which currently is ice-free year-round to as far as Ilulialik Bay or the Ujarassuit paavat fjord-arm. The western border is the permanently ice-free seacoast of the Davis Strait, and the eastern border is the Greenland Ice Cap.

The coastal topography in the north is mountainous. Elevations are often 1000 to 2000 m and glaciers predominate. Midway, the coast is mountainous with peaks from about 500 to 1200 m. In the south, coastal topography is rugged lowlands of elevations generally below 200 m.

Field methods

Since 2000, early March has been the chosen period for 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 the Akia-Maniitsoq caribou population was 01-12 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 the 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 became combined during the survey, line identification numbers are not consecutive.

The surveyed Central region, 11,575 km^2, was divided into four sub-areas, named Akia (4,150 km^2), Maniitsoq Coast (3,375 km^2), Maniitsoq Inland (2,011 km^2) and Ujarassuit (2,039 km^2) (Fig. 2). Sampling design for the 2019 survey considered 50 systematic parallel line transects (track lines flown) of variable length placed over the four sub-areas (Fig. 3). Line transects were separated by 10 km, excepting Maniitsoq Coast sub-area, which were 20 km.

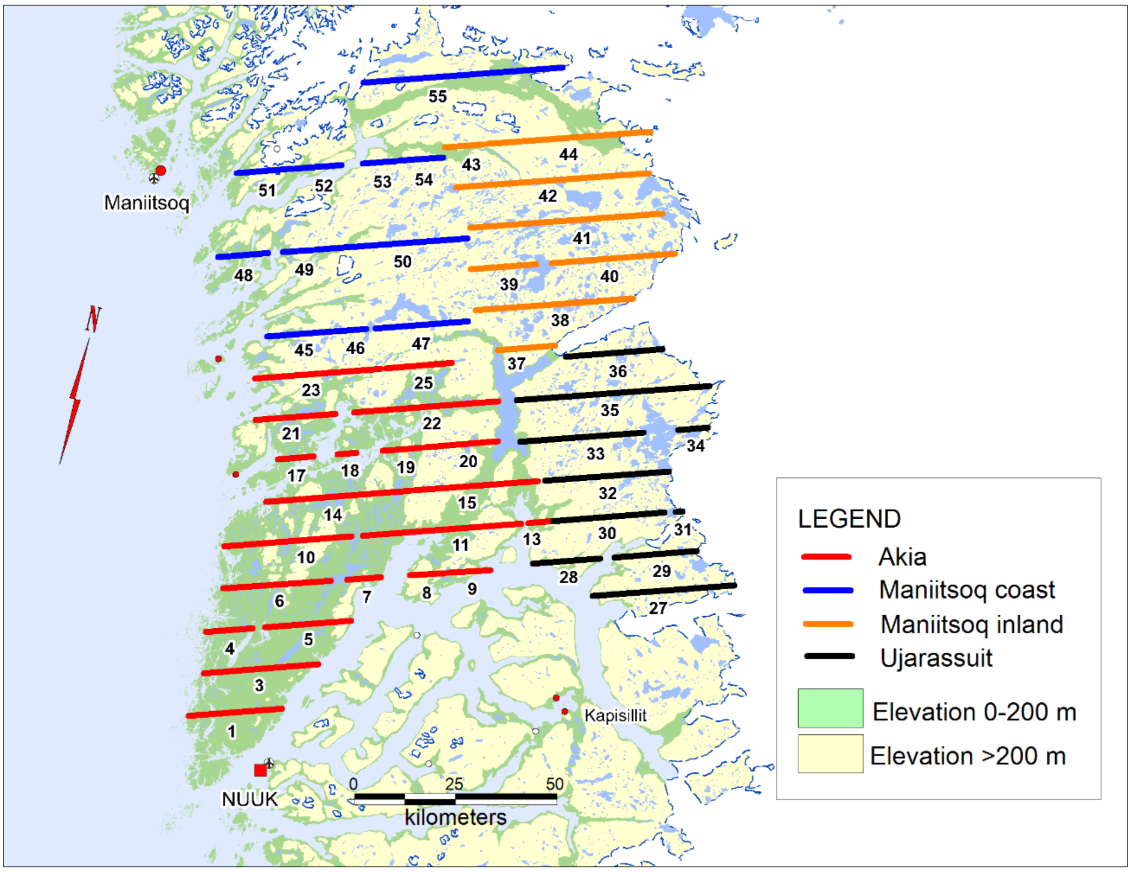

Figure 3. The 50 line transects used in the 2019 survey of the Central region, Akia-Maniitsoq caribou population, employing the same four colours as applied to the four sub-areas in figure 2: Akia (red, 21 lines), Maniitsoq Coast (blue, 11 lines), Maniitsoq Inland (orange, 8 lines), and Ujarassuit (black, 10 lines). Line transects separated by 10 km, except Maniitsoq Coast, which were separated by 20 km. Line transect numbering is not consecutive, as some a priori lines became amalgamated during survey.

The 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, 800-900, 900+. *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 re-coded the reported upper distance values to 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, 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 to determine 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). The model presenting the lowest AIC value was chosen. Details regarding DS theory, methods and analysis are available in Buckland et al. (2001, 2015), and a briefer summary provided in Appendix 3, with a summary of DS assumptions in Appendix 4. 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 the 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 12 and 13 March, large areas of the Central region were flown, including the south coast of Ujarassuit and Ilulialik, Akia-Nordlandet between Fiske- and Nuuk fjords, Narssarssuaq Valley and peninsula, area surrounding line 32 and between line 32 and 30.

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 the survey began. Before analysis, the helicopter's flight altitude of 40 m 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 Central region. 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 owing to natural causes. 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 Akia-Maniitsoq caribou population occurred within the period 01-14 March, which period was shared with the survey of the Ameralik caribou population. Poor weather made three days non-flyable, as did airport closures on two Sundays. DS data for the Akia-Maniitsoq caribou population was obtained over six days (01, 05, 06, 07, 09 and 12 March). Demographics data was obtained 12-13 March. Typical 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.

Table 2. Summary of unprocessed results: Survey of the Akia-Maniitsoq caribou population by helicopter in the Central region, 01-12 March 2019.

Parameter	**Central region sub-area**				**TOTAL**
	Akia	**Maniitsoq Coast**	**Maniitsoq Inland**	**Ujarassuit**	
Flight altitude (m)	40	40	40	40	**40**
Flight speed (km/hr)	60-70	60-70	60-70	60-70	**60-70**
Sub-area size (km^2)	4,150	3,375	2,011	2,039	**11,575**
Number of lines	21	11	8	10	**50**
Distance flown (km)	423.12	197.26	244.17	241.02	**1105.57**
Strip width[1] (m)	1000-1500	1000-1500	1000-1500	1000-1500	**1000-1500**
Surveyed area ca. (km^2)	846 - 1,269	394 - 592	488 - 732	482 - 723	**2,211 - 3,316**
Coverage[2]	20.4-30.6 %	11.7-17.5 %	24.3-36.4 %	23.6-35.5 %	**19.1-28.7 %**
Coverage post-truncation[3]	10.2 %	5.8 %	12.1 %	11.8 %	**9.6 %**
Total caribou observed	1540	276	391	608	**2,815**
# Groups observed	385	73	116	175	**749**
Mean group size	3.99	3.78	3.37	3.47	**3.75**
Std Deviation group size	± 3.46	± 3.80	± 1.97	± 2.04	**± 3.03**
Median group size	3	3	3	3	**3**
Maximum group size	25	22	10	15	**25**
Minimum group size	1	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 600 m.

[3] Coverage after truncation of the strip width to 600 m for DS analyses (see page 24).

The helicopter flight time totaled 34 hours and 38 minutes. This is 10 hours and 38 minutes more than flown in the last Central region survey, 2010. Time flown was divided between line transect DS survey (25 hours; 42 minutes) and the demographics survey (08 hours; 56 minutes). The 2019 survey used 50 line transects for a total distance flown of 1,106 km, i.e., Akia 423.1 km, Maniitsoq Coast 197.3 km, Maniitsoq Inland 244.2 km and Ujarassuit 241 km (Table 2).

Given the 1,106 km of line transects flown, an optimistic calculation of survey coverage of the Central region's surveyed Akia-Maniitsoq area (11,575 km^2) would be 19-29%, i.e., topography permitting and assuming maximum strip width of 1000-1500 m to either side of the helicopter (Table 2). However, for analyses (see DS analysis, page 24), the strip width was truncated to 600 m. Thus, coverage of the Central region surveyed was 9.6% for the final abundance and density estimates of the Akia-Maniitsoq caribou population. The observed raw totals were 749 caribou groups, which included 2,815 caribou (Table 2). Mean group size was 3.75 ±3.03 caribou, and median group size was 3 caribou.

Data processing

The raw data set was in Excel format containing the survey variables, including region, sub-area, respective areas (km^2), transect identification, recorded distances, group size, and GPS coordinates. Sometimes included with caribou group observations were flight characteristics such as helicopter velocity and side, as well as survey characteristics such as solar glare, weather, snow covering and depth, dead ground, and surface conditions providing camouflage backgrounds for the caribou. All 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 re-coded to make them sensible in R. One caribou observation lacked distance. Given just one observation relative to the large amount the data (n = 749), and since the actual impact of using any given distance value is minor, the pragmatic solution was to use the average observed distance. No observations lacked group size, so no replacements were necessary. Data truncation was set at 0.6 km.

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 Central region met these recommendations. Regarding observations (detections of groups of one or more caribou), for analysis the untruncated sample size was 749, while the truncated sample size was 734. Similarly, regarding the number of parallel transect lines separated by 10 or 20 km, there were 50 lines. Time required to complete a transect line depended on total length of the line. The following are the results for the truncated data (n = 734 detections).

Of the four sub-areas, the Akia sub-area dominated in observation frequency, i.e., number of detections (caribou groups) per sub-area (Fig. 4, 5). This was expected as Akia was the largest sub-area (ca. 4,150 km^2) and received the greatest line transect distance flown relative to the sub-areas, Maniitsoq coast, Maniitsoq inland, and Ujarassuit. Further, of the four sub-areas, Akia possesses the most lowlands (elevation < 200 m), and the Akia-Maniitsoq caribou population are known to prefer lowland elevations in late winter (Cuyler et a. 2017). Although caribou were detected on most of the 50 line transects, six line transects lacked caribou detections, i.e., line 4 (Akia), lines 51, 52, 53 (Maniitsoq Coast) and lines 31, 34 (Ujarassuit).

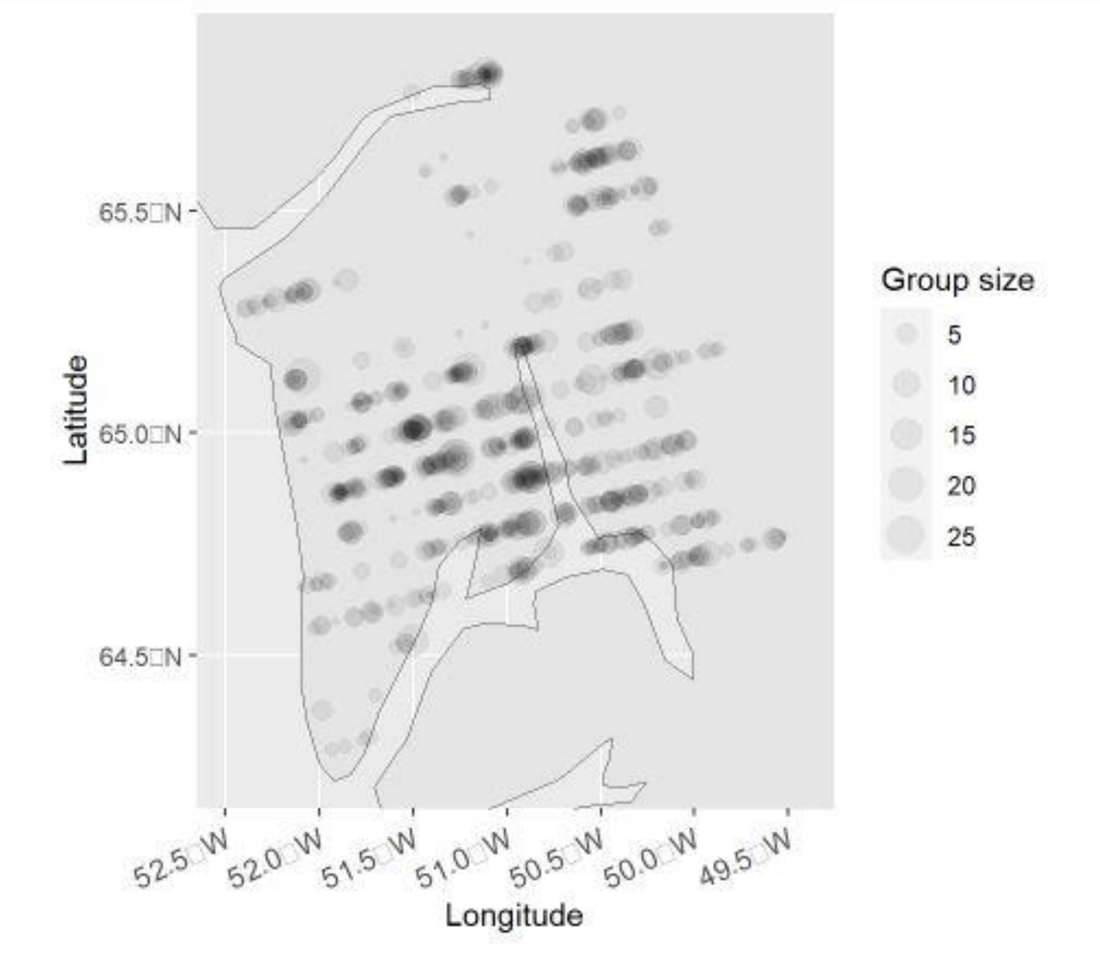

Figure 4. Location and group size of the detections (truncated data) observed along the line transects flown, 2019 survey of the Akia-Maniitsoq caribou population.

The detected objects of interest, i.e., caribou groups, typically included no more than six animals, while the most observed group size was two animals (n = 193 observations) (Fig. 6). Groups consisting of less than five individuals made up 73% of the observations, while groups counting less than ten individuals made up 96%. Larger groups were scarce and typically observed at greater distances.

For example, the largest caribou group size, observed once, had 25 caribou, and was detected at 0.4 km from the transect line. The helicopter's flight direction during the detections was relatively "even", but "West to East" direction was slightly more frequent.

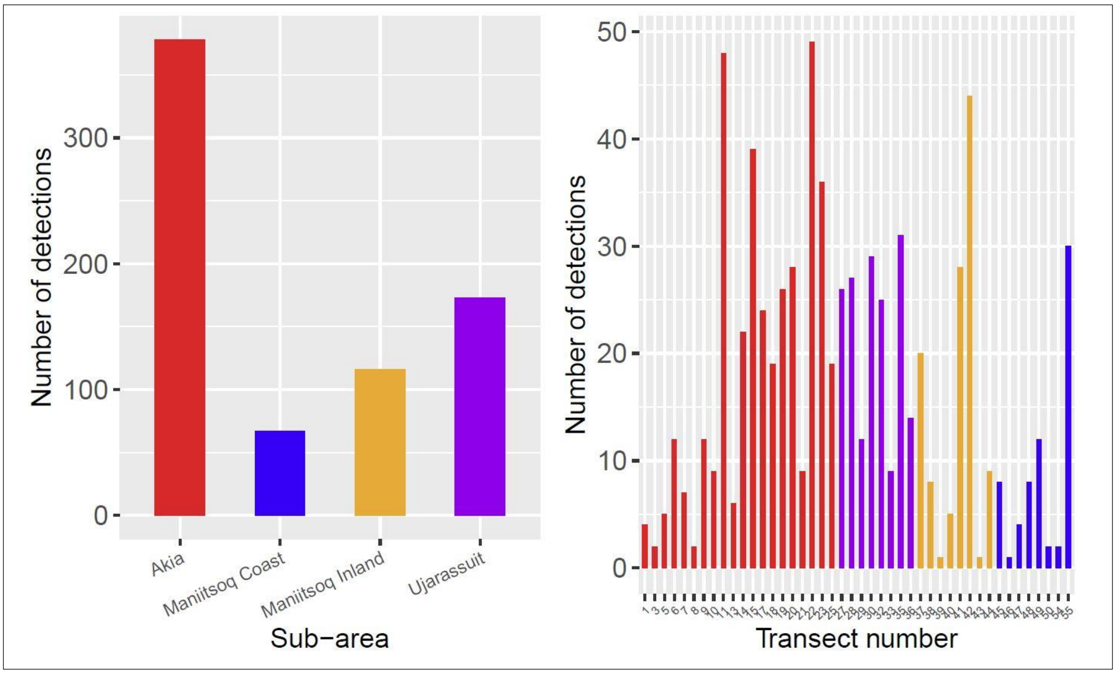

Figure 5. Exploratory analysis for the number of detections by sub-area (left), and number of detections per line transect by sub-area (right): Akia (red), Maniitsoq Coast (blue) Maniitsoq Inland (orange), and Ujarassuit (purple). Akia-Maniitsoq caribou population survey 2019.

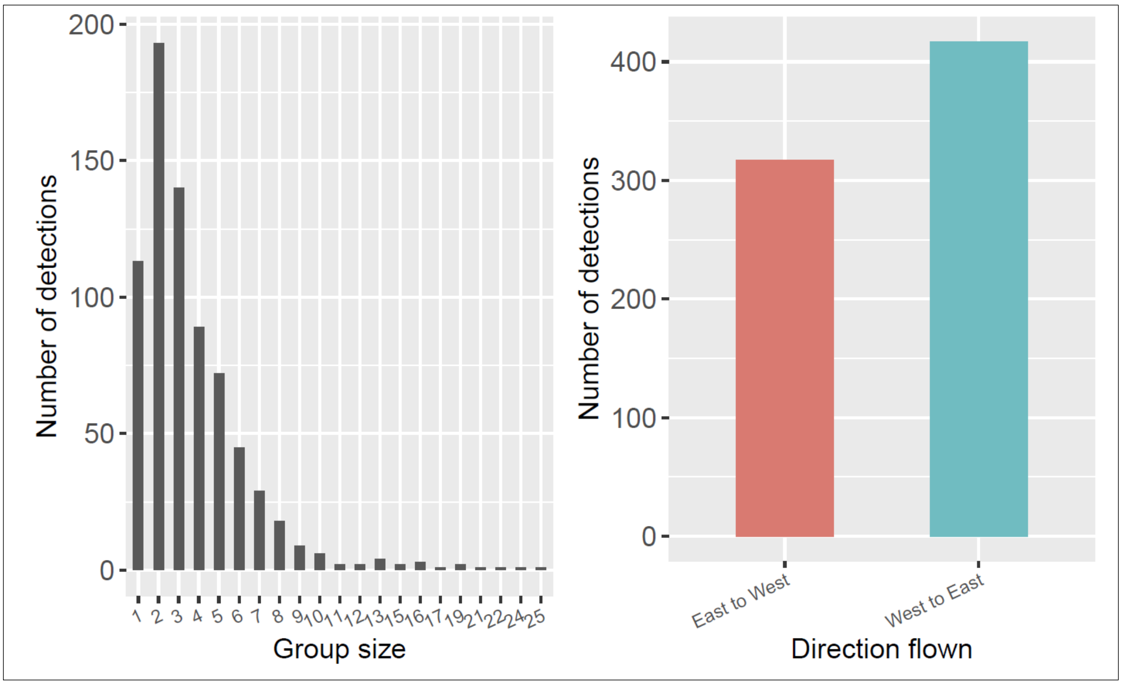

Figure 6. Exploratory analysis for caribou group size distribution among detections and for flight direction. Akia-Maniitsoq caribou population survey 2019:

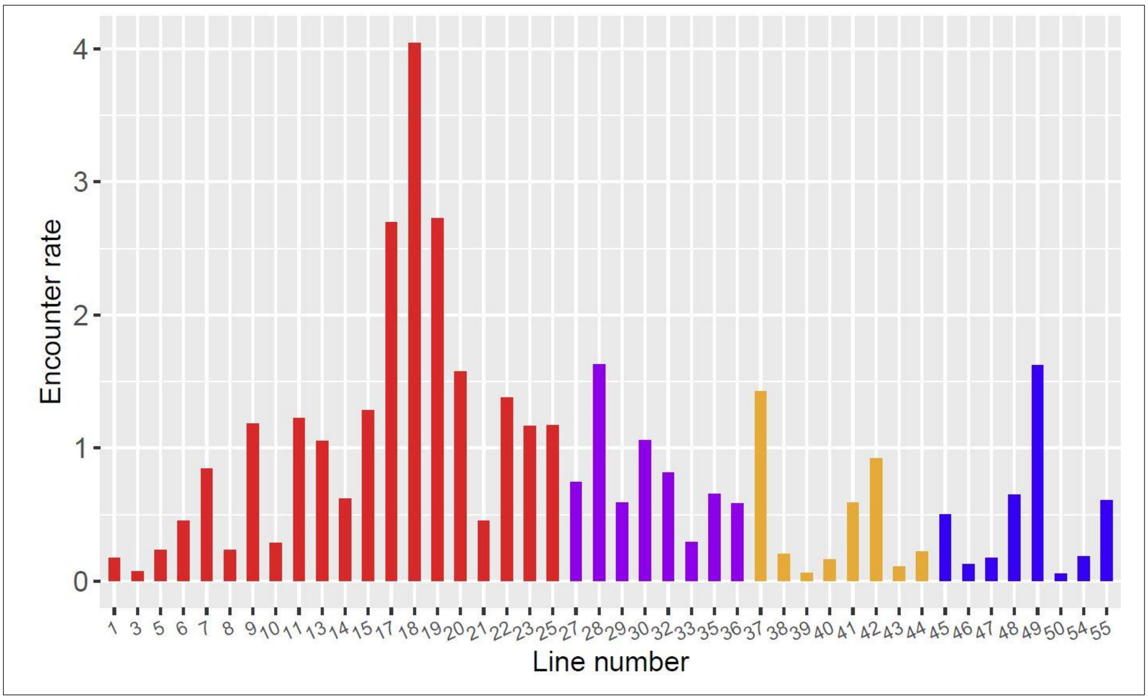

Figure 7. Exploratory analysis for caribou encounter rate (groups per km) per line transect and illustrating sub-area encounter rate: Akia (red), Ujarassuit (purple), Maniitsoq Inland (orange), and Maniitsoq Coast (blue). Akia-Maniitsoq caribou population survey 2019.

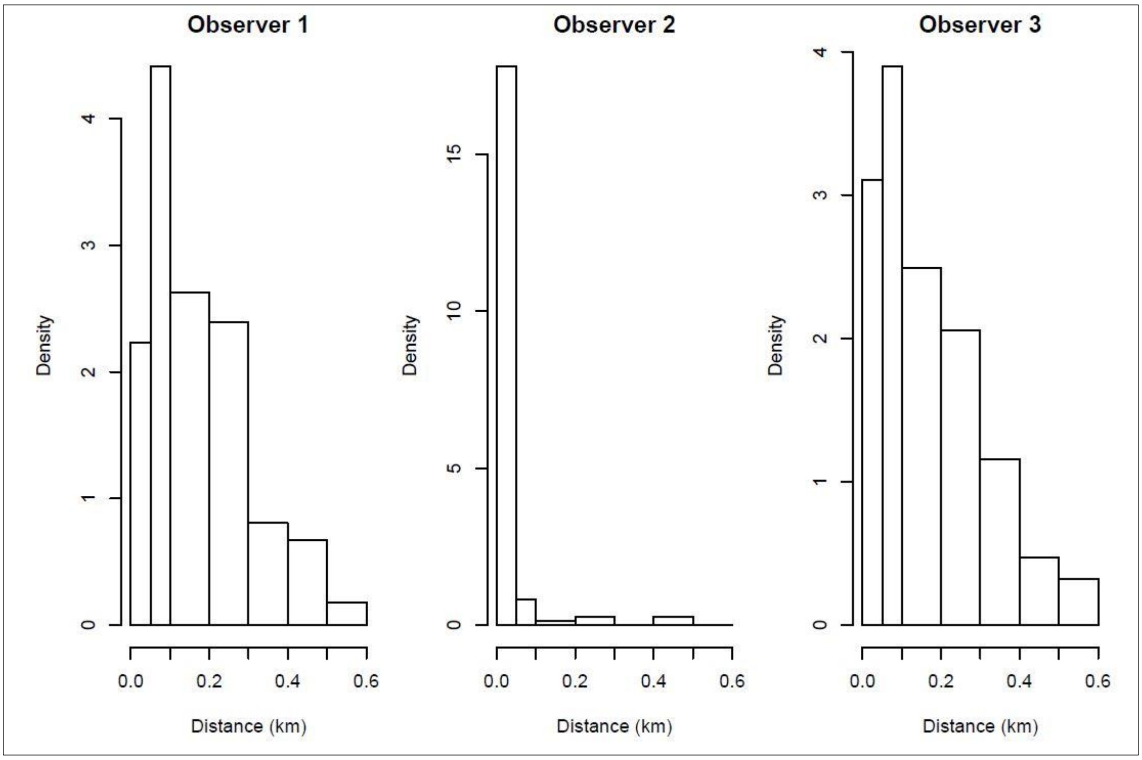

Figure 8. Observer effect: histograms illustrating detected distances for the three observers (a covariate with three levels). Density, y-axis, refers to the density of observations.

The number of detections per unit transect length is the encounter rate. The Akia sub-area had the highest mean encounter rate, at 1.143 caribou groups per km, followed thereafter by Ujarassuit (0.796), Maniitsoq coast (0.49), and

Maniitsoq inland (0.463) (Fig. 7). Encounter rates were highly variable across the line transects within each sub-area and across all lines. This will lead to less precise density estimates.

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 around 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 (Appendix 6). 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 (Appendix 1). Detecting caribou was sometimes compromised by weather (sunshine, partly cloudy, overcast), lack of horizon (flat light) or the west-east orientation of the lines. The latter 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, flat light, 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).

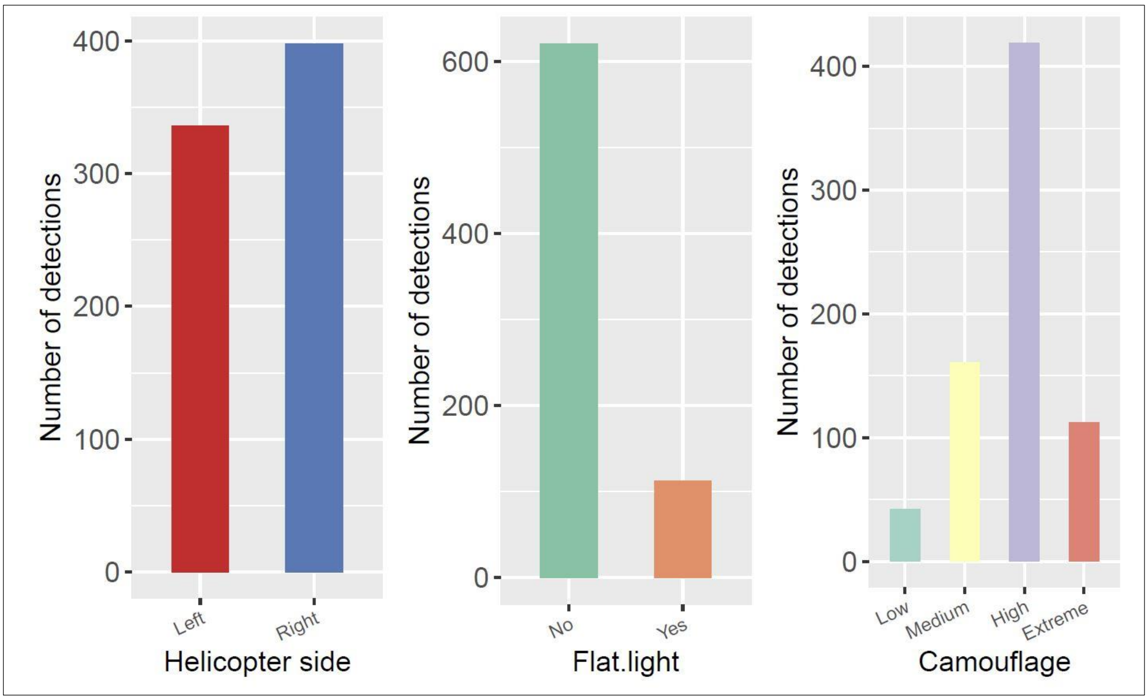

Figure. 9. Number of caribou detections per three covariates: helicopter side, flat light, and camouflage (truncated data).

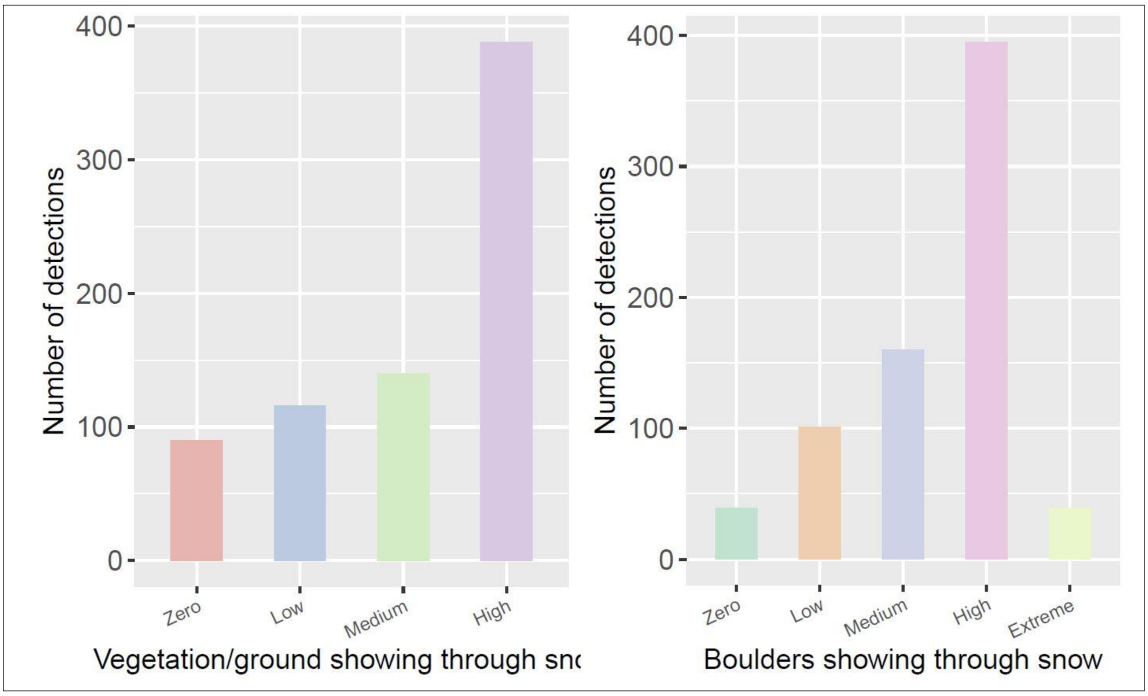

Figure. 10. Number of caribou detections per two covariates: vegetation/ground or boulders showing through the snow surface (truncated data).

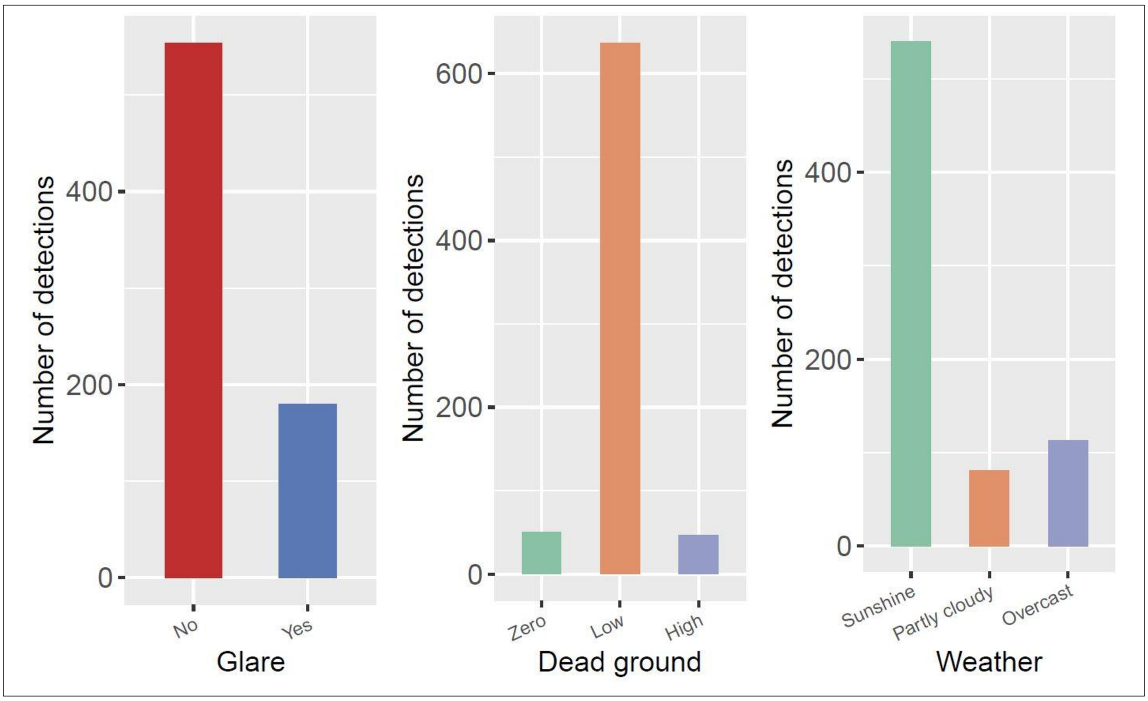

Figure. 11. Number of caribou detections per three covariates: solar glare, dead ground, and weather (truncated data).

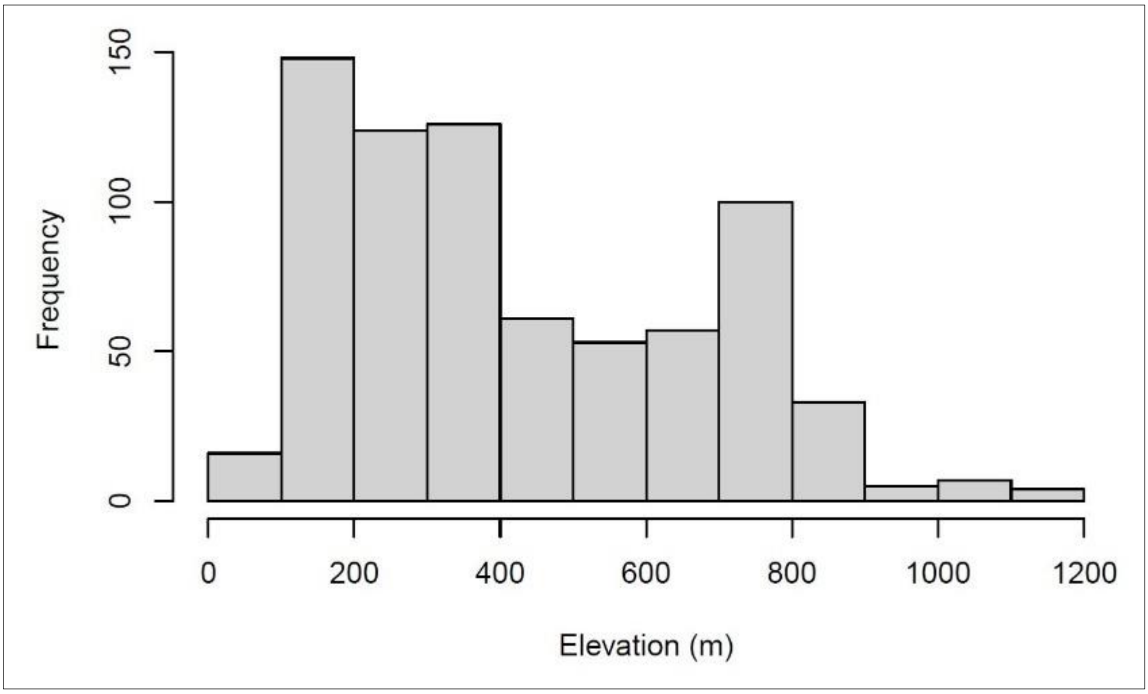

Figure. 12. Summary of the frequency of elevations flown.

Elevations encountered while flying the line transects usually were between 200 and 900 m (Fig. 12). Helicopter flight speed was predominantly 40 knots, and a constant altitude of 40 m was maintained.

Given the preliminary analysis we expect reasonable precision in further analyses of detections, because the information agreed well with anticipated a priori, e.g., Akia sub-area would have more caribou than the other three 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 is similar to typical DS data, perhaps showing some over-dispersion, with not-equally-spaced bins (Fig. 13). Given the histogram of binned distances, a strip half-width of w = 0.60 km was selected (i.e., all observations at distances beyond 600 meters were discarded). This truncation reduced the sample size from 749 to 734 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. Further, little information is lost by truncation, since data observations located more than 0.60 km from each side of the line make a minimal contribution to the final abundance estimate.

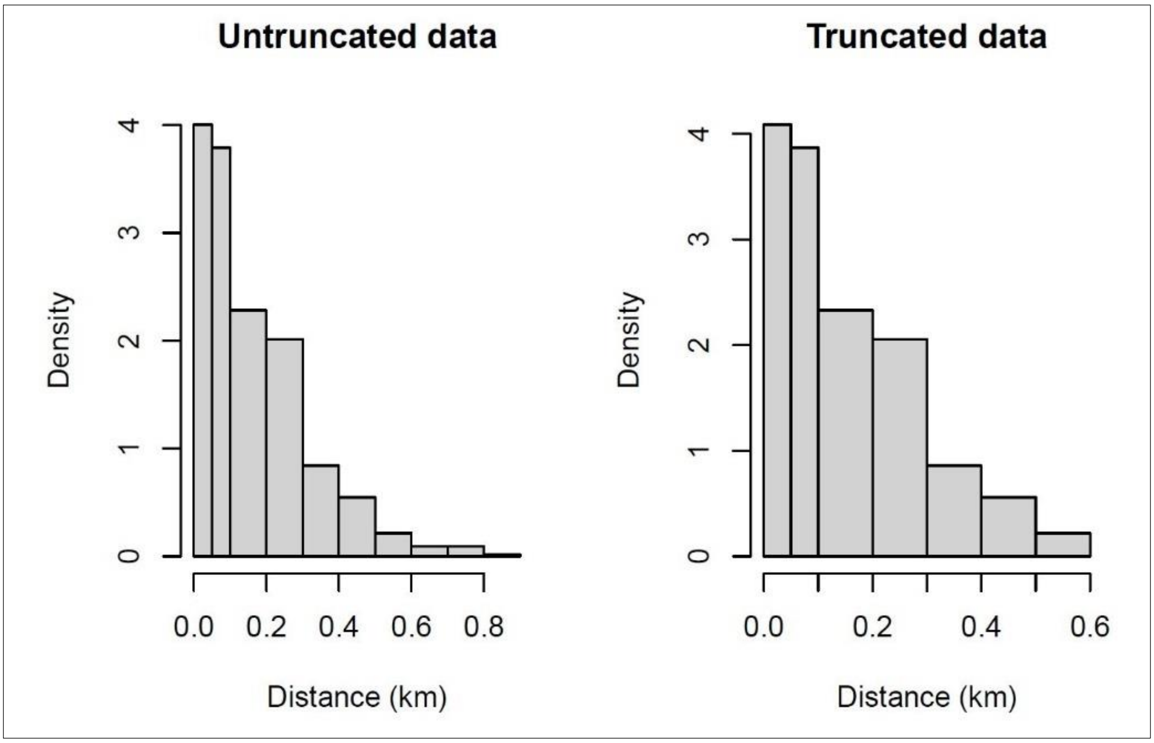

Figure 13. Histogram of observed caribou distances for non-truncated data (left), and truncated data (right). The area of the rectangles is proportional to the number of points within each bin.

Detection function models were fitted to the truncated data, i.e., strip width, w = 0.60 km, to each side of the helicopter. For these models, every combination of key function and adjustment terms was tested (Appendix 8). Additional covariates assessed were Camouflage, Boulders showing through the snow surface, Group size, Observer, Flat light, Weather, Dead ground, Vegetation and Ground showing through the snow surface, Solar Glare, Helicopter side. Group size, as covariate, did little to explain caribou detection. Regardless, we did not consider converting Group size into a categorical variable, e.g., small, medium, large, because much information is lost for no perceivable gain, since we can estimate a probability of detection for each group size when this covariate is included in the model.

A summary of the information from each model fitted to the data (Table 3) provides a simple overview of several 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 for the Akia-Maniitsoq caribou population, this model has the Hazard-rate function as a key function, Camouflage as a covariate (AIC = 2590.006). The second-best model was the half-normal key with Camouflage as a covariate (AIC = 2590.042, i.e., ΔAIC = 0.037). This strongly suggests that Camouflage is the relevant covariate in detectability.

Thus, we chose the 'Hazard-rate with Camouflage as covariate', which had the estimated averaged probability of detection for the Central region of $\hat{P}$a = 0.471 (se = 0.019) (Fig. 14). It is an averaged estimate since Camouflage is included in model. Consequently, each Camouflage level has its separate detection function, corresponding to different estimates for probability of detection (Fig. 15).

The effect of Camouflage was marked on estimated probability of detection (Fig. 15). When Camouflage covariate was low, the estimated probability of detection was greatest. Interestingly, medium Camouflage had the lowest detection probability estimates, while those with high or extreme Camouflage had middle values for detection probability. Large group sizes (≥ 15 caribou) were typically detected when Camouflage was high, which may provide a partial explanation.

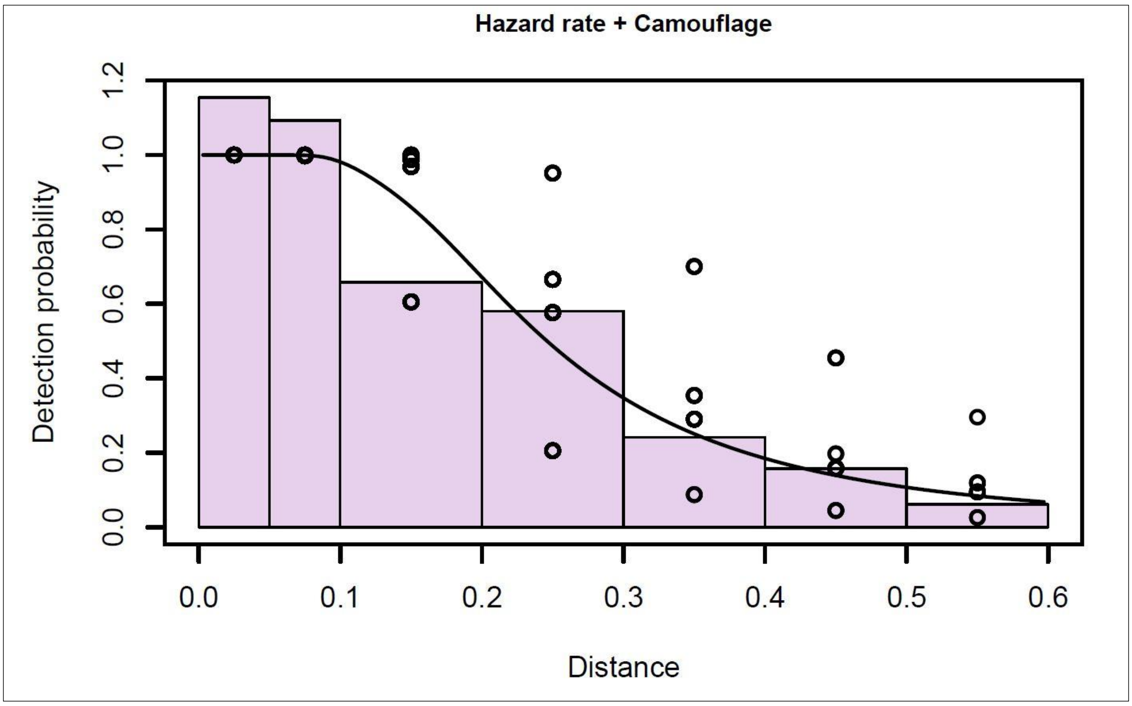

Figure 14. Histogram for Hazard-rate with Camouflage as covariate of detected distances with the estimated detection function overlaid.

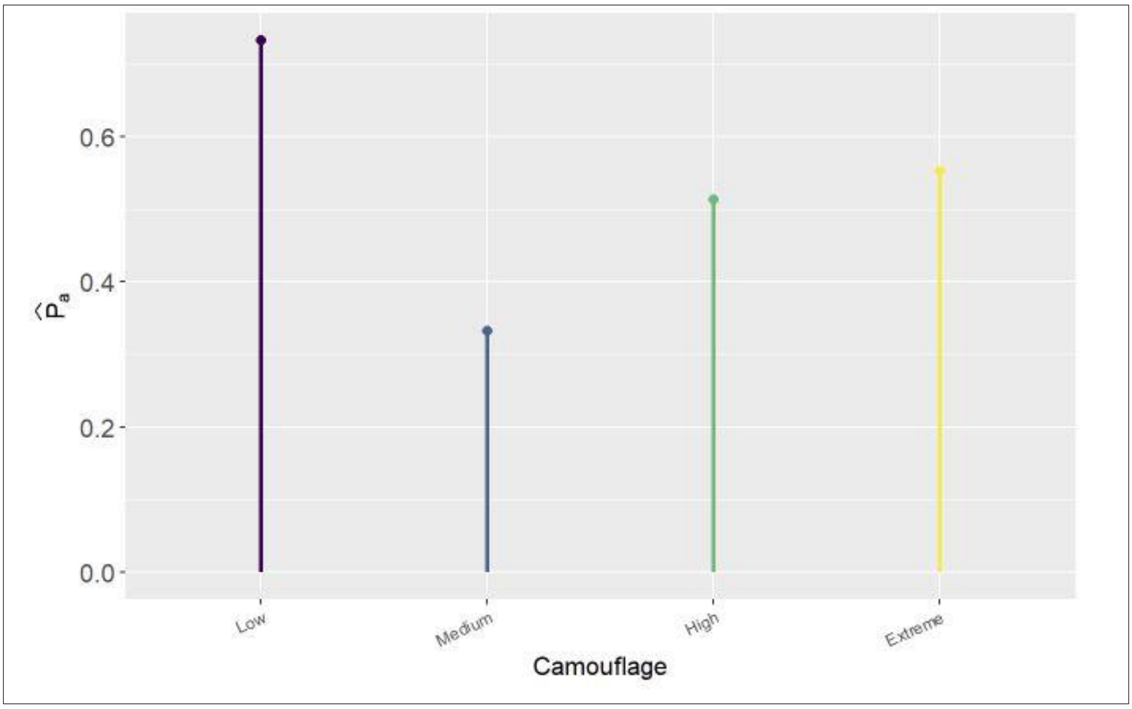

Figure 15. Estimated probabilities of detection for each observed group size per Camouflage obtained with the fitted model).

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

Key function	**Formula (variable)**	**χ^2 *p*-value**	**$\widehat{P}_a$**	**se ($\widehat{P}_a$)**	**AIC**	**ΔAIC**
Hazard-rate	Camouflage	0.000	0.471	0.019	2590.006	0.000
Half-normal	Camouflage	0.000	0.453	0.012	2590.006	0.037
Half-normal	Boulders showing through snow	0.000	0.456	0.013	2590.006	7.794
Half-normal	Group size	0.002	0.458	0.013	2590.006	8.211
Half-normal	Group size + Observer	0.001	0.458	0.013	2600.209	10.204
Hazard-rate	Boulders showing through snow	NA	0.448	0.020	2600.420	10.414
Half-normal with cosine adjustment term of order 2	1	0.000	0.426	0.019	2604.323	14.318
Hazard-rate with Hermite polynomial adjustment term of order 4	1	0.000	0.402	0.032	2604.566	14.561
Hazard-rate with cosine adjustment term of order 2	1	0.000	0.429	0.019	2604.722	14.716
Half-normal	Flat light	0.000	0.461	0.013	2605.587	15.582
Hazard-rate with simple polynomial adjustment terms of order 4,6	1	0.000	0.398	0.034	2605.946	15.941
Half-normal with simple polynomial adjustment term of order 4	1	0.000	0.451	0.021	2606.378	16.372
Half-normal	Weather	0.000	0.460	0.013	2606.469	16.464
Uniform with cosine adjustment terms of order 1,2,3	NA	0.000	0.427	0.020	2606.608	16.602
Half-normal	1	0.000	0.462	0.013	2606.810	16.804
Hazard-rate	Group Size	0.000	0.458	0.020	2606.884	16.878
Half-normal	Dead ground	0.000	0.461	0.013	2606.923	16.917
Half-normal	Vegetation/Ground through snow	0.000	0.460	0.013	2606.991	16.985
Hazard-rate	Group size + Observer	0.000	0.452	0.020	2607.879	17.873
Half-normal	Solar glare	0.000	0.462	0.013	2608.513	18.508
Half-normal	Helicopter side	0.000	0.462	0.013	2608.704	18.699
Half-normal	Observer	0.000	0.462	0.013	2608.774	18.768
Uniform with simple polynomial adjustment terms of order 2,4,6,8	NA	0.000	0.458	0.023	2610.950	20.944
Hazard-rate	Flat light	0.000	0.446	0.020	2614.757	24.751
Hazard-rate	Dead ground	0.000	0.447	0.020	2615.115	25.109
Hazard-rate	Weather	0.000	0.455	0.020	2615.783	25.778
Hazard-rate	Observer	0.000	0.442	0.020	2617.808	27.802
Hazard-rate	Helicopter side	0.000	0.449	0.020	2619.033	29.027
Hazard-rate	Solar Glare	0.000	0.450	0.020	2619.190	29.184
Hazard-rate	Vegetation/Ground through snow	0.000	0.454	0.020	2619.800	29.795
Uniform with Hermite polynomial adjustment term of order 2,4,6	NA	0.000	0.661	0.035	2708.504	118.498

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

The estimates for encounter rates indicate that the Akia 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, Akia is also the sub-area presenting more caribou (Tables 5, 6, Fig. 16).

Table 4. Encounter rate (ER) estimates per sub-area (stratum) for caribou groups of the Akia-Maniitsoq caribou population, considering four strata, seven bins, and a detection function fitted with Camouflage as a covariate.

Sub-area	Encounter rate	Standard Error (se)	Coefficient of Variation (cv)
Akia	0.918	0.145	0.158
Maniitsoq Coast	0.409	0.131	0.321
Maniitsoq Inland	0.475	0.140	0.294
Ujarassuit	0.746	0.105	0.141
TOTAL	**0.662**	**0.071**	**0.108**

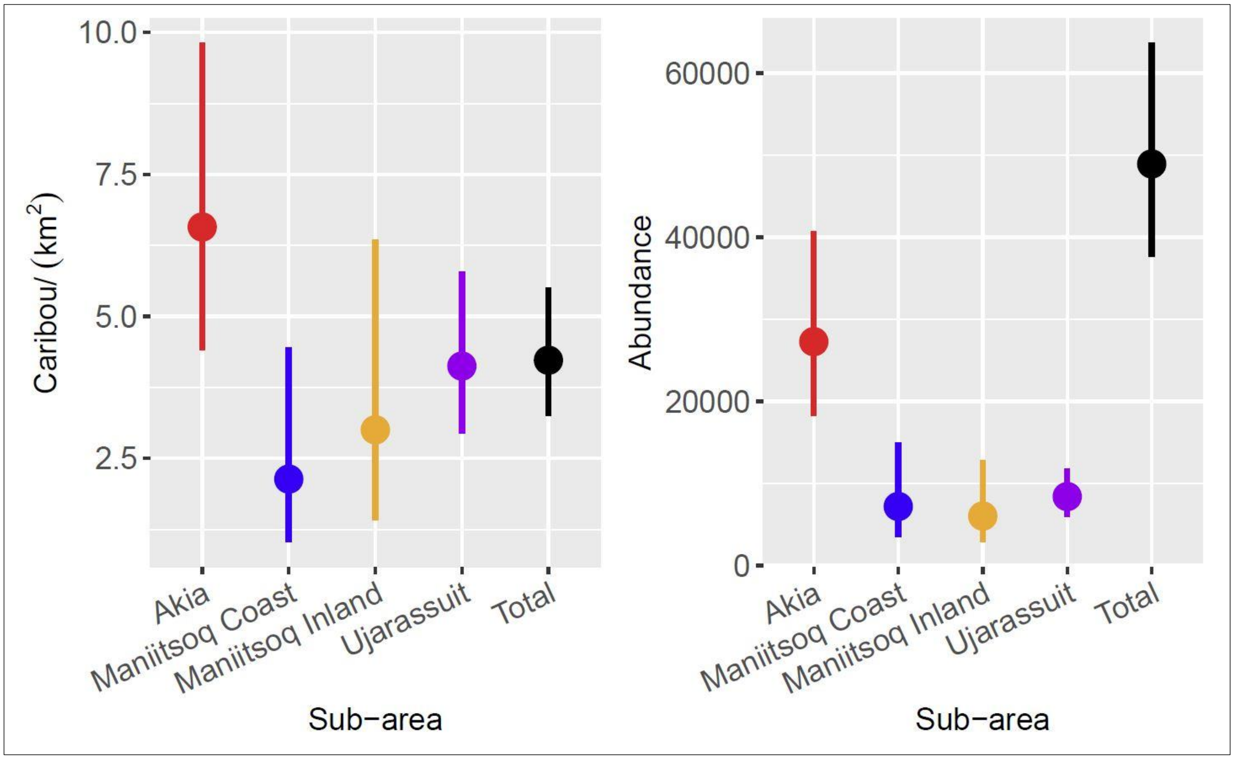

Figure 16. Caribou density (left) and abundance (right) estimates with corresponding confidence intervals for the four sub-areas, Akia, Maniitsoq Coast, Maniitsoq Inland, and Ujarassuit, and finally for the total Central region.

In March 2019, the Central region had an estimated population size of 48,941 caribou (95% CI: 37,612 – 63,682) (Table 5, Fig. 16). Sum of abundance estimates for each sub-area equals total estimated abundance for the region. CV of 0.13 is excellent and indicates the Akia-Maniitsoq caribou abundance estimate for 2019 is accurate. The design–based density estimate for the whole survey region was 4.23 caribou/km^2, with 95% CI: 3.23 – 5.50 (Table 6, Fig. 16).

Table 5. Estimates of abundance per sub-area (stratum) for Akia-Maniitsoq caribou population in the Central region, March 2019, considering four strata, seven bins and Hazard-rate detection function with Camouflage as a covariate.

Sub-area	Abundance Estimate	Standard Error (se)	Coefficient of Variation (cv)	95% Confidence Interval	
				Lower	Upper
Akia	27,286	5306	0.194	18,276	40,737
Maniitsoq coast	7,205	2323	0.322	3,456	15,024
Maniitsoq inland	6,037	1978	0.328	2,853	12,777
Ujarassuit	8,412	1257	0.149	5,992	11,809
TOTAL	**48,941**	**6390**	**0.131**	**37,612**	**63,682**

Table 6. Estimates of density per sub-area (stratum) for Akia-Maniitsoq caribou population in the Central region, March 2019, considering four strata, seven bins and Hazard-rate detection function with Camouflage as a covariate.

Sub-area	Density Estimate	Standard Error (se)	Coefficient of Variation (cv)	95% Confidence Interval	
				Lower	Upper
Akia	6.575	1.279	0.194	4.404	9.816
Maniitsoq coast	2.135	0.688	0.322	1.024	4.452
Maniitsoq inland	3.002	0.984	0.328	1.419	6.354
Ujarassuit	4.126	0.616	0.149	2.939	5.791
TOTAL	**4.228**	**0.552**	**0.131**	**3.249**	**5.502**

Caribou flight reaction or lack thereof

Like the North region survey of 2018 (Cuyler et al. 2021), the Akia-Maniitsoq 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. Behavior was recorded for a total of 683 groups, which involved 2,551 caribou.

The size of caribou groups that exhibited movement was significantly different from those that did not move, mean group size 3.98 caribou for moving and 3.00 for non-moving (t Stat = -4.767; two-tailed t-testing: $P < 0.0001$, $t = 1.965$, $df = 477$). Further, non-moving caribou groups were generally 100 m further from line transect flown by the helicopter than caribou groups showing movement (Table 7). There was a significant difference between the mean distance for groups with movement, 199.02 m, and groups lacking movement, 299.42 m (t Stat = 7.577; two-tailed t testing $P < 0.0001$, $t = 1.968$, $df = 304$).

Caribou groups reacting to the helicopter fly-by with movement made up 74.8% of all observations for which behavior was reported. Conversely, 25.2% of all caribou groups exhibited little or no movement. A quarter of all caribou groups observed lacked movement. Percentages change when considering the absolute number of caribou involved. There were 2,551 caribou in the 683 groups (Table 7) for which behavior was reported, and of those caribou, 79.8% (n=2,035) moved and 20.2% (n=516) did not move.

Table 7. Movement or non-movement of caribou reacting to helicopter fly-by, March 2019. Dataset that included group size, behavior, and distance from track line was n= 683.

Parameter	**Akia-Maniitsoq caribou population**		
	Movement	**Non-Movement**	***p* – value**
Number of groups	511	172	
% Group Observations	74.8%	25.2%	
GROUP SIZE			
Mean	3.98	3.00	< 0.0001
Confidence Level (95%)	0.2762	0.2975	
Standard Error	0.1406	0.1507	
Median	3	2	
Mode	2	2	
Standard deviation	3.1780	1.9765	
Sample Variance	10.0997	3.9064	
Maximum	25	16	
Minimum	1	1	
Number of caribou involved	2035	516	
DISTANCE [1]			
Mean	199.02 m	299.42 m	< 0.0001
Confidence Level (95%)	13.4252	22.4071	
Standard Error	6.8335	11.3515	
Median	200	300	
Mode	50	300	
Standard deviation	154.4726	148.8738	
Sample Variance	23861.7858	22163.4027	
Maximum	850	750	
Minimum	50	50	

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

Among the 441 'running' groups (Running- away, high speed, parallel, later standing, Table 8), 431 groups exhibited unabated flight, i.e., they never stopped while within view of the helicopter. Rough group composition (calf, adult) was determined for 202 of those groups and recorded calf presence in 85.6%, with remaining 14.4% groups adults only.

Considering only the 113 caribou groups whose original position was on the line transect (n = 50) or within 50 m of the line transect (n=63), 110 of those groups (97.3%) never stopped running away from the helicopter. The remaining three groups (2.7%) initially ran away but then stopped, looked at the helicopter and ran no further. A calf was present in two of those three groups.

Table 8. Details for movement or non-movement of caribou reacting to helicopter fly-by, March 2019. Dataset of observations, which included caribou group size, behavior, and distance from line transect, was n= 683 groups, which contained n = 2,551 individual caribou.

Akia-Maniitsoq caribou population				
Category	**Groups (n = 683)**	**%**	**Individuals (n = 2,551)**	**%**
Exhibiting Movement				
Running away	405	59.3	1652	64.8
Running away high speed	13	1.9	65	2.5
Walking	38	5.6	124	4.9
Approach*	8	1.2	29	1.1
Confused (jostling/circling)	14	2.0	31	1.2
Running parallel to line transect	13	1.9	55	2.2
Running, later standing looking	10	1.5	49	1.9
Trotting away	9	1.3	25	1.0
Mixed: some moved, others did not[1]	1	0.1	5	0.2
TOTAL	**511**	**74.8**	**2035**	**79.8**
Lacking Movement				
Standing still	156	22.8	476	18.7
Standing, later walking	3	0.4	8	0.3
Lying down	7	1.0	13	0.5
Lying down, later stood up	4	0.6	11	0.4
Some lying, others standing still	1	0.1	6	0.2
Lying down, later walking	1	0.1	2	0.1
TOTAL	**172**	**25.2**	**516**	**20.2**

*Approach movement (walking, trotting, running) was towards 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.

Demographics & recruitment

Sex, age, and late-winter calf recruitment data were collected in separate specific efforts that were not part of the line transect DS dataset. On the 12th and 13th of March 2019, and using ca. 8 hours helicopter flight time, we sexed and aged 276 groups of caribou, for a total of 1257 animals, in the Akia-Maniitsoq caribou population (Table 9). Cows were ca. 50% of the population, followed by bulls (age >1-year) at ca. 24% and calves at 26%. The calf percentage may be considered artificially high owing to the large number of calves lacking their dam, i.e., orphan calves.

While obtaining demographics for Akia-Maniitsoq caribou population, we observed a loose aggregation of numerous caribou on the lowland flats (elevation < 200 m) at the north end of the Narssarssuaq Valley (Fig. 17). Most of these groups of caribou were not sexed and aged because they were too large, e.g., largest > 50 animals. The high group size combined with the confusion of constant jostling change of positions among the fleeing caribou, made it difficult to sex and age all group members. Further, groups fleeing the helicopter often mixed or split apart to regroup with yet other groups before sex/age determination was complete. Where group separation and size permitted, demographics were obtainable (Fig. 18).

Table 9. Demographics for Akia-Maniitsoq caribou population, Central region, March 2019.

Parameter	**Akia-Maniitsoq caribou population**					
Number of groups observed	276					
GROUP SIZE						
Mean	4.55					
Confidence Interval (95%)	0.3896					
Standard Error	0.1979					
Standard Deviation	3.29					
Sample Variance	10.8079					
Median group size	4					
Mode group size	3					
Maximum group size*	24					
Minimum group size	1					
DEMOGRAPHIC	**All data**			**83 orphan calves removed**		
Total sexed & aged (*n*)	1257		100 %	1174		100 %
Cow (age >1 year)	624		49.6 %	624		53.15 %
Calves from previous spring	326		25.9 %	243		20.70 %
		(148 females)	11.77 %		-	-
		(171 males)	13.60 %		-	-
		(7 unknown)	0.56 %		-	-
Bull (age >1 year)	307		24.4 %	307		26.15 %
		(145 adults age >3)	11.54 %		(145 adults age >3)	12.35 %
		(162 juveniles 1< age <3)	12.89 %		(162 juveniles 1< age <3)	13.80 %
Recruitment (calves / 100 cows)	52.24			38.94		
Sex ratio (Bull age >3 year/Cow)	0.23			0.23		
Sex ratio (Bull age >1 year/Cow)	0.49			0.49		

* This is maximum for only those groups that were sexed and aged. It was not possible to sex and age the individuals in the exceedingly large groups on the flats of the Narssarssuaq Valley (Fig. 17).

Figure 17. Unusually high numbers of caribou, often in exceptionally large groups were observed on the low elevation (< 200 m) flats of the valley, Narssarssuaq, Central region, early March 2019: Left are 45 caribou, above right 33 and below 14. Sex and age determination was only possible on the latter.

Figure 18. These 17 caribou could be sexed and aged owing to group separation and relatively small group sizes, i.e., six (left), nine (foreground) and two (in distant background).

Calf lacking their dam

The demographics data collection included a total of 326 calves (Table 9). Only 243 calves (74.5% of all calves observed) were in the company of cows, while 83 calves (25.5% of all calves observed) appeared to be orphans, i.e., lacking a dam/cow.

Of the 83 calves, 52 (16% of all calves observed) were designated 'true' orphans. Primarily because they were solitary individuals (n = 4) or in the company of other calves (n = 30 calves, 10 groups), always with no older caribou nearby. Orphan pairs were observed five times, and triplet once. Four orphans together were observed three times. The maximum orphan group size was five calves and was observed once. The ratio of orphan females to males was almost 50:50, as there were 16 female and 18 male orphans. Secondly, 'true' orphans were also considered those in the company of bull only groups (n = 18, 14 groups). A single orphan calf was present in 11 of the bull groups. There were six orphans present in juveniles-only bull groups (n=5), eight present in adult bull groups (n=5) and four in mixed juvenile plus adult bull groups (n=4).

The remaining 31 calves, out of the above 83, were designated 'possible' orphans because these were 'extra' calves observed in the company of cow-calf pairs, i.e., for 20 cow-calf groups (n = 117 caribou; 43 cows, 74 calves) the number of calves exceeded the number of cows. The group composition for half of these groups consisted of a single cow followed by two calves. Five cow-calf groups included multiple pairs and just one 'extra' calf. Two cow-calf groups included multiple pairs and two 'extra' calves. A further two cow-calf groups included multiple pairs and three 'extra' calves. Finally, one cow-calf group with multiple pairs included six 'extra' calves. The result was a 31 (9.5%) 'possible' orphan calves.

Although only one orphan was in visibly poor body condition, owing to possible foraging difficulties we suspect that the 83 orphan calves have less chance of surviving their first winter than calves with their dams. If these orphan calves are removed from the dataset, then the resulting demographics becomes cows ca. 53%, bulls (age > 1-year) ca. 26% and calves ca. 21%, with calf recruitment reduced to ca. 39 calves per 100 cows (Table 9).

Group size & composition

The sex and age composition of caribou groups may have influenced group size. The results were almost identical for groups of all bulls (juveniles and adults) and those containing only adult bulls (age > 3-years) (Table 10). The groups of juvenile bulls (1-year < age < 3-year) had the lowest mean group size, 1.60 animals. The highest mean group size observed, 7.44 caribou, applied to groups consisting of a combination of cows, calves and bulls, which also exhibited the largest maximum group size, 24. The next largest maximum group size, 17, was for groups composed of just cows and calves.

Table 10. Group size relative to composition, Akia-Maniitsoq caribou population, Central region, March 2019 (for demographic dataset).

	Akia-Maniitsoq caribou population, group composition								
Parameter	**Adult Bull**	**Juvenile Bull**	**Mixed Bull[1]**	**Bull[1] & Calf**	**Bull[1] & Cow**	**Bull[1], Cow & Calf**	**Cow**	**Cow & Calf**	**Calf**
Number caribou	57	8	26	54	84	536	123	335	34
Number groups	20	5	6	14	22	72	50	73	14
GROUP SIZE									
Mean	2.85	1.60	4.33	3.86	3.82	7.44	2.46	4.59	2.43
CI (95%)	0.91	1.11	1.58	0.90	0.69	0.89	0.44	0.70	0.77
Std Error	0.44	0.40	0.61	0.42	0.33	0.44	0.22	0.35	0.36
Std Deviation	1.95	0.89	1.50	1.56	1.56	3.77	1.57	2.98	1.34
Sample Variance	3.82	0.80	2.27	2.44	2.44	14.25	2.46	8.91	1.80
Median	2.5	1	4	3.5	3.5	6	2	3	2
Mode	1	1	3	3	3	6	1	3	2
Maximum	8	3	7	7	7	24	8	17	5
Minimum	1	1	3	2	2	3	1	2	1

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

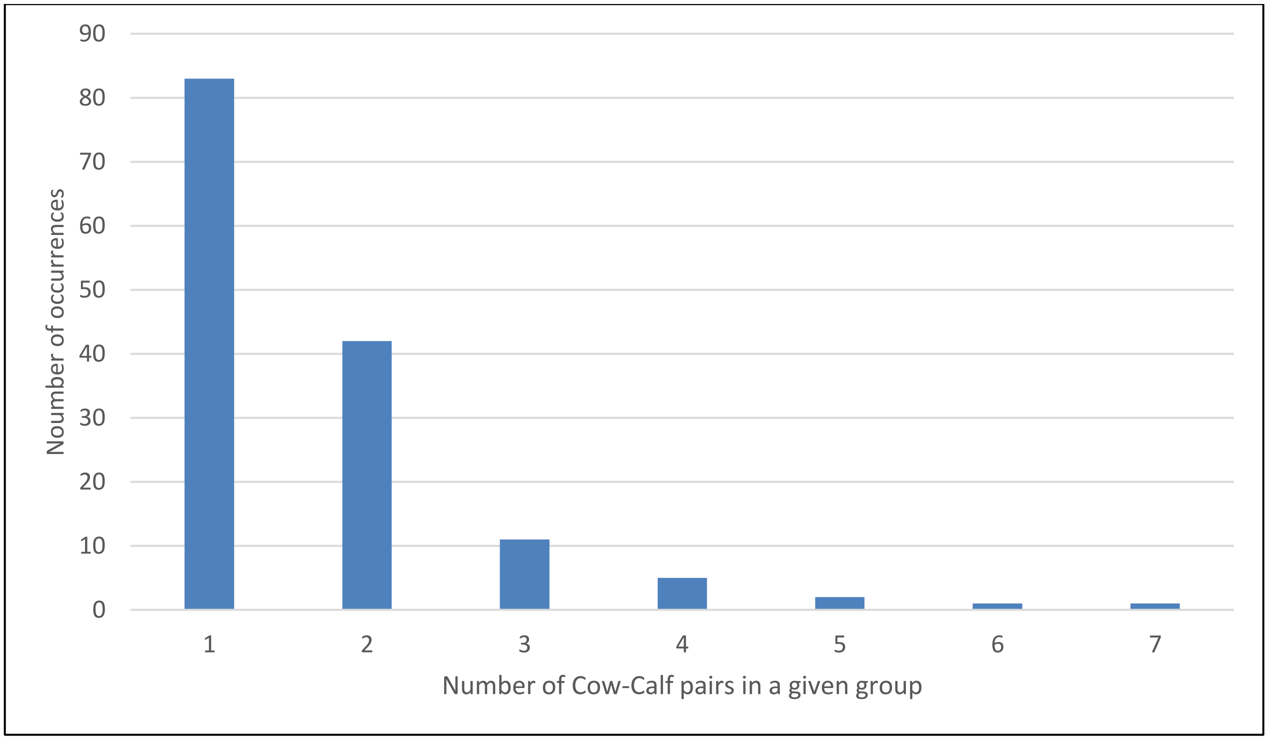

Figure 19. Observed frequency of cow-calf pairs for 145 groups for which demographics information was available.

Out of the total 276 groups that were sexed, and aged, cow-calf pairs occurred in 145 of those groups, which involved 871 caribou (Table 10) and 245 cow-calf pairs. Usually there was just one cow-calf pair per group (Fig. 19), however, two cow-calf pairs were also common, with the mean number of cow-calf pairs per group at 1.7 ± 0.1 standard deviation. Few groups were notable for their large number of cow-calf pairs. Only twice did a group contain more than five cow-calf pairs, i.e., one group contained six cow-calf pairs and another seven. Even five cow-calf pairs were rare, occurring just twice.

Late-winter antler possession

The demographics dataset for the 1257 sexed and aged caribou (Table 9) included antler possession observations for 1228 of those caribou. Adult (age >3-years) bulls lacked antlers and were ca. 47% of all males observed for age >1-year. Juvenile (age 1½ - 2½-years) bulls made up 53%. In contrast to adult bulls, 87.0% of juveniles possessed one or both of their antlers from the previous autumn (13% had just one antler, while 74% had both). The remaining 13% of juvenile bulls lacked antlers. Meanwhile, adult cows possessing one or both antlers made up 32.1% of all females (one antler 15.3%: two antlers 16.8%). Most cows, 67.9%, were polled (no antlers). Female calves were predominantly polled, 94.33%. Only 5.67% possessed one or both antlers (one antler 4.96%: two antlers 0.71%). Like the female calves, most male calves, 60.0% also lacked antlers. For male calves, only 40.0% possessed one or both antlers (one antler 20.63%: two antlers 19.38%).

Elevations where caribou detected

All elevation results for observed caribou indicate only approximate values. 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 ca. 1.0 km in front of the helicopter's position. Additionally, caribou not on the flown track line 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 had changed somewhat.

Table 11. Approximate elevations for caribou groups observed: Survey of the Akia-Maniitsoq caribou population by helicopter in the Central region, 01-12 March 2019.

Parameter	**Central region sub-area**				**Total Central region**
	Akia	**Maniitsoq Coast**	**Maniitsoq Inland**	**Ujarassuit**	
Sample size	386	73	116	175	**750**
ELEVATION					
Mean (m)	254	265	572	581	**380**
Standard Error (SE)	7.58	16.06	24.31	17.39	**8.99**
Median	233	221	693	631	**301**
Mode	156	211	738	677	**156**
Standard Deviation	± 148.9	± 137.2	± 261.8	± 230.1	**± 246.3**
Variance	22180.04	18836.71	68534.33	52945.37	**60659.02**
Range	740	660	1028	1108	**1149**
Minimum	6	45	41	47	**6**
Maximum	746	705	1069	1155	**1155**
Confidence level (95%)	14.90	32.02	48.15	34.33	**17.65**

Estimated natural mortality

Using an assumed natural adult mortality of 8-10% for West Greenland caribou populations in general (Kingsley & Cuyler 2002) and the 2019 estimated population size (48,941), the calculated natural mortality for the Akia-Maniitsoq caribou population would be between ca. 3,915 and 4,894 caribou annually. The assumed 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 ptarmigan (*Lagopus muta*, n=489), hare (n=79), arctic fox (n=16), Gyr falcon (*Falco rusticolus*, n=2), sea eagle (*Aquila chrysaetos*, n=8), and snowy owl (*Bubo scandiacus*, n=1). No muskoxen (*Ovibos moschatus*) or feral sheep were observed during the early March 2019 survey of the Central region in West Greenland. A tiny lake bordering the north side of Narsap Sermia (glacial tongue) appeared to have emptied recently.

Snowmobile use observed in Akia-Nordlandet

During the early March 2019 survey of the Central region, we had several opportunistic observations of snowmobile activity (Fig. 20). Activity was assumed to be recent, since Akia (Nordlandet) is generally windswept, which would partially obscure older tracks with blowing snow. There were two foci for snowmobile use, and both were groups of cottages on the Akia (Nordlandet) coast. One cottage group was located on the west side of an unnamed small bay behind the small island, Maaluto. The other group of cottages was deep inside the bay named Kanajorsuit. Observed snowmobile use included one long route that extended from the cottages behind Maaluto to the west side of the bay named Qussuk, where the trail extended further into the distance than we were able to follow. Several trail fragments were observed in the vicinity of Kanajorsiut and between Kanajorsuit and Kanassut. Photos recorded the snowmobile routes.

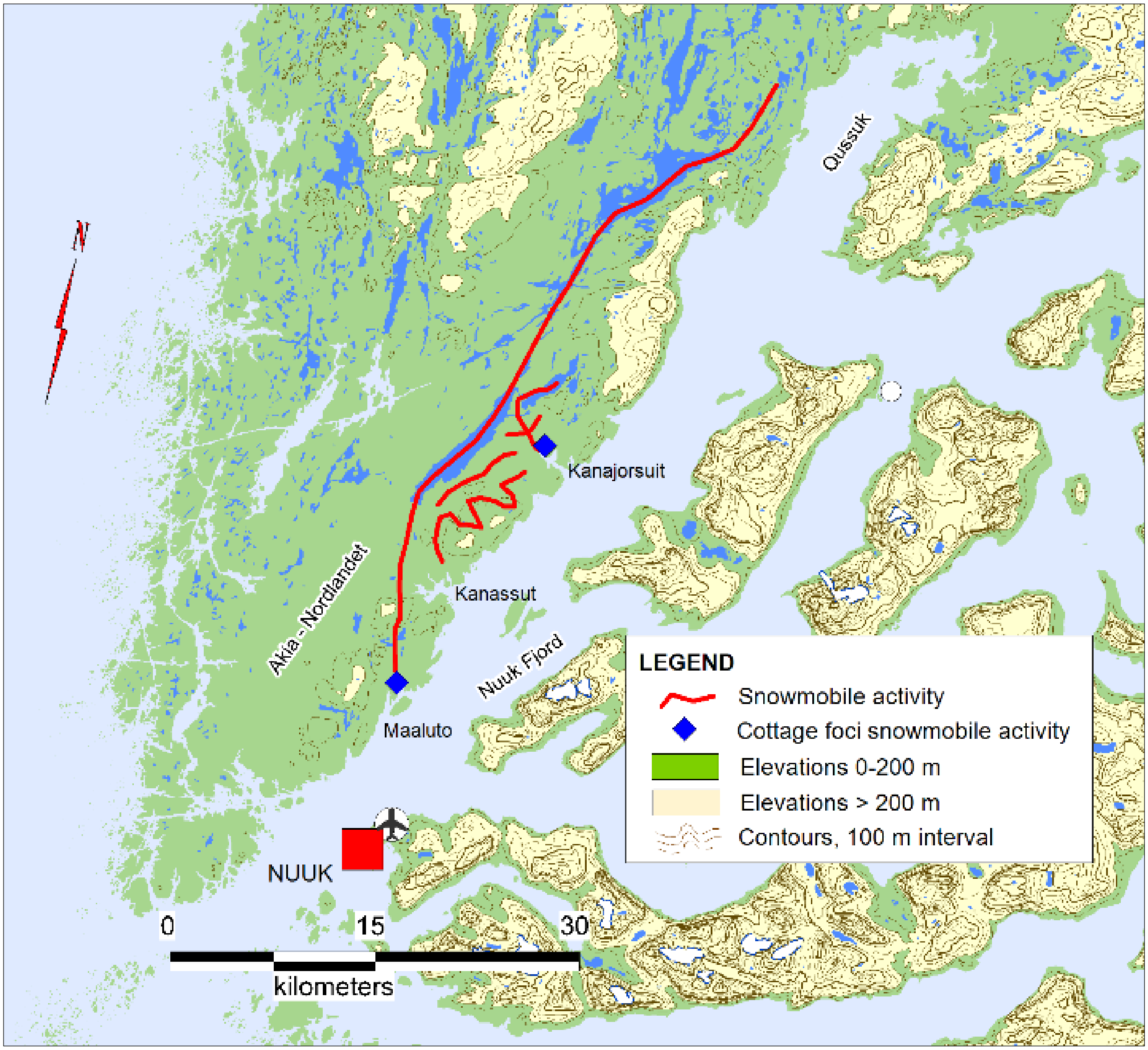

Figure 20. Observed recent snowmobile activity in Akia (Nordlandet), which is in the southern portion of the surveyed Central region, early March 2019.

Discussion

Akia-Maniitsoq caribou 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. 2019 results for Akia-Maniitsoq caribou population of West Greenland illustrating recent growth diverge sharply from the global situation (Figs. 21, 22).

In 2019, the Akia-Maniitsoq population size and density were much greater than expected, and highest ever estimated since helicopter surveys began in 2001 (Figs. 21, 22). This population has doubled in size since the last census of 2010. The Akia-Maniitsoq population is located immediately north of the greatest concentration of commercial and recreational hunters in Greenland, i.e., Greenland's Capital city, Nuuk. Between 2001 and 2010 the Akia-Maniitsoq caribou population size steadily declined. The decline was assumed owing to caribou harvest management initiatives aimed at reducing population size and many avid hunters nearby. However, the results of the 2019 survey bring that assumption into doubt. In the nine years since 2010, the caribou population doubled in size despite among other things unlimited harvesting, long hunting seasons, rising hunter numbers and ability to access caribou near the coast (Cuyler et al. 2016). Albeit harvest magnitude is unknown, whatever its level, it has been insufficient to prevent substantial growth in the Akia-Maniitsoq population. This suggests that hunter harvest is not a major factor regulating population size of the Akia-Maniitsoq caribou population.

Despite the change in survey methods, i.e., from strip transect to Distance Sampling, the following support the conclusion that the Akia-Maniitsoq population size truly doubled from 2010 to 2019. The 2019 Akia-Maniitsoq caribou population size and density estimates are accurate since the Coefficient of Variation (CV) value, 0.13, is excellent and much lower than expected for Distance Sampling (DS) surveys of wildlife populations, where a CV of 0.2 is considered reasonable (Pollock et al. 1990). Further, the Confidence Intervals for the 2010 and 2019 population estimates do not overlap. The doubling 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.

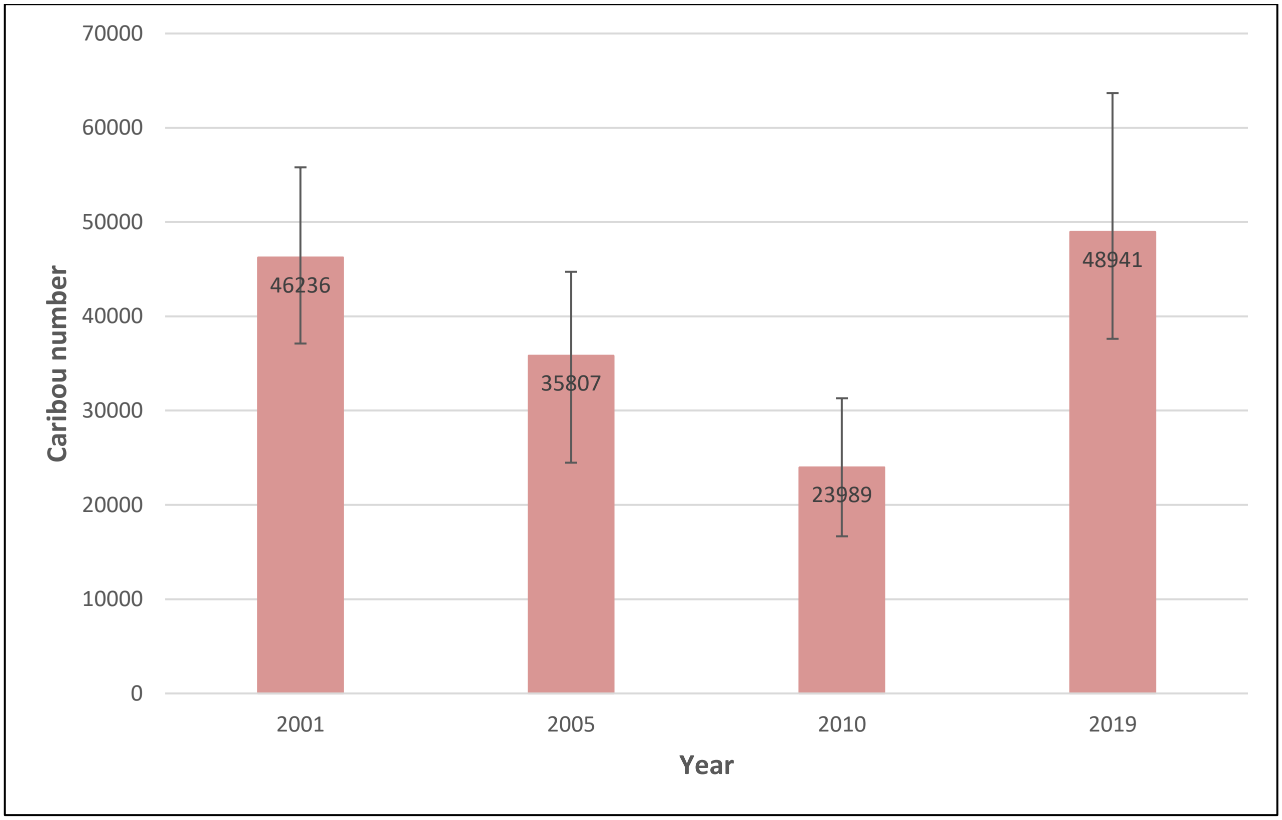

Figure 21. Past and present caribou population size estimates with confidence intervals for the Akia-Maniitsoq population. Confidence Interval varied: 80% in 2001, 90% for 2005 and 2010, and 95% for 2019.

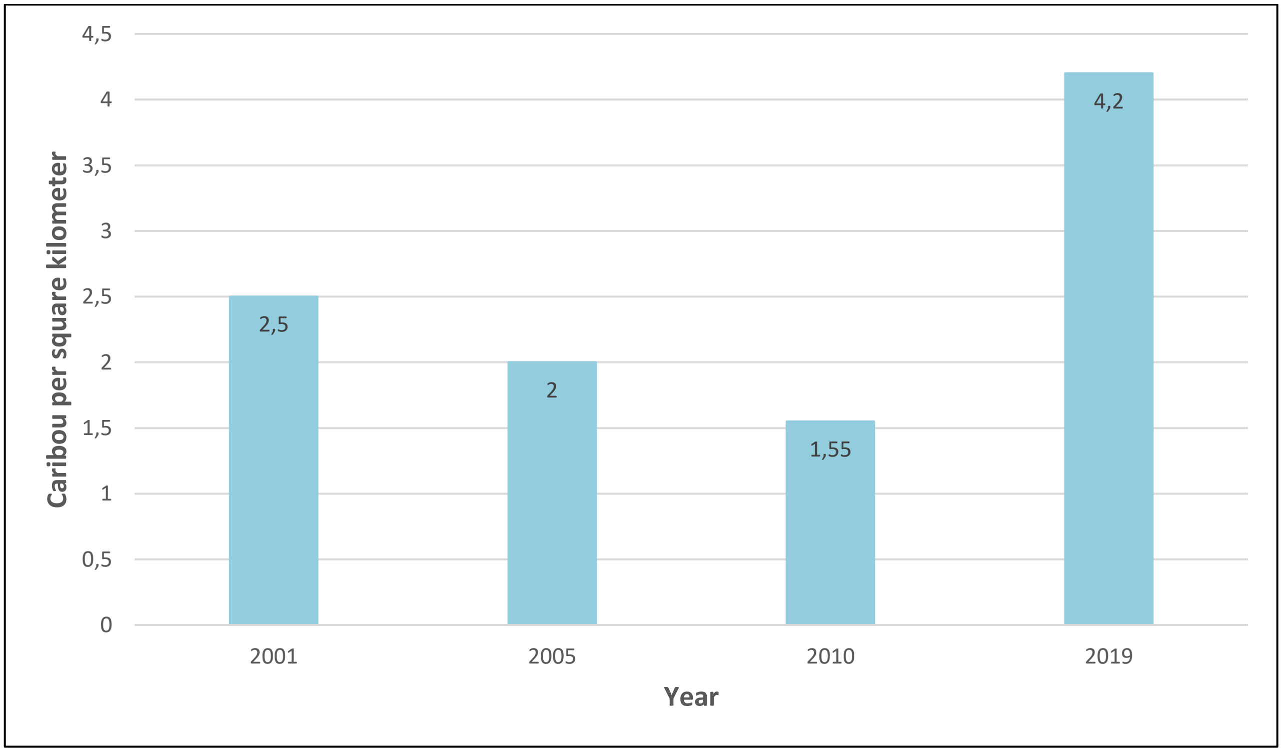

Figure 22. Past and present caribou density estimates for the Akia-Maniitsoq population, West Greenland.

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 for camouflage (e.g., extreme, high, medium, low, none). Combined, we expect this 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.

About 75% of the observed caribou groups exhibited movement in response to the helicopter fly-by, while about 25% did not, which included some on the track line. This large proportion of stationary caribou groups underlines the importance of skilled observers able to detect caribou despite the extraordinary degree caribou are camouflaged for typical background conditions. From experience we know that observer skill can only succeed in detecting camouflaged caribou present if the helicopter is flying 'low & slow', as the current study did. Because stationary animals make up almost 1/4 of all caribou groups observed and include some on the line transect itself (where for DS analyses all caribou present must be detected), detecting non-moving caribou is essential to avoid underestimating population size.

Caribou groups that exhibited movement in response to the helicopter fly-by had a mean group size of 4. This was significantly ($p < 0.0001$) larger than the non-moving caribou mean group size of 3. Also, groups that exhibited movement were closer to the helicopter than groups that did not move (Table 9). 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 that at greater distances the helicopter may be perceived by the caribou as less threatening. Additionally, group composition may be involved.

For caribou groups that ran from the helicopter, most exhibited unabated flight reaction, i.e., they never stopped while we could see them. This was specifically true for those groups whose original position was the track line itself. Calf presence appears to be an important factor determining whether unabated flight occurs, since ca. 86% of unabated flight involved groups with calves.

Demographics

In early March 2019, the Akia-Maniitsoq caribou population's demographics suggested a composition that provides potential for further growth in abundance, albeit notwithstanding future catastrophic stochastic events, including pathogen outbreaks and extreme weather.

Ratio of bulls to cows appeared to be recovering from the 2001 to 2010 bull decline (Fig. 23). The 2019 calf percentage and recruitment (number calves per 100 cows) were the highest since helicopter surveys began in 2001 (Fig. 24). The 2019 values remained high even after removing the surprisingly high number of orphan calves (n = 83). Further, the 2019 percentage of calves was similar to the high 1998 level (Table 1) obtained from ground survey. The 2019 level of calf recruitment strongly suggests the possibility of future population growth (Bergerud et al. 2008).

A discussion of Akia-Maniitsoq's demographics in 2019 would not be complete without discussing that ¼ of all observed calves were orphans. Although the late winter calf recruitment was initially ca. 52 calves per 100 cows, the high incidence of orphan calves (n=83), ca. 25% all calves observed, brought calf recruitment value down to 34 calves per 100 cows. It is not unreasonable to assume that to create those orphans a similar number of cows died before the 2019 survey occurred. This suggests two possibilities. First, that some pathogen increased mortality among cows but not their calves, and not among bulls.

Common sense makes this unlikely since caribou pathogens are not so selective. The second possibility is that hunters harvesting from the Akia-Maniitsoq caribou population predominantly selected only the cow from cow-calf pairs.

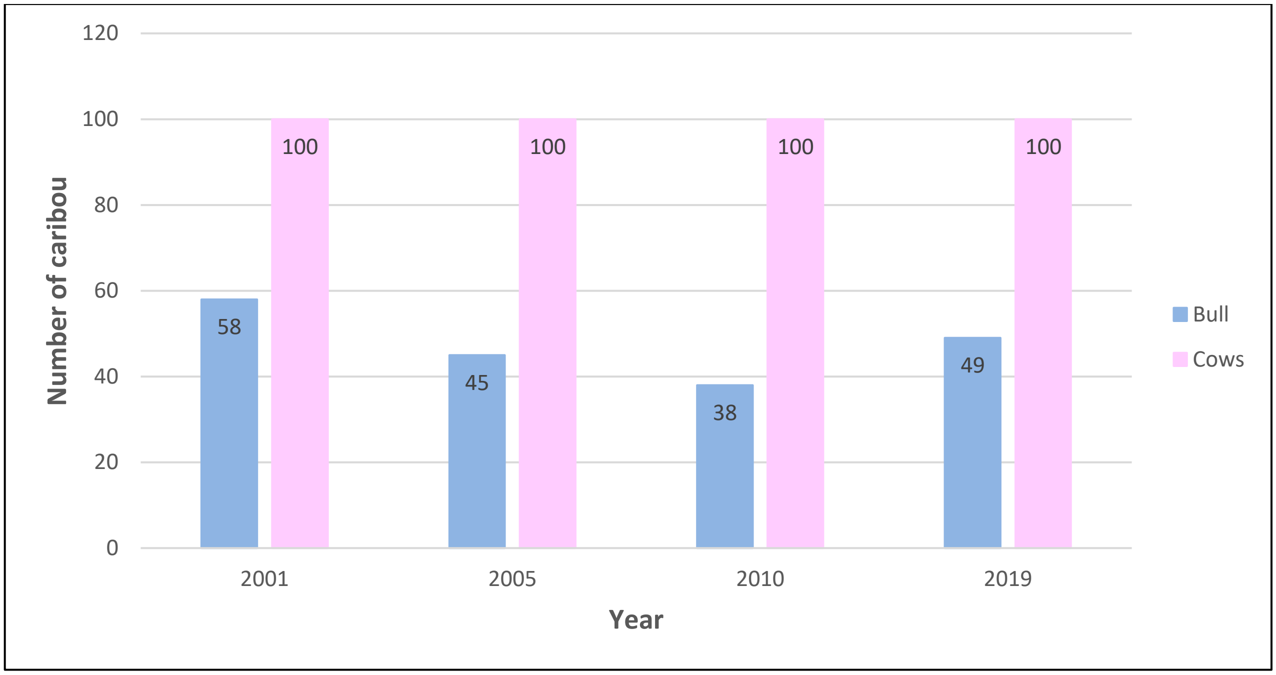

Figure 23. Past and present late winter bull to cow ratios for the Akia-Maniitsoq caribou population. Bull classification includes both juveniles, 1-year < age < 3-year, and adults, age > 3 years.

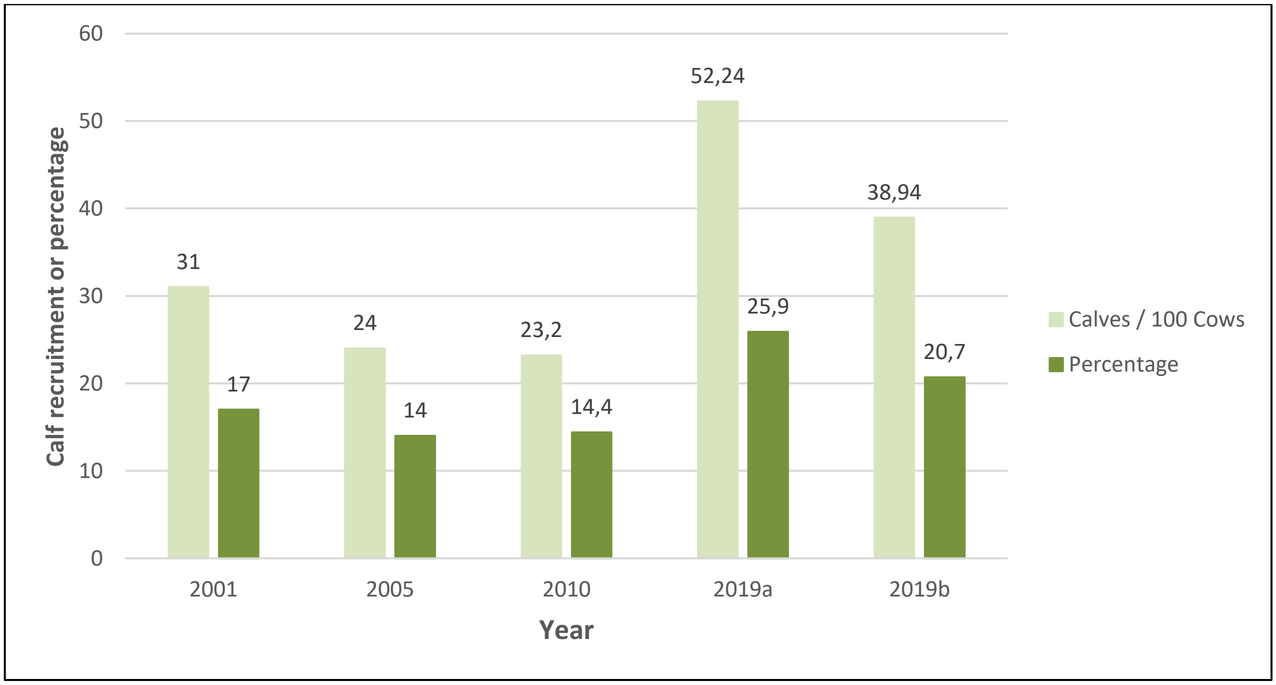

Figure 24. Past and present late winter calf (age 10-month) recruitment (number calves per 100 cows) and calf percentage for the Akia-Maniitsoq caribou population. Column 2019a included all calves observed, while 2019b removed all orphan calves (n = 83).

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 Akia-Maniitsoq population were observed at elevations of mean 361 m ±246 with the mode being 156 m. This use of relatively low elevations in late winter (March) is supported by 2008-2010 GPS telemetry data from for Akia-Maniitsoq cows, mean elevation ca. 200 m (Cuyler et al. 2017). This may reflect a caribou preference for low elevations or just that the Central region has more available lowland habitat than is usual in West Greenland, i.e., Akia sub-area is mostly < 200 m elevation (Figs. 1, 2). The caribou are likely to prefer low elevations because of a higher quality and quantity of available winter forage, which would be expected for lowland elevations at the latitude of the Central region (Körner 2007). Use of low elevations may also suggest that winter disturbance by humans on the Akia-Maniitsoq population is minimal.

The winter 2019 caribou hunting season for the Central region was 01-15 February, ending 2-weeks before the 2019 survey began. The similar late winter elevation use across years suggests Akia-Maniitsoq caribou are not using high elevations to avoid hunters. Meanwhile, the Akia-Maniitsoq caribou population is not readily accessible to humans, regardless of season because the Central region can only be reached by boat. Specifically for winter, snowmobile use is prohibited over the entire region, rendering these vehicles illegal for winter hunting season transport or recreational use.

Nevertheless, and despite being illegal, snowmobile use on the Akia (Nordlandet) area of the Central region was observed in March 2019 (Fig. 20). The same was observed during the previous survey of 2010, when snowmobile use was associated with high harvest number of caribou (Cuyler et al. 2011). In both 2010 and 2019, high numbers of caribou in unusually large groups were observed on the low elevation (< 200 m) flats in the northern portion of the Narssarssuaq Valley, Central region (Fig. 17). As suggested earlier (Cuyler et al. 2011), this caribou aggregation may be the result of animals avoiding the snowmobile activity in the extensive lowlands of Akia (Nordlandet). Unfortunately for the caribou, Akia (Nordlandet) is a prime winter foraging habitat (Cuyler et al. 2017), which is opposite Greenland's capital city, Nuuk, and illegal snowmobile use may be common. The abnormally large aggregation of caribou in the Narssarssuaq Valley suggests that current levels of snowmobile disturbance are sufficient to cause avoidance behavior, albeit to another lowland area rather than to higher elevations.

All the above may explain why the Akia-Maniitsoq caribou population averaged elevations ca. 300 m lower than the Ameralik caribou population, which were also surveyed in March 2019 (Cuyler et al. 2023). There should be less access by humans to the Akia-Maniitsoq caribou population, and their Narssarssuaq Valley appears to provide them with a remote and large lowland area where they can avoid winter hunters or snowmobile recreation. The current remoteness of the Narssarssuaq Valley will change if human access increases. Until then, elevation use by the Akia-Maniitsoq population will not likely be influenced by human disturbance.

Late-winter antler possession

Bulls

As expected for caribou populations, adult (age > 3-years) bulls from the Akia-Maniitsoq population lacked antlers in March, while most, 87%, juvenile bulls retained one or both their antlers from the previous autumn. Thus, late-winter antler possession among bulls age > 1 year of the Akia-Maniitsoq population is similar to bulls in both the Kangerlussuaq-Sisimiut and Ameralik caribou populations (Cuyler et al. 2021, 2023). However, in those same three populations, antler possession varied for late-winter male calves (age < 1-year). Antler possession in male calves was poor, 40%, in the Akia-Maniitsoq population. In contrast, antler possession in male calves was common and similar in male calves for the Kangerlussuaq-Sisimiut and Ameralik populations at 86.2% and 87.5%, respectively (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, 2021). 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).

Albeit polled (antlers lacking) cows are common among caribou populations in West Greenland, the Akia-Maniitsoq population far exceeds the norm, i.e., just 32% of cows had antlers in late winter 2019. Instead, most cows are polled (68%). This was also reflected in antler possession or absence among female calves, and to a lesser extent even male calves.

The 2019 results for poor antler possession among Akia-Maniitsoq cows are supported by 1998 observations of 19% antlered Akia-Maniitsoq cows (Cuyler unpublished).

Lack of antlers in Akia-Maniitsoq cows is in sharp contrast to the situation in North America. There, antler possession is assumed to confer dominance among large aggregations of caribou that must feed by cratering through deep snow (Kelsall 1968, Reimers 1993, Bergerud *et al.* 2008). Nevertheless, Bergerud *et al.* (2008) presented evidence that a high percentage of polled cows would be expected in populations that had small group sizes and little dependence on cratering. Akia-Maniitsoq caribou do have small group sizes, mean 3.75 ± 3.0 standard deviation. Further, xeric conditions occur in inland areas and can result in negligible snow depth covering food resources in the Ujarassuit sub-area and anywhere adjacent the Greenland Ice Cap (Appendix 1, Figs. 31-34, 37-46). Thus, the percentage of polled Akia-Maniitsoq cows may be unrelated to range condition, but rather reflect a reduced need for the dominance conferred by antlers.

With only 32% of cows possessing antlers in 2019, the Akia-Maniitsoq population is in sharp contrast to either of the other two large caribou populations (Kangerlussuaq-Sisimiut and Ameralik) that have been surveyed in West Greenland. For example, for the same survey year, 2019, 92% of Ameralik cows had antlers (Cuyler et al. 2023), and although not as great a difference, in 2018, antlered Kangerlussuaq-Sisimiut cows were 54% (Cuyler et al. 2021).

It is notable that despite cows being predominantly polled in March 2019, the Akia-Maniitsoq population had an excellent percentage of calves and calf recruitment. High calf numbers contradict any assumption that cows are in poor body condition (e.g., owing to overgrazed range) rather the opposite is indicated. We suggest that an inherited trait may be the major influence causing predominantly polled Akia-Maniitsoq cows.

Snowmobile use Akia-Nordlandet

Akia-Nordlandet is a peninsula of rugged lowlands just opposite Greenland's capital city, Nuuk, on the north side of Nuuk (Godthåb) fjord. There are no permanent human habitations, but there are numerous recreational summer houses/cabins. Despite the continued prohibition on snowmobile use for this area, recent snowmobile activity was observed. Snowmobile use was first observed in March 1997 (Cuyler unpublished) and was extensive during the 2010 caribou winter harvest (Cuyler et al. 2011).

Other species observed

During the early March 2019 survey multiple species other than caribou were observed. Ptarmigan and hares were relatively abundant and appeared to support a healthy arctic fox population. Gyr falcons, sea eagles and snowy owls were also observed. Although since ca. 2000 local knowledge has reported muskox presence in the Central 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 Central region and another in the South region (Cuyler et al. 2023). Although the surveys occurred almost simultaneously, each of the observed species (other than caribou) were more numerous in the Central region than in the South (Cuyler et al. 2023). For example, there were three times more ptarmigan in the Central region and almost twice as many hares. Not unexpectedly then regarding predators, there were four times the number of arctic foxes and several avian predators in the Central region. Still, the Central region's area of survey effort (Table 2) was 2.4 times greater than for the South region (Cuyler et al. 2023). This partially explains the greater number of observations. However, it remains that the Central region had more ptarmigan and foxes as well as avian predators. Late winter 2019 habitat conditions in the Central region supported a greater abundance of several species than conditions in the South region.

Acknowledgements

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Appendix 1

Photos, Central region aerial survey conditions for census of the Akia-Maniitsoq caribou population, March 2019.

Figure 25. Akia sub-area, illustrating typical conditions. Photo C. Cuyler.

Figure 26. Fog over the Maniitsoq Coast sub-area, which prevented planned flights. Photo C. Cuyler.

Central region aerial survey conditions, March 2019

Figure 27. Akia sub-area of the Central region, illustrating just north of Greenland's capital city, Nuuk, view NNW across bay, Kanassut, and over the expanse of rugged lowlands that is Akia (Nordlandet), showing conditions typical for line transects 1, 3, 4, 5, and 6. Photo C. Cuyler.

Figure 28. Akia sub-area of the Central region, illustrating rugged Akia (Nordlandet) lowlands and snow conditions typical for line transects 1 to 6, view to south with lake Saarlup Tasersua in upper center. Photo C. Cuyler.

Central region aerial survey conditions, March 2019

Figure 29. Akia sub-area, west end of line transect 10, view ENE. Photo A. Jensen.

Figure 30. Akia sub-area, thin mouth of Niaqungunaq (Fiskefjord) and conditions typical for line transect 17, view SW. Photo A. Jensen.

Central region aerial survey conditions, March 2019

Figure 31. Akia sub-area in the valley, Narssarssuaq, illustrating ground conditions for line transect 15. Note: There are eight caribou within 50 m of the helicopter (above), view west across the valley, and 45 caribou within 50-150 m (below), view north up the valley. Photos A. Jensen.

Figure 32. Akia sub-area illustrating ground conditions at the east end of line transect 22. The frozen surface of the large lake, Taserssuaq, in foreground. Line transect 22 ran west through the valley that appears just left of center. Photo A. Jensen.

Central region aerial survey conditions, March 2019

Figure 33. Akia sub-area, valley north of Ilulialik fjord, illustrating ground conditions, frozen surface of the large lake, Taserssuaq, in background, slope up to Ujarassuit on the right. Line transect 15 ran across this valley. Photo A. Jensen.

Figure 34. *Akia sub-area, view west across unnamed peninsula (which is immediately south of the valley, Narssarssuaq) and towards the partially frozen bay, Qussuk, illustrating thin snow depth and predominance of bare ground. Photo A. Jensen.*

Central region aerial survey conditions, March 2019

Figure 35. Maniitsoq Coast sub-area, view to the north from line transect 55, in the far northern portion of the Central region, illustrating snow covered terrain and glacial tongue (left) spilling into frozen lake. Photo A. Jensen.

Figure 36. Maniitsoq Coast sub-area illustrating mountainous terrain and conditions typical for line transect conditions near the Davis Strait coast, e.g., line transects 45, 48, 49 and 51. Here a view to the northeast into the Kangia Fjord. Photo A. Jensen.

Central region aerial survey conditions, March 2019

Figure 37. Ujarassuit sub-area, illustrating typical conditions for terrain, snow, and sunlight present for most of the line transects. Photo A. Jensen.

Figure 38. Ujarassuit sub-area on the one day with sunshine, view west from the east end of line transect 27, illustrating rugged highland terrain and lack of snow. Photo C. Cuyler.

Central region aerial survey conditions, March 2019

Figure 39. Ujarassuit sub-area, east end of line transect 35, view to west illustrating snow depth and flat light. Photo A. Jensen.

Figure 40. Ujarassuit sub-area, illustrating typical terrain, snow, and sunlight conditions for line transects 36, 35 and 33. Note the rather xeric landscape, view to the west with the large lake, Taserssuaq, in background. Photo A. Jensen.

Central region aerial survey conditions, March 2019

Figure 41. Ujarassuit sub-area terrain, snow, and flat light conditions at the east end of line transect 36, view to the west. Photo A. Jensen.

Figure 42. Ujarassuit sub-area, illustrating typical terrain, snow, and sunlight conditions in a rather xeric landscape, view northwest from line transect 33 towards the large lake, Taserssuaq, in far background. Photo A. Jensen.

Central region aerial survey conditions, March 2019

Figure 43. Ujarassuit sub-area, illustrating rugged highland terrain, snow depths and sunlight typical of line transect 30. Similar conditions existed for line transects 27, 29, 31 and 28. This view southwest from line transect 30 towards Innajuattoq (Bird Mountain) in left background. Photo A. Jensen.

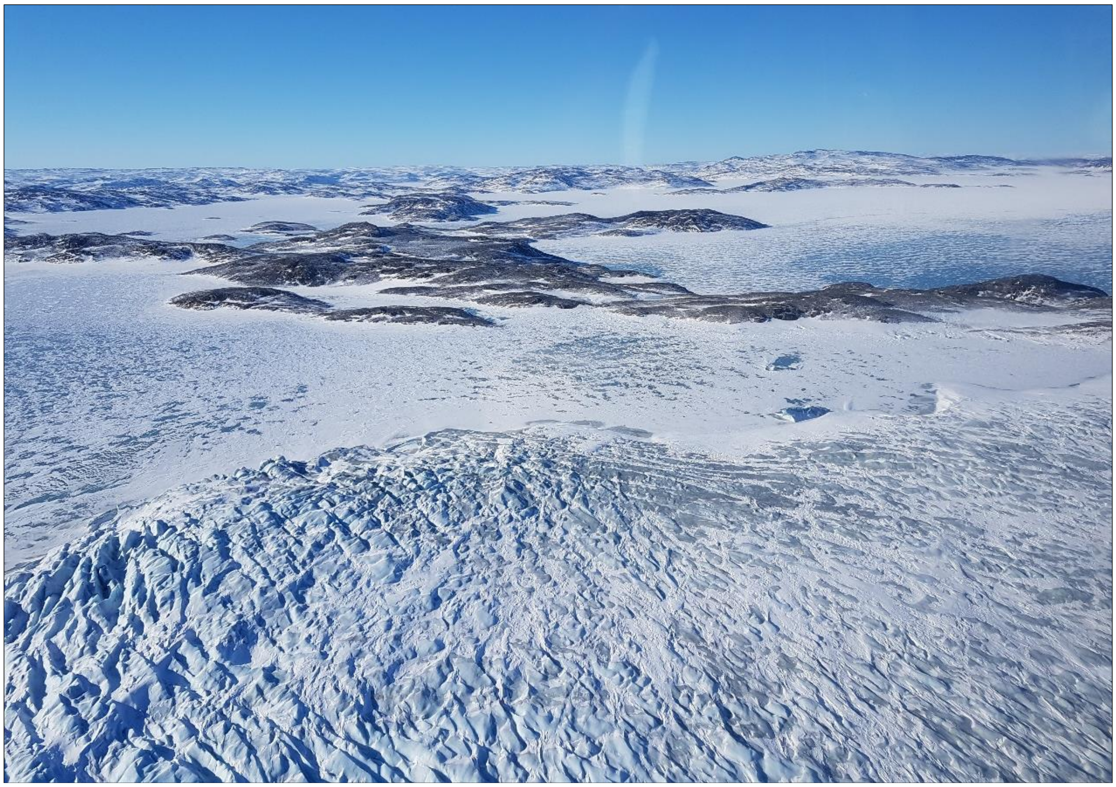


Figure 44. Ujarassuit sub-area, Ivisartoq highlands, xeric conditions of east end line transect 32, view N across the many frozen lakes and edge of Greenland Ice Cap in foreground. Photo A. Jensen.

Central region aerial survey conditions, March 2019

Figure 45. Ujarassuit sub-area, Ivisartoq highlands view east towards small bay in the Ujarassuit Kangerluat fjord. Thin snow layer with ground showing through. Photo C. Cuyler.

Figure 46. Ujarassuit sub-area, Ivisartoq highlands illustrating almost non-existent snow layer, view west towards Innajuattoq (Bird Mountain) in far-left background. Photo A. Jensen.

Appendix 2

Place names for the Central region

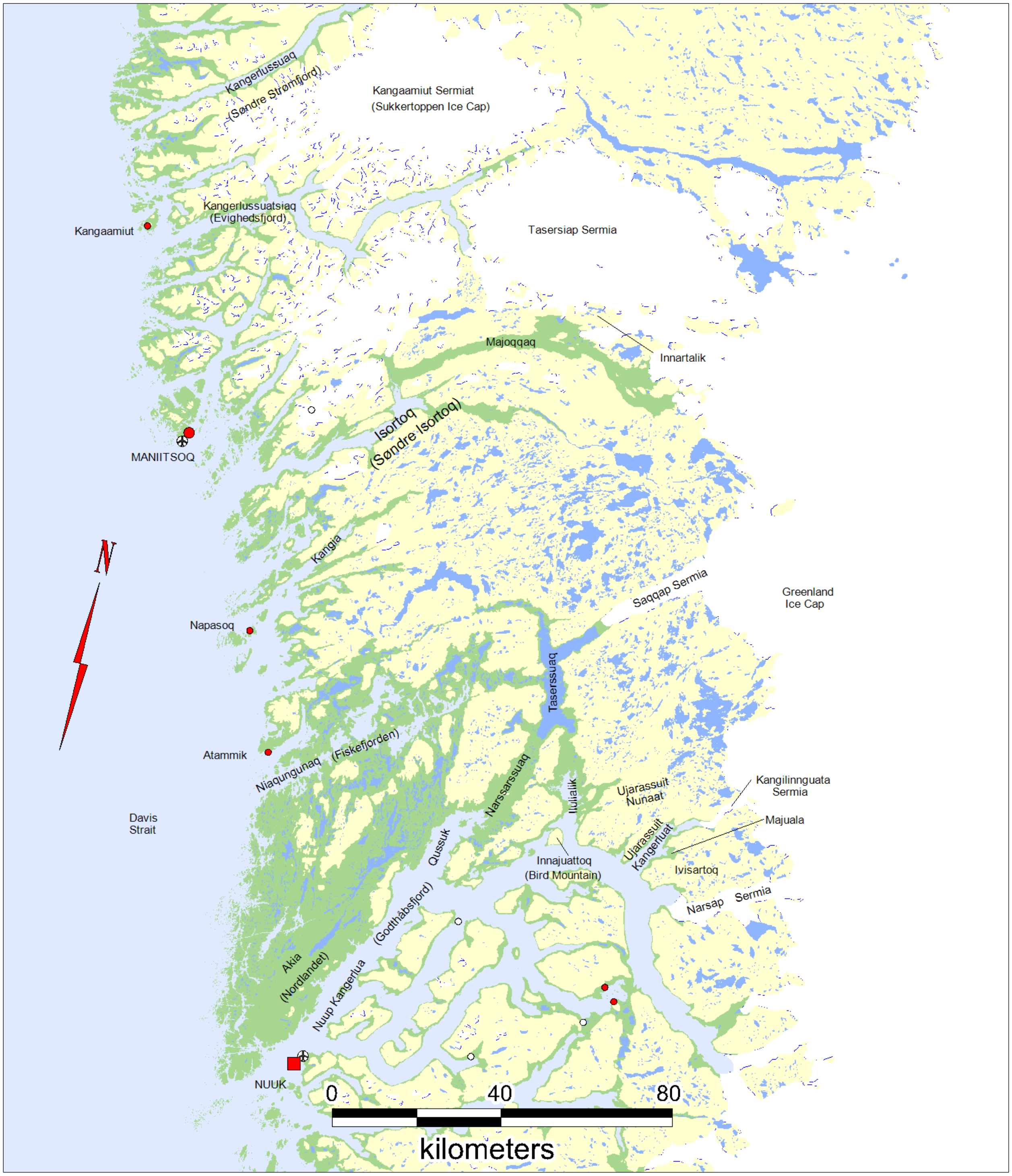


Figure 47. Place names used regarding Central region (ca. 64°–66°N; 50°–53°W), which is inhabited by the Akia-Maniitsoq caribou population.

Appendix 3

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. 48). Some of these small plots are randomly chosen for sampling and the total number of individuals within these, n_{plot}, is recorded.

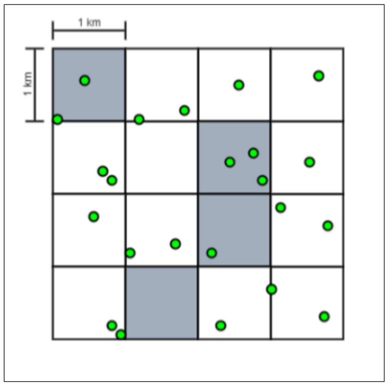


Figure 48. Plot sampling grid example of total area A divided into smaller plots of area a_{plot}

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. 48) 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 were not 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

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

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

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

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

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

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, $\hat{P}_a$, 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. 49). 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., $\hat{P}_a = 1/3$) 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).

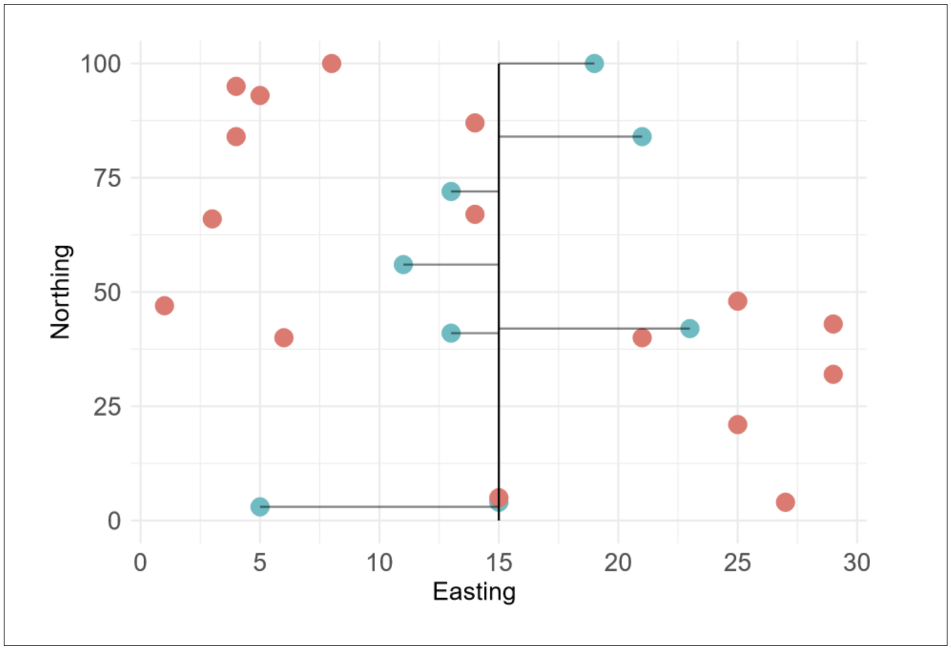


Figure 49. Example of a patch of tundra with the transect in the middle. Blue dots represent eight observed caribou, while orange dots represent the 16 undetected ones. The lines perpendicular to the transect represent the recorded distances.

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, $\hat{P}_\mathrm{a}$ can be obtained via the following equation

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

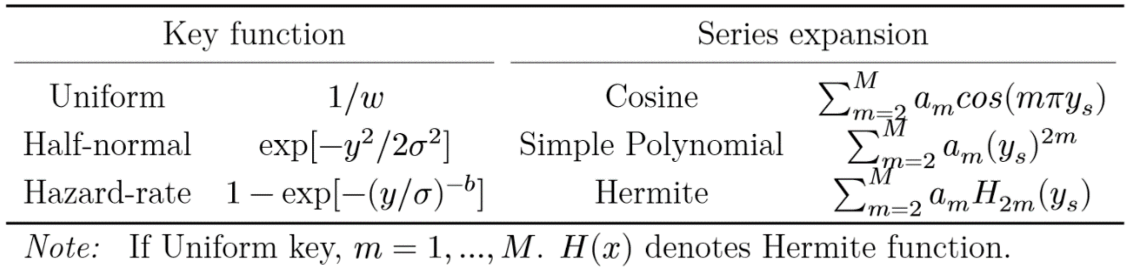
where $\pi(y) = \frac{1}{\omega}$ and, therefore, used to estimate density using Equation (3). For $g(y)$ it is also specified a flexible semi-parametric model, composed by a key function and some additional series expansions, known as adjustment terms, and their parameters are estimated (Marques et 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. 50). 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. 51). 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).

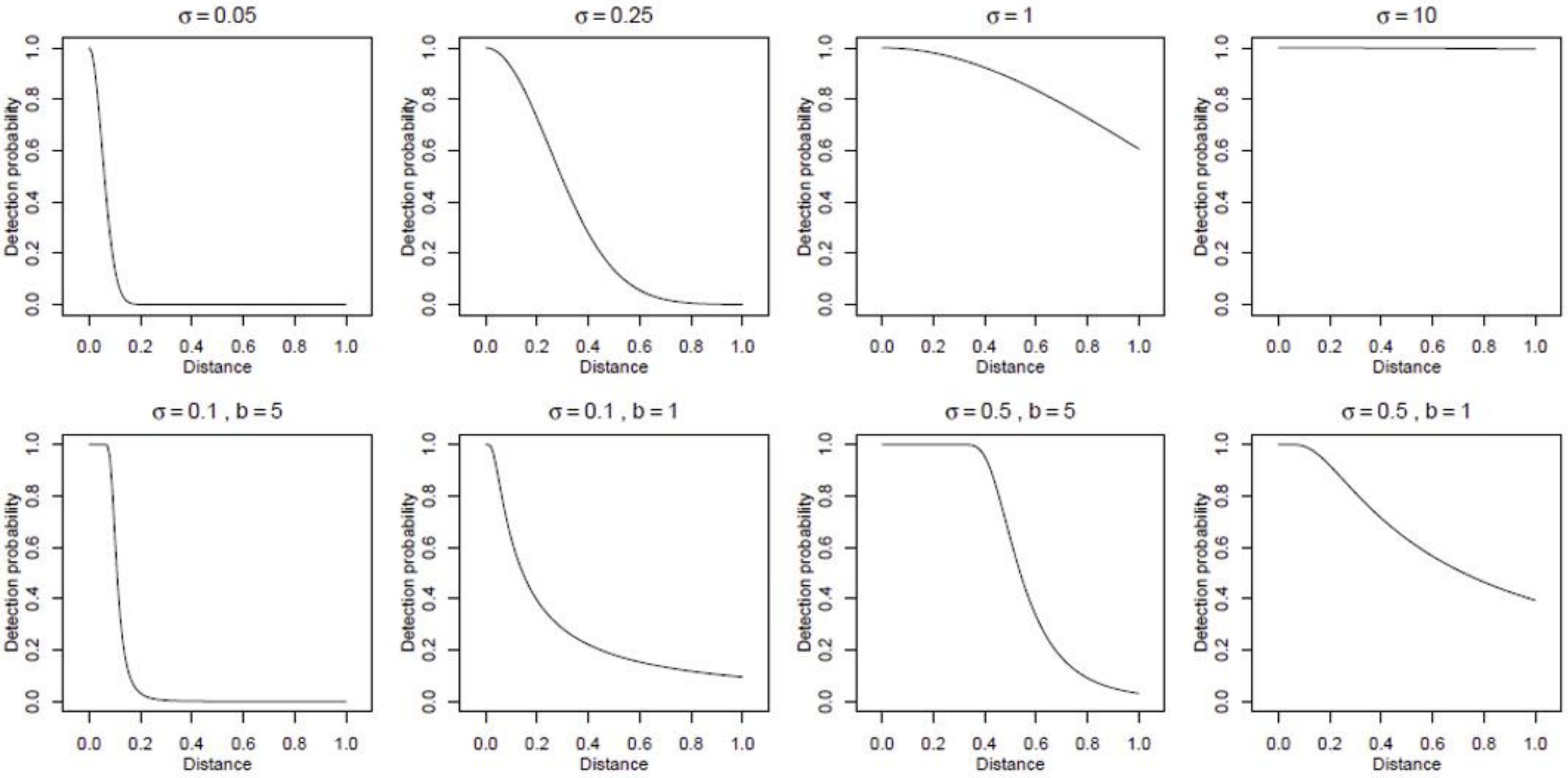


Figure 50. Half-normal (top row) and hazard-rate (bottom row) detection functions without adjustments, varying scale (σ) and, only for hazard-rate, shape (b) parameters. Values tested are presented above the plots. On the top row from left to right, the study species becomes more detectable (higher probability of detection at larger distances). The bottom rows show the hazard-rate model's more pronounced shoulder. Adapted from Buckland et al. (2001).

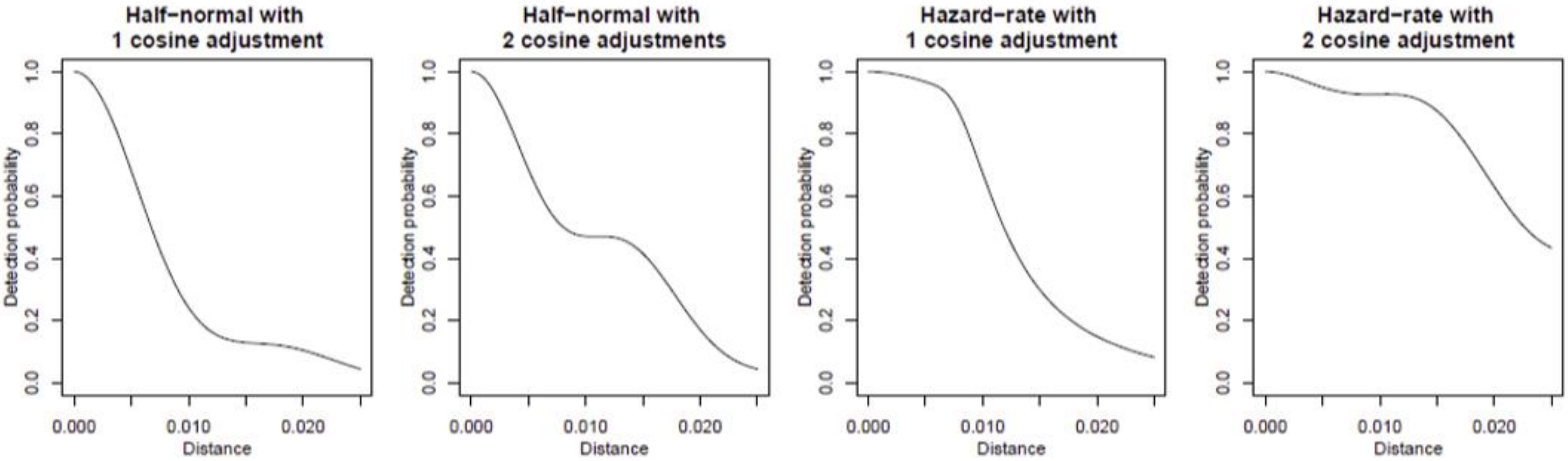


Figure 51. Possible shapes for the detection function when cosine adjustments are included for half-normal and hazard-rate models. Adapted from Buckland et al. (2001).

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, $\mathbf{z_i} = z_{i1}, \ldots, z_{iJ}$, $i = 1, \ldots, n$. 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 favors 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. 52), 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.

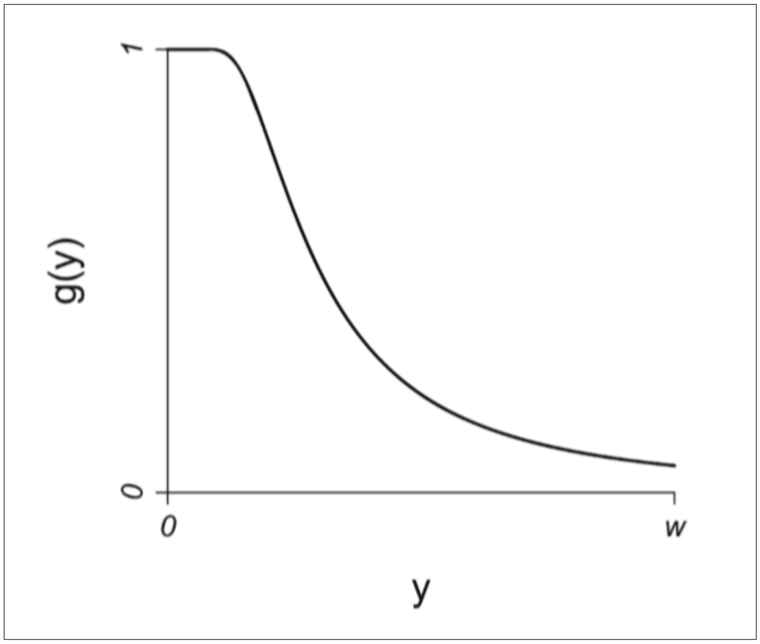


Figure 52. A good model for the detection function should have a shoulder, with probability of detection staying at or close to one at short distances from the track line or point. At larger distances, it should fall away smoothly. The truncation distance ω corresponds to the strip half-width (for Line 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. 52) (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

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

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

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

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

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

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

27

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 $X^2_{obs} > X^2_{1-\alpha;(u-q-1)}$, 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 4

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 5

Photos of camouflaged caribou observed March 2019.

Figure 53. Eight caribou, several camouflaged against background, within 200 m of helicopter. Photo A. Jensen.

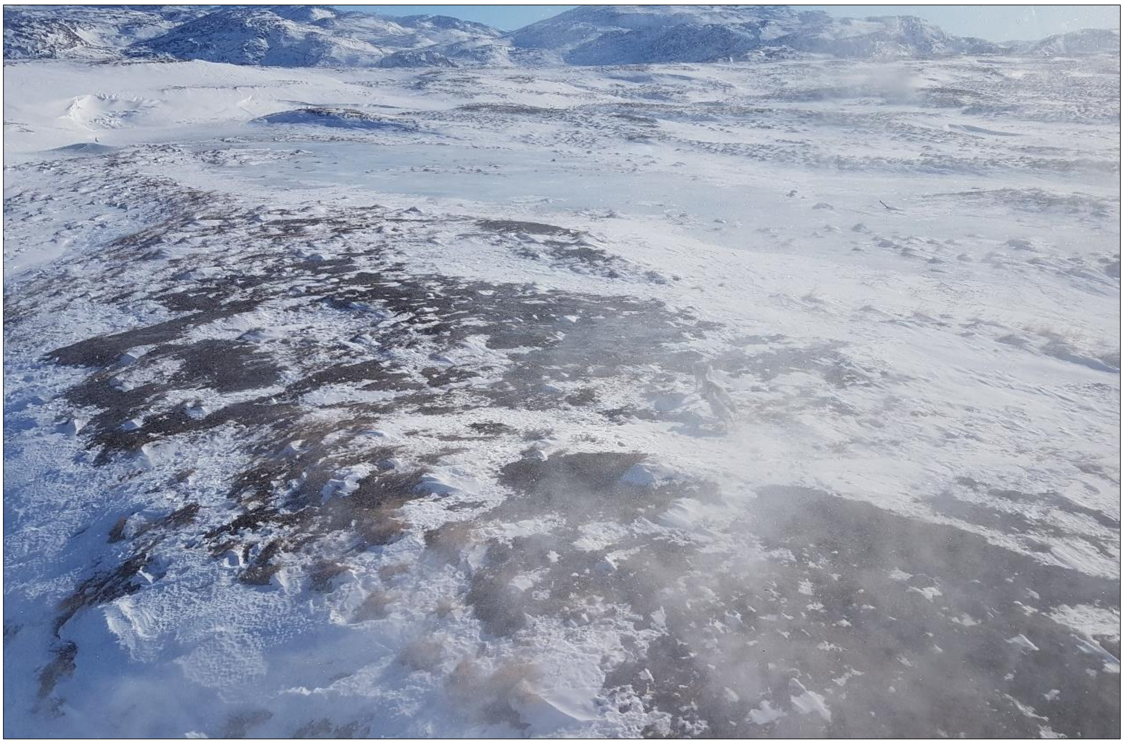
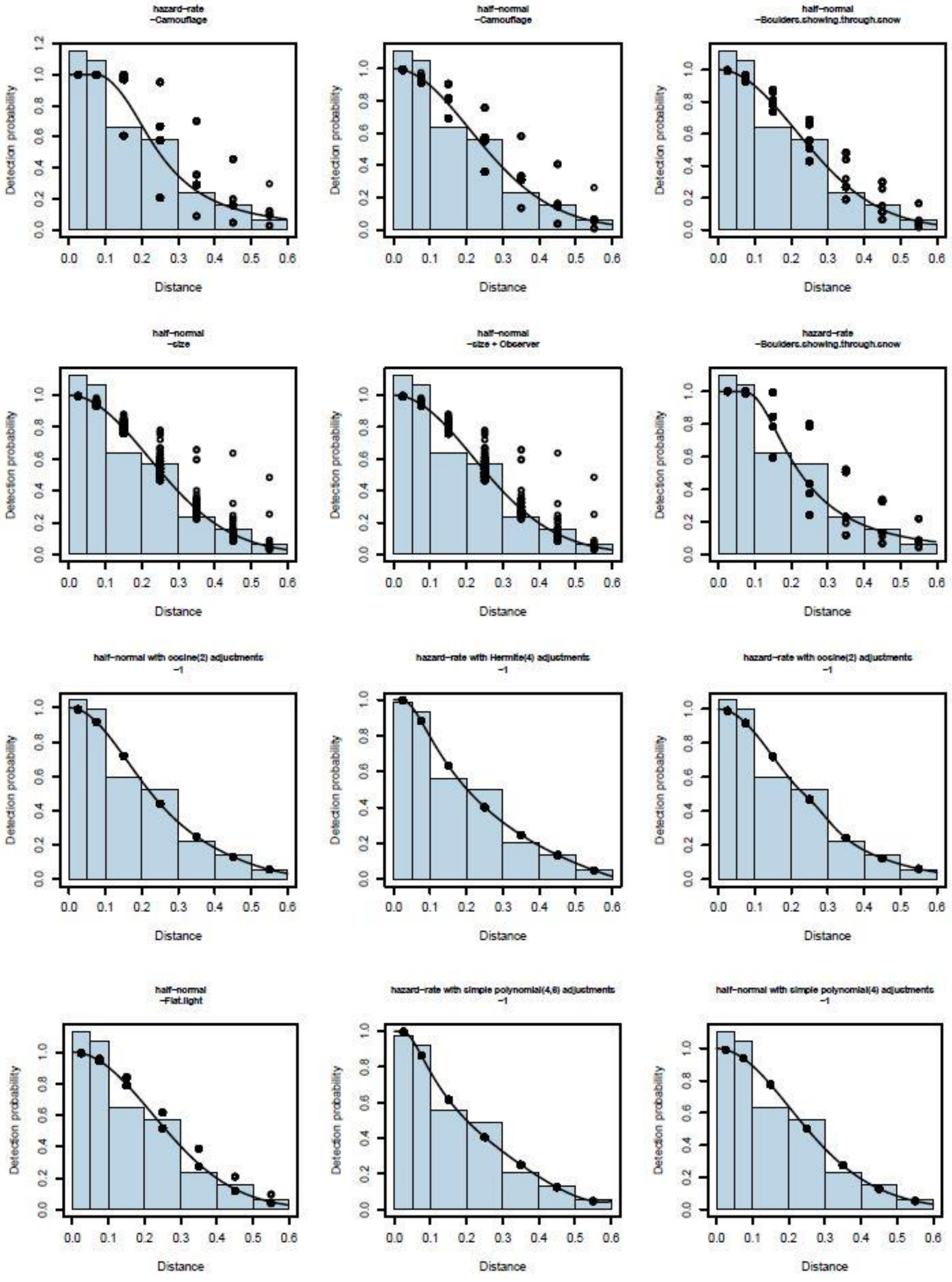


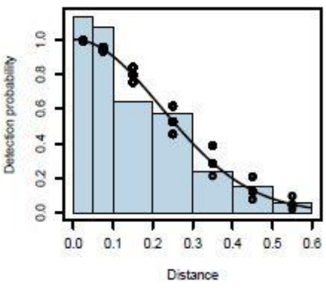
Figure 54. Three caribou camouflaged against background, within 100 m from helicopter. Photo A. Jensen.

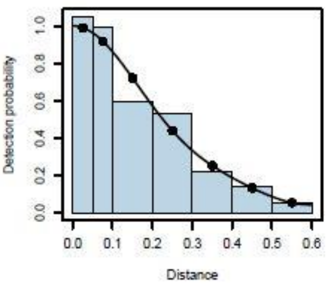
Appendix 6

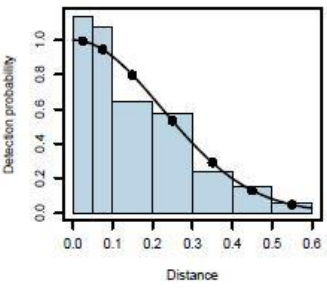
Histograms for detected distances

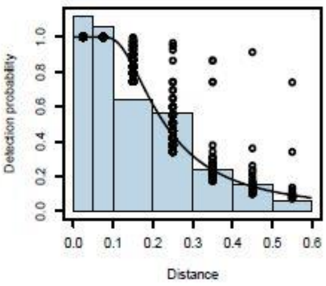
Histograms for detected distances superimposed with estimated detection functions for all truncated fitted models, presented order as in Table 3

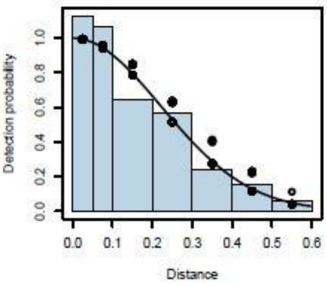


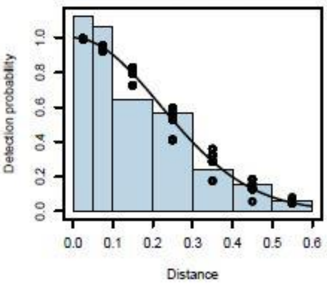

half-normal
~Weather

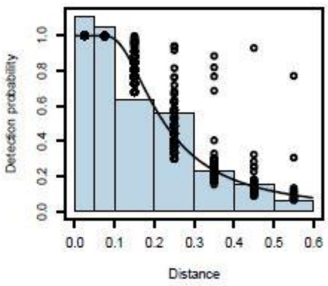

uniform with cosine(1,2,3) adjustments

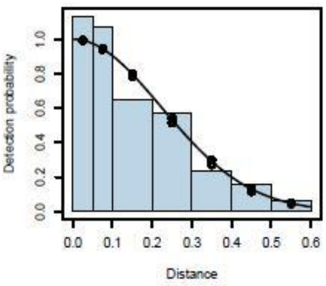

half-normal
~1

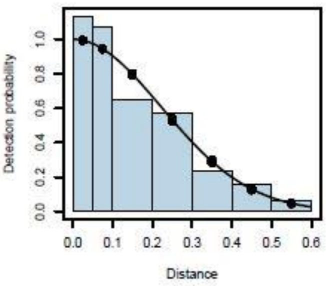

hazard-rate
~size

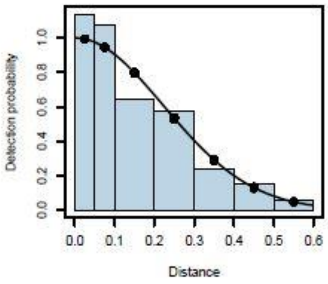

half-normal
~Dead.ground

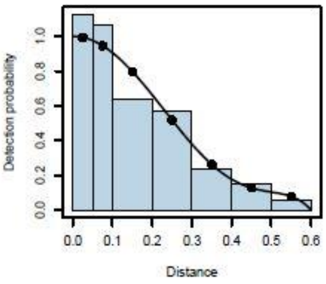

half-normal
~Vegetation.or.ground.showing.through.snow

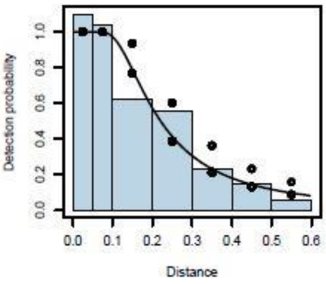

hazard-rate
~size + Observer

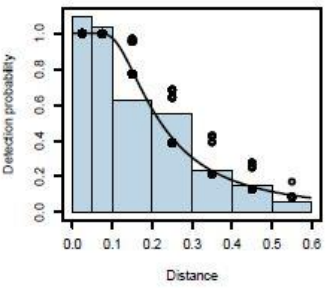

half-normal
~Glare

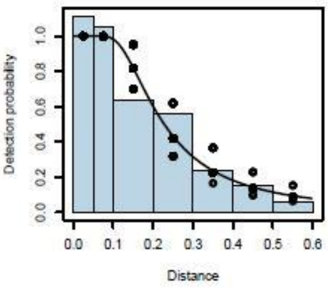

half-normal
~Helicopter.side

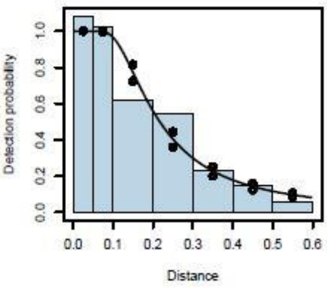

half-normal
~Observer


uniform with simple polynomial(2,4,6,8) adjustments


hazard-rate
~Flat.light


hazard-rate
~Dead.ground


hazard-rate
~Weather


hazard-rate
~Observer

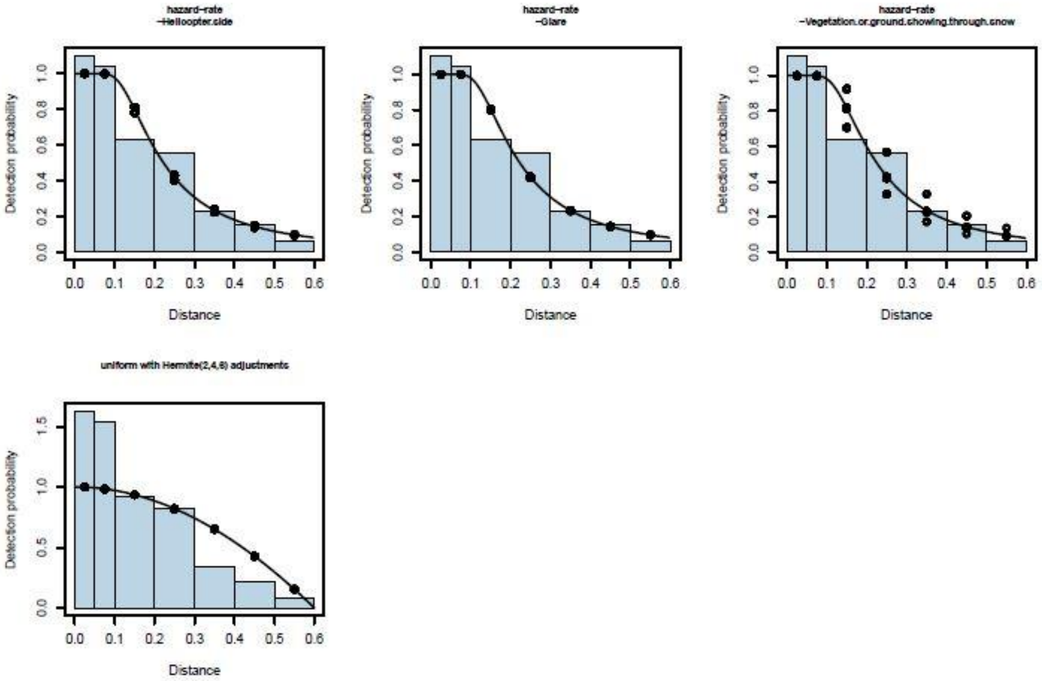


Figure 55. Histograms for detected distances superimposed with estimated detection functions for all truncated fitted models.

The parameter estimates and variability associated with them (Table 13), with Extreme as the reference level for comparison. Illustrates that High camouflage has a lower (negative) but similar (estimate close to 0) detection probability as Extreme camouflage. Medium camouflage has a more negative estimate and thus lower probability of detection relative to Extreme and High. Further, Low camouflage, being positive, means the probability of detection is greater when compared with Extreme camouflage (as also shown in Fig. 15).

Table 13. Detection function parameters' estimates.

	Estimate	**Standard Error**
Intercept	-1.353	0.115
Camouflage High	-0.089	0.122
Camouflage Medium	-0.571	0.140
Camouflage Low	0.371	0.226

Note: Estimates are on log scale.

Appendix 7
Recommendations for improving future surveys

Aerial survey methods & design

The 9.6% survey coverage for the 2019 Distance Sampling (DS) surveys of the Akia-Maniitsoq caribou population promotes accuracy of abundance estimates and should be continued 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. 56), 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., at sea or in helicopters. Even the usually sedate helicopter maneuvers for transect lines can illicit nausea in some. Meanwhile, the non-stop abrupt flying maneuvers required for caribou demographics cause nausea in most persons.

Note: Even previous helicopter experience, including animal live capture, does not guarantee lack of nausea during sharp maneuvers specific to caribou demographics work.

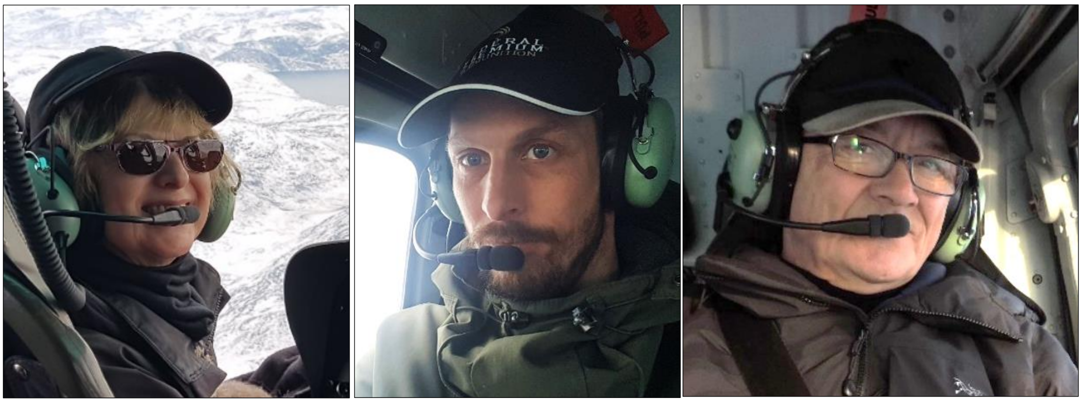


Figure 56. The three observers, Dr. Christine Cuyler, scientific leader (left), Aslak Jensen, commercial hunter (center), and Hans Mølgaard, Sisimiut hunting officer (right).

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.

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. 57). 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.

Figure 57. AS350 Helicopter viewing windows for the left and right sides, illustrating small rear window size and the numerous impediments obstructing viewing.

Appendix 8

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 was derived by Correia (2020).

Sources: Cuyler et al. 2002, 2003, 2004, 2005, 2007, 2011, 2016, 2021, 2023 and current study.

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