2018 Status
Kangerlussuaq-Sisimiut caribou
West Greenland

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Title: 2018 status Kangerlussuaq-Sisimiut caribou West Greenland

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Cover photo: Aslak Jensen: Three polled caribou cows and a male calf, with top of one prong visible.

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By

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

Summary

West Greenland (south of 69°N) has six caribou (*Rangifer tarandus*) regions that contain several distinct populations. This report presents new information, from a survey carried out in 2018, about the Kangerlussuaq-Sisimiut (KS) population, which inhabits the North region.

The KS caribou were last surveyed in March 2010. Since then, there have been long autumn hunting seasons of unlimited harvest, as well as a winter season. A new estimate of abundance was overdue. Helicopter surveys in 2000, 2005 and 2010 used strip transect counts. In March 2018, helicopter was again used, and for the first time Distance Sampling methods and analyses were applied.

Previous surveys have documented that Greenland caribou are extraordinarily camouflaged against typical environmental conditions in Greenland, and how this could reduce detection of caribou present within the surveyed area. While almost anyone can detect running animals, stationary animals can be difficult to detect. To investigate the proportion of non-moving caribou, the 2018 survey recorded caribou flight responses or lack thereof for every group observed. Flight movement was absent in almost 32% of all caribou groups observed during the survey. This underlines the importance of skilled observers, as well as flying low and slow to make detection of caribou easier. The 2018 survey's Distance Sampling methods and analyses corrected for undetected caribou and provided a robust estimate for caribou abundance and density (below). 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. Additional results from two Greenland caribou surveys completed in 2019, will confirm whether the observed proportion in 2018, almost 1/3 non-moving caribou groups, is atypical or typical. If typical, this suggests that a survey dataset including few observations of stationary caribou groups would underestimate population size correspondingly.

In early March 2018, observed KS caribou were at relatively low elevations, mean 361 m. A high proportion of polled KS cows was observed, 46%, which is similar to earlier reports for this population. Polled cows are not likely due to poor body condition, as is the common assumption for populations elsewhere. For KS, polled cows may be the result of a reduced need for the dominance conferred by antlers, given their small group sizes, and the xeric

climate reducing the need of competing for feeding craters dug down through deep snow to obtain forage.

The March 2018 demographics were improved relative to observed in 2005 and 2010. Specifically, late winter calf (age ≤ 10-months) percentage was ca. 21.8%, and calf recruitment was ca. 42 calves per 100 cows. However, 26-32% of all calves were likely orphans without dams. This suggests that the true late winter value for calf percentage was closer to 17% and recruitment ca. 31 calves per 100 cows. This level of recruitment is higher than the observed in 2005 and 2010. The March 2018 sex ratio was ca. 51 bulls per 100 cows. The March 2018 demographics describe a caribou population that appears capable of withstanding current harvests, while the calf recruitment is not high enough to suggest the possibility of rapid population growth. Stochastic catastrophic events excepted, there appears to be a low risk for future population decline, while there is potential for slow growth.

For March 2018, survey coverage was 10.6% of the study area, which is a substantial improvement from the 1% coverage of the 2000-2010 strip transect count surveys. The North region's 2018 KS caribou population abundance was estimated at ca. 60,469 caribou (95% CI: 51,932–70,410; CV = 0.074; SE = 4,501), with a density of ca. 2.59 caribou/km^2 (95% CI: 2.23–3.02). This Distance Sampling estimate was precise (CV = 7.4%). The population estimate is ca. 38.5% lower than the estimated number of KS caribou in 2010. Before concluding that a large decline has occurred, caution is needed because several mitigating factors must be recognized. The 2010 survey had low coverage and a high Coefficient of Variance (CV). Thus, it was likely not as accurate or precise as the 2018 survey. Also, better GIS mapping in 2018 resulted in a smaller total area, which means that the 2010 estimate was inflated. Furthermore, in 2018 survey methods changed to Distance Sampling. This by itself precludes trend projections based on just the current and the 2010 strip transect count surveys. To predict a somewhat reliable population trend, a time series of at least three estimates is needed and these must be obtained with comparable methods. Albeit the 2018 Distance Sampling estimate of ca. 60,469 caribou suggests decline in KS caribou abundance and some decline could be expected, given both the poor calf recruitment of the 2005-2010 period and over a decade of harvest management aimed at reducing KS caribou abundance. Regardless, this report's good late winter calf recruitment for 2018 does not support future decline. Instead, it suggests possible stability or slow growth in future. It is also worth mentioning that an alternate Model-based analysis of the 2018 dataset estimated a somewhat higher 73,895 caribou (95% CI: 65,983-82,757, CV = 0.037) (Correia 2020). Given there are two estimates begs the question, which is the most accurate and precise? This is currently being investigated, requires additional results from two other West Greenland caribou surveys completed in 2019, and conclusions regarding Distance Sampling and Model-based estimates will be published in a peer-reviewed journal.

Whether 60,469 (95% CI: 51,932–70,410) or 73,895 (95% CI: 65,983-82,757), the 2018 KS caribou population size remains large relative to the area available, 23,303 km^2. The KS caribou density from Distance Sampling was 2.6 caribou per km^2. Given good calf recruitment, population decline is not expected in the immediate future. Like all estimates since 2000, the 2018 density exceeds the recommended management target of 1.2 caribou per km^2. Exceeding the target density was assumed to raise risk of overgrazing and lead to abundance decline. In Alaska and Canada, when overgrazing played a major role, caribou declines took place over 15 to 20 years. Nevertheless, even after almost two decades of high densities exceeding the target have passed, there is no strong evidence of extensive overgrazing or decline in the KS caribou. Since in 2018 recruitment improved to at least 31 calves per 100 cows, despite an overall density of 2.6 caribou per km^2, it appears that the North region can support a higher density than expected. Pending additional results from two other West Greenland caribou surveys completed in 2019, the target density for caribou management will receive re-evaluation regarding what level is compatible with demographics that facilitate sustainable populations and harvests in Greenland.

Resume (Dansk)

Vestgrønland (syd for 69°N) har seks regioner med rensdyr (*Rangifer tarandus*), der indeholder flere forskellige populationer. Denne rapport præsenterer nye oplysninger fra en undersøgelse, der blev udført i 2018, om Kangerlussuaq-Sisimiut (KS)-bestanden, i Nordregionen.

KS-rensdyr blev sidst undersøgt i marts 2010. Siden da har der været lange efterårsjagtperioder med ubegrænset fangst samt en vintersæson. Et nyt skøn over bestandsstørrelse var på høje tid. Helikopterundersøgelser i 2000, 2005 og 2010 anvendte striptransekter til optælling. I marts 2018 blev der igen brugt helikopter, og for første gang blev der anvendt distance-samplingsmetoder og -analyser.

Tidligere undersøgelser har dokumenteret, at grønlandske rensdyr er særdeles godt camoufleret i forhold til de typiske miljøforhold i Grønland, og at andelen af de rensdyr, der er til stede i det undersøgte område, der bliver opdaget, dermed kan blive reduceret. Mens næsten alle kan få øje på dyr i løb, kan stationære dyr være vanskelige at opdage. For at undersøge hvor stor en andel af rensdyrene, der ikke bevæger sig, registrerede 2018-undersøgelsen rensdyrflugtrespons eller mangel på samme for hver observeret gruppe. Flugtbevægelse var fraværende i næsten 32 % af alle de rensdyrgrupper, der blev observeret under undersøgelsen. Dette understreger vigtigheden af dygtige observatører samt af at flyve lavt og langsomt, så det er lettere at få øje på rensdyrene. Endvidere korrigerede 2018-tællingens distance-samplingsmetoder og -analyser for uopdagede rensdyr og tilvejebragte et robust estimat over rensdyrbestandens størrelse og tæthed (se nedenfor). Det er rimeligt at forvente, at der ved enhver flytælling af rensdyr vil være en vis andel af ikke-løbende rensdyr til stede i det undersøgte område af linjetransekterne. Yderligere resultater fra to grønlandske rensdyrtællinger, der blev gennemført i 2019, vil bekræfte, om den observerede andel i 2018, næsten 1/3 ikke-bevægelige rensdyrgrupper, er atypisk eller typisk. Hvis den er typisk, antyder det, at et undersøgelsesdatasæt, der inkluderer få observationer af stationære grupper af rensdyr, undervurderer populationsstørrelsen tilsvarende.

I begyndelsen af marts 2018 synes bestanden af KS rensdyr at have opholdt sig i lavereliggende områder (gns. 361 m.o.h.). En høj andel, 46 %, af KS-køer var gevirløse, hvilket svarer til tidligere rapporter for denne bestand. Køer uden gevir skyldes sandsynligvis ikke dårlig kropskondition, som er den almindelige antagelse for bestande andre steder. Der kan være flere årsager til, at hunner i KS-bestanden ikke har gevirer. Generelt set er flokstørrelsen lille, og behovet for at udvise dominans, som et gevir giver, er derfor mindre. Det tørre klima i området medfører, at snedybden om vinteren er begrænset. Derved mindskes behovet for at konkurrere om føden, der i andre områder ville være dækket af et tykt lag sne.

Demografien i marts 2018 var forbedret i forhold til den, der blev observeret i 2005 og 2010. Specifikt var procentdelen af senvinterkalve (alder ≤ 10 måneder) ca. 21,8 %, og kalverekrutteringen var ca. 42 kalve pr. 100 køer.

Imidlertid var 26-32 % af alle kalve sandsynligvis uden deres mødre. Dette tyder på, at den sande senvinterværdi for kalveandelen var tættere på 17 % og rekrutteringen ca. 31 kalve pr. 100 køer. Dette rekrutteringsniveau er højere end det, der blev observeret i 2005 og 2010. Kønsforholdet i marts 2018 var ca. 51 tyre pr. 100 køer. Demografien i marts 2018 beskriver en rensdyrbestand, der synes at være i stand til at modstå den nuværende fangst, mens kalverekrutteringen ikke er høj nok til at antyde muligheden for hurtig bestandsvækst. Bortset fra stokastiske katastrofale begivenheder synes der at være en lav risiko for fremtidig tilbagegang af bestanden, mens der er potentiale for langsom vækst.

I marts 2018 var tællingens arealdækning 10,6 %, hvilket er en væsentlig forbedring fra 1 % dækning under striptransekttællingerne i 2000-2010. Nordregionens rensdyrbestandsstørrelse i 2018 blev estimeret til ca. 60.469 rensdyr (95 % CI: 51.932-70.410; CV = 0,074; SE = 4.501) med en tæthed på ca. 2,59 rensdyr/km^2 (95 % CI: 2,23-3,02). Dette distance-samplingsestimat var præcist (CV = 7,4 %). Bestandsestimatet er ca. 38,5 % lavere end det estimerede antal KS-rensdyr i 2010. Man skal dog være forsigtig med at konkludere, at der er sket et stort fald, da flere formildende faktorer skal tages i betragtning. Undersøgelsen i 2010 havde lav dækning og en høj variationskoefficient (CV). Således var estimatet sandsynligvis ikke så nøjagtigt og præcist som 2018-tællingen. Desuden resulterede bedre GIS-kortlægning i 2018 i et mindre samlet areal, hvilket betyder, at 2010-estimatet var kunstigt højt. Desuden ændredes tællingsmetoderne i 2018 til distance-sampling. Dette udelukker i sig selv trendfremskrivninger baseret på kun de nuværende tælling og dem fra 2010. For at kunne foretage en nogenlunde pålidelig trendfremskrivning er der behov for en tidsserie på mindst tre bestandsestimater, og disse skal opnås med sammenlignelige metoder. Omend distance-samplingsestimatet i 2018 på ca. 60.469 rensdyr antyder en nedgang i KS rensdyrbestandsstørrelsen, og der kunne forventes en vis nedgang i betragtning af både den dårlige kalverekruttering i perioden 2005-2010 og mere end et årti med en fangstforvaltning, der havde til formål at reducere KS-rensdyrbestandsstørrelse. Uanset hvad, understøtter denne rapports gode rekruttering af kalve i senvinteren 2018 ikke en fremtidig tilbagegang. Den antyder snarere en mulig stabilitet eller langsom vækst i fremtiden. Det er også værd at nævne, at en alternativ modelbaseret analyse af datasættet fra 2018 estimerede et noget højere antal på 73.895 rensdyr (95 % CI: 65.983-82.757, CV = 0.037) (Correia 2020). Det at der findes to estimater giver anledning til at spørge, hvilket af de to der er mest nøjagtigt og præcist.

Dette undersøges i øjeblikket, det kræver yderligere resultater fra to andre vestgrønlandske rensdyrtællinger, der blev gennemført i 2019, og konklusioner vedrørende distance-sampling og modelbaserede estimater vil blive offentliggjort i et peer-reviewed tidsskrift.

Uanset om den er på 60.469 (95% CI: 51.932-70.410) eller 73.895 (95% CI: 65.983-82.757), forbliver KS-bestandsstørrelsen stor i forhold til det tilgængelige areal, 23.303 km^2. KS-rensdyrbestandens tæthed var ud fra distanceprøvetagning 2,6 caribou pr. km^2. I betragtning af god kalverekruttering forventes der ikke at ske en nedgang i bestanden i den nærmeste fremtid. Ligesom alle estimater for tæthed siden 2000 overstiger tætheden i 2018 det anbefalede forvaltningsmål på 1,2 rensdyr pr. km^2. Det var antagelsen, at overskridelse af måltætheden ville øge risikoen for overgræsning og føre til et fald i antallet af dyr. I Alaska og Canada, hvor overgræsning spillede en vigtig rolle, faldt rensdyrbestanden i løbet af 15 til 20 år. Selv efter næsten to årtier med høje tætheder, der overstiger målet, er der dog ingen stærke beviser på omfattende overgræsning eller tilbagegang i KS-rensdyrbestanden. Da rekrutteringen i 2018 blev forbedret til mindst 31 kalve pr. 100 køer på trods af en samlet tæthed på 2,6 rensdyr pr. km^2, ser det ud til, at Nordregionen kan understøtte en højere tæthed end tidligere forventet. Når yderligere resultater foreligger fra to andre vestgrønlandske rensdyrtællinger, der blev gennemført i 2019, vil måltætheden for rensdyrforvaltning blive revurderet med hensyn til, hvilket niveau der er kompatibelt med demografien, der fremmer bæredygtige bestande og fangst i Grønland.

Eqikkaaneq (Kalaallisut)

Tuttu (*Rangifer tarandus*) Kalaallit Nunaata kitaani nunap immikkoortuini arfinilinni uumasuuvoq, tamakkerlutillu tuttoqatigiiaanut immikkoortunut arlalialunnut agguarsimasuullutik. Una nalunaarusiaq nunap immikkoortuani Avannaata tuttoqatigiiaavi Kangerlussuaq-Sisimiut´mik (KS) taaneqartartunut tunngatillugu paasissutissanik nutaanik saqqummiussassaqarpoq.

Tamaani tuttoqatigiiaat kingullermik marts 2010 kisitsivigineqarput. Taamanimiit ukiarnerani sivisuumik killeqanngitsumillu pisaqarsinnaatitaalluni aammalu saniatigut ukiuunerani tuttunniartitsisoqartarsimavoq. Taamaattumik tamaani tuttoqassutsip naliliiffigeqqinneqarnissaa pisariaqalivissimavoq. Qulimiguulik atorlugu 2000-mi, 2005-imi 2010-milu kisitsinerit naatsorsueriaaseq transekt-kisitsinernik (strip transect counts) taaguuteqartinneqartoq naapertorlugu ingerlanneqartarnikuupput. Kisitsinermilu 2018´imi pisumi timmisartoq qulimiguulik aamma atorneqarpoq, kisiannili kisitseriaaseq misissueriaaserlu alla siullerpaamik atorneqarpoq, taaneqartartoq: ″Distance Sampling″.

Aamma siusinnerusukkut qulimiguulik atorlugu kisitsisarnerni paasinarluareerpoq tuttut avatangiisiminnut qanoq ilassuutillaqqitiginerat, taamaammallu tuttoqassutsimik naliliiniarnermi ikinaarisoornissaq qanissinnaalluni. Tuttut pangalluttut kikkunnilluunniit takuneqarsinnaapput, kisiannili uninngasut avatangiisiminnut ilassuulluarsimasut takuniapiloornartupilussuusarlutik. Kisiannili taamani 2018-kisitsinermi tuttut qassit uninngaannartarnerat qimarrattarnerallu ilanngullugit misissuivigineqarmata, tuttut eqimattakkuutaarlutik katersuussimasut tamarmik alaatsinaalluarniarneqarput. Misissuinerit paasinarsitippaat tuttoqatigiiaat uninngaartut qulimiguulimmik qulangiuaarneqaleraangamik, taakkunannga 32 %-ii uninngaannartartut. Pissutsit taamaannerisa takutippaat pikkorissunik qulimiguullillu atsissumik kigaatsumillu qulangiuaarisarnissaata pingaassusiinik, taamaattoqarpammi tuttut uninngasut aatsaat takuneqarsinnaalissammata. Ilanngullugu oqaatigineqassaaq 2018-imi kisitsinermi periuseq atugarput Distance Sampling periutsip naatsorsuusiornermini tuttut takkuitsoorsimasinnaasat ilanngullugit nalimmassaatigisarmagit. Periuseq taanna tuttut amerlassusiannik eqimassusiannillu (ataatungaani) tutsuiginateqarluartumik naatsorsuisarppoq. Taamatut timmisartumik qulangiuaarilluni kisitsinermi ilimanaateqarluinnarpoq tuttut ilaat uninngaannartut kisitsisunit arajutsisoorneqartarsimanissaat. Ilanngullugu aamma 2019-imi kisitsinerit marluk tunngavigalugit nalilersorsinnaanngortussaavarput ilumut 2018-imi kisitsinermi tuttut pingajorarterutaasa nikittannginnerat nalinginnaanersoq imaluunniit nalinginnaasuunnginnersoq. Nalinginnaasuusimassappat taava misissuisarnernit paasissutissaatit, assersuutigalugu uninngasunik - taamaalillunilu takkuitsoorsimasanik - peqassuseq paasiniarlugu naatsorsuusiornerni ikinaakkamik nalimmassaatigiineqartarsimanissaat, taamaaqataanillu tuttut amerlasusiannik ikinaarisarsimanissaat eqqarsaatigineqarsinnaavoq.

Tuttoqassutsimik nalilersuineq

KS-p tuttui sumiiffinni marts 2018-imi pukkikujoortuniinniarnerusimapput (gns. 361 m.o.h.). Kulavaat nassoqanngitsut amerlapput (46 %), tamanna siusinnerusukkut misissuisarnerni paasisanut naapertuuppoq. Arnavissat nassoqanngikkunik imaanngilaq timimikkut uinnaarilluartuussanngitsut taava, naak uumasoqatigiinni allani taama nalilerneqakkajuttaraluartoq. Tuttoqatigiit KS nunami paneqisumi (nunap immikkoortua Avannaa ilaatigut taamattoqartarami) uumasuupput eqimattanut agguarsimallutik. Pissutsillu taamaannerat peqqutaalluni tuttut nerisassarsiorniarlutik apummi assaasariaqartarnissaat pisariaqarunnaassaaq aammalu kulavaat ningiunngorniuunnermik pisariaqartitsitsinnginnerulissallutik.

Tuttoqatigiiaat iluminni agguataarsimanerannik marts 2018 paasisat 2005-imi 2010-milu misissuisarsimanernit paasisanut sanilliullugit pitsaanerupput. Tamanna tigussaasumik oqaatigissagutsigu imaappoq, ukiorissilluarnerata naajartornerani piaqqat amerlassusiat (piaqqat tassaapput qaammatit qulit angullugit utoqqaassusillit) 21,8 % missaanniissimavoq, piaqqiaasartullu kulavaat 100-gaangata 42-t missaanniittarsimapput. Kisiannili piaqqat tamakkerlutik amerlassusianniit 26-32 %-iisa missaanni amerlassusillit iliarsororsimarpasittarlutik. Pissutsit taamaannerisa ilimanarsisippaat ukiup ataatsip ingerlanerani piaqqat iluatsittumik aniguisut 17 % missaanniittut, taamalu tuttut inerilersut pisarineqarsinnaangajalersullu ukiumut amerlassusiat imaalerluni; tuttut 100-gaangata 31-t piaqqat allingaatsiariivissuusarput. Inerileriivissullu 2018-imi amerlassusiat 2005-imi 2010-milu misissuinernit kisitsinit qaffasinnerupput. Angutivissat arnavissallu nikingassutigaat tuttut 100-gaangamik 51-it angutiviaasarmata pannipajaarsuit. Misissuinerit 2018-imi pisut takutippaat tuttoqatigiiat iluminni katitigaanerisa maanna pisarineqartartut amerlassusiat nammassinnaalluaraat, kisiannili piaqqat amerlassuserisartagaasa takutippaat peqassuseq sukkasuumik qaffakkiartorunnangitsoq. Naatsorsuutigineqarsinnaanngitsunik ajorluinnartunillu pisoqanngippat, taavani tuttoqassutsip appariartuaalernissaa ilimanaateqarpallaanngilaq, akerlianili qaffakkiartulaarnissaanik ilimanaateqarsinnaavoq.

Nunap kisitsiffiusup tamakkerluni angissusiata 10,6 %-ia 2018-imi qulangiuaarneqarpoq. Tamanna siuariarnerujussuuvoq, tassami 2000-mi 2010-milu 1 %-iata timmisartumik qulangiuaarneqarnera taamaallaat angumerineqarsimavoq. Nunap immikkoortuani Avannaani tuttoqassuseq 2018-imi 60.469-inut missiliuunneqarpoq (95 % CI: 51.932 – 70.410; CV = 0,074;

SE = 4.501), tuttut eqimassusiat kvadratkilometer-imut tuttut amerlassuseqartinneqarlutik 2,59 (CI: 2,23 – 3,02). Kisitsisit uku pissarsiarineqartut tutsuiginartuupput, tassami peqassutsimik naatsorsueriaaseq Distance Sampling eqqoqqissaartumik missiliuussineruvoq (CV = 7,4%). Aqutsiveqarfik Kangerlussuaq – Sisimiuni tuttoqassutsimik missiliuussineq una 2010-mi missiliuussinermit 38,5 %-imik appasinneruvoq. Ikileriarfiusupilussuusimasutut naggasiisoqannginnerani mianersortoqartariaqarpoq, tassami pissutsit assigiinngitsut arlallit taama ajortoqartiginnginneranik sunniuteqartut atuussimapput. Misissuinerit 2010-mi ingerlanneqartut nuna annertuallaanngitsoq qulangiuaarpaat, tuttulli amerlassuserisinnaasaasa nikerarfiat nikingasupilussuulluni (CV). Taamaattumik ilimanaateqarluarpoq 2010-mi kisitsinerit 2018-imi kisitsinernut sanilliullugit eqqoqqissaannginnerullutillu tutsuiginaateqannginnerussasut. Aamma 2018-imi kisitsinermut atatillugu nunap assiliortariaaseq GIS-imik taaneqartartup atorneqartup nutaaliaanerunera pitsaaneruneralu peqqutaalluni (tassa kisitsiffiusumi assersuutigalugu tatsit ersertut kisitsiffiup annertussusianut ilanngunneqanngimmata) nuna kisitsiffiusoq 2010-mi kisitsiffiusumut sanilliullugu mikineruleriataarpoq) mikinerulinnguaratarpoq.

Periuseq ataaseq atorlugu kisitsinerit immikkoortut imminnullu sanilliunneqarsinnaasut pingasut ingerlanneqareerpata aatsaat KS-imi tuttoqassutsip ingerlarnga – ikiliartornersut amerliartornersulluunnit - oqaatigineqarsinnaalissaaq, aammalu tuttoqassutsip siunissami suup tungaanut ingerlanera immaqa maluginiarneqaarsinnaalissalluni. Naak naatsorsueriaaseq Distance Sampling atorneqaraluartoq tuttullu 60.469 amerlassuseqassangatinneqaraluartut KS-imi tuttut ikileriarsimasutut isikkoqarput, aammalu piffissami 2005-imiit 2010-p tungaanut piaqqiorsimanerat pitsaavallaarsimanngillat, ukiunilu qulikkaani arlalinni killeqanngitsumik - tuttunillu ikilisaanissamik siunertaqartumik - aqutsisoqarsimanera eqqarsaatigalugit taamaattoqaratarsinnaavoq. Suullu tamaasa kattukkaanni uani nalunaarusiami allaaserisarput 2018-ip ukiorluarnerani piaqqiorluartoqarsimanera qulananngitsumik tuttoqassutsimut iluaqutaasimasinnaavoq. Tassa ikiliartortoqarnera ersinngilaq, akerlianillu nikittoqarsimarpasinngikkuni siunissami amerliartuaalaalersimasinnaapput. Aamma inissaminiippoq eqqaassallugu 2018-imi paasissutissaatit tunngavigalugit naatsorsuusiortitsinerup tuttut KS-imi 73.895-inik amerlassuseqarsinnaanerinik missiliuussimmat (95 % CI: 65.983 – 82.757; CV = 0,037) (Correia 2020). Tuttut amerlassuserisinnaasaannik missiliuussinerit marluk pigineqalermata aperisoqarsinnaagaluarpoq periuseq sorleq tutsuiginaateqarnerunersoq. Apeqqut akissutissarsiniarlugu maannakkorpiaq tamannarpiaq ulapputigineqarpoq, tassa Kalaallit Nunaata kitaaani 2019-imi kisitsinerit marluk suliarineqarmata. Taakkunannga inernerusut ilisimatuussutsikkut allaasereriarlugit saqqummiunneqarumaarput, taakku aamma Distance Sampling naapertorlugu suliarineqarput.

KS-imi tuttoqassuseq nunap tuttoqarfittut aqutsiveqarfiusup 23.303 km^2 angissuseqarnera eqqarsaatigalugu tuttut amerlassusiat 60.469-galuarpata (95 % CI: 51.932 – 70.410; CV = 0,074; SE = 4.501) imaluunniit 73.895-uppata (95 % CI: 65.983 – 82.757; CV = 0,037) nuna uumaffigisaat amerlassusiannut sanilliullugu mikivallaarpoq. Distance Sampling atorlugu naatsorsuusiortitsinermi KS-imi tuttut 2018-imi eqimassusiat kvadratkilometer-imut 2,6-iuvoq. Siunissami qanittumi ikiliartulernissaat naatsorsuutigineqanngilaq piaqqiorluaqimmatami. Tuttut eqimassusiannik naatsorsuisarnerit 2000-miilli ingerlanneqartalernikuusut assigalugit 2018-imi tuttut eqimassusiannik kisitsit pissarsiarineqartoq aamma Aqutsinikkut anguniagaagaluartoq tuttut kvadratkilometer-imut 1,2-junissaannik aaliangiussaq qaangerneqartuaannavinneqarsimavoq. Killiliussap qaangerneqartuaannarnera peqqutaalluni nunap neriniarfiusartup naggorlutsinnissaa naggataagullu allaat tuttoqassutip appariartulerneranik kinguneqarsinnaaneranik pisoqarsinnaanera erseqqissaatigineqassaaq. Tuttoqarpallaalernera peqqutaalluni nunap neriniarfiusartup aserugaaneranik assersuutissat papput Canadami Alaskamilu naggorlutsikkiartuaarnera ilutigalugu tuttut ukiut 15-it 20-llu akornanni ikiliartuaarsimammata. Taamaattorli KS-imi tuttoqatigiiaat ukiuni qulikkaani marlunni amerlavallaarsimagaluarlutik nunap naggorlutsinneranik uppernarsaatitaqartunik paasititsisoqarneq ajorpoq, taamaattumillu oqartoqartariaqarpoq tuttoqarfiup Avannaata tuttut taama amerlatigisut ″nerisaqartinnissaat – uumatinniarnissaat″ naatsorsuutaanngikkaluartumik nappassinnaasimavaa. Kalaallit Nunaata kitaani tuttunik 2019-imi kisitsinerit marluk suliarineqartut naammassinissaasa tungaanut, Aqutsinikkut tuttut annerpaamik eqimassusissaannik anguniakkap, tassa tuttut kvadratkilometer-imut 1,2 – junissaannik aaliangiussap naliliiffigeqqinnissaa eqqarsaatigineqarsinnaavoq. Nunap saannaa isiginiarlugu killissarititaasup sumiinnissaa pitsaanerpaaq, piniagaanerallu eqqarsaatigalugit piujuartitsiniarnerpaaq ujartorneqartariaqarmat.

Introduction

In Greenland, most caribou occur along the central to southwest coast, which is locally known as West Greenland, coastal area south of *ca.* 76° Lat. In 2000-2001, the Greenland Institute of Natural Resources (GINR) gave the names North, Central and South, to the regions in West Greenland that together contain several distinct caribou populations (Jepsen *et al.* 2002). This report focuses on the North region and Kangerlussuaq-Sisimiut (KS) caribou population (Fig. 1). The North region lies between Sukkertoppen (66° N) and Nordre Strømfjord (68° N) and corresponds with the Greenland government's caribou management hunting area 2 and is within the Qeqqata municipality of West Greenland. Within the North region is the coastal city of Sisimiut, and on the eastern side of region near the inland Ice Cap is the country's largest international civil airport, Kangerlussuaq, also previously known as Søndre Strømfjord airport. Like elsewhere in Greenland, the KS caribou are a financial resource for local hunters, both professional and recreational, as well as for the service industries associated with boating and outdoors. Monetary profits aside, caribou are the prized game meat served at all major family events and many official ones. Caribou are undeniably intrinsic to the hunting traditions and culture of all the communities in West Greenland.

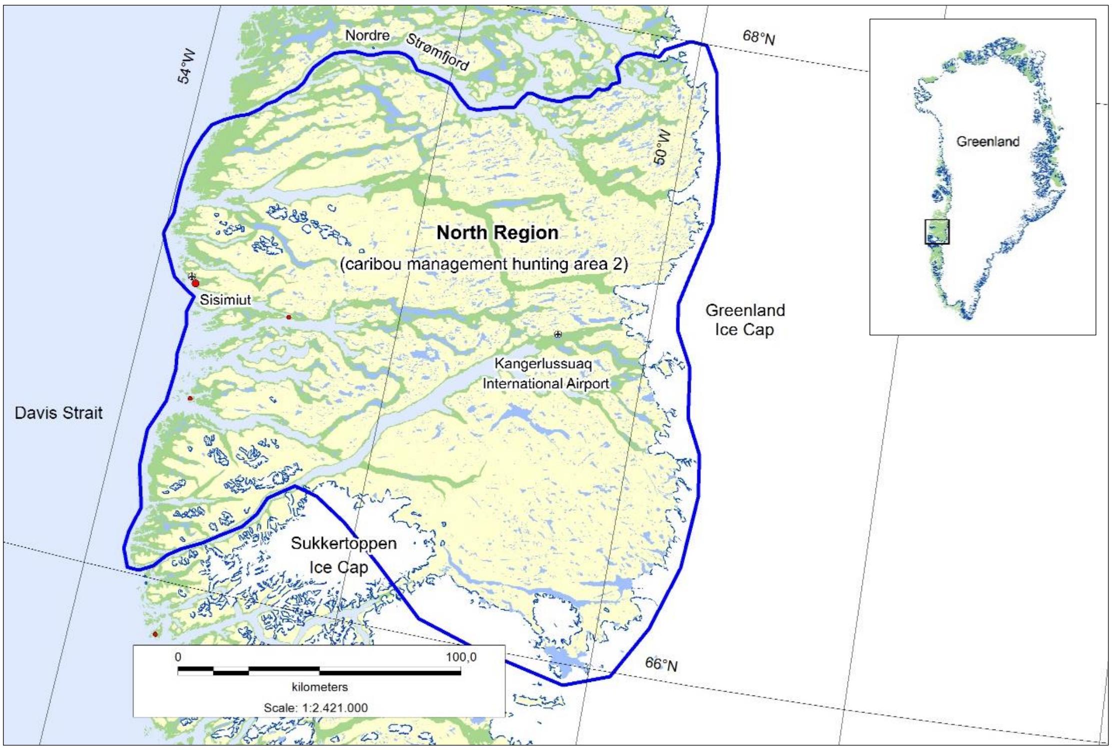

Figure 1. North region borders (caribou management hunting area 2) containing the Kangerlussuaq-Sisimiut caribou population. Elevations over 200m are in light yellow, below 200m are green.

Since 1977, the KS population has been monitored for abundance with debatable results that were often invalidated by harvest data (Born et al 1998, Cuyler *et al.* 2005, Cuyler 2007). In the period 1993-1996, surveys employed fixed-wing aircraft, high altitude, high speed, long systematic transects, disregarded observer fatigue and were unable to maintain a constant altitude over Greenland's mountains and rugged terrain. The surveys of 1993 and 1996 resulted in late winter pre-calving population estimates of *ca.* 3,788 and 7,727 respectively (Table 1, Ydemann & Pedersen 1999 unpublished report to GINR). Despite Distance Sampling analyses of the data set, these were underestimates (Cuyler *et al.* 2005; Cuyler 2007) caused by undetected caribou at all distances, specifically on the transect's 0-line (centreline of strip flown). The latter violates the primary assumption of Distance Sampling, *i.e.*, all animals/objects-of-interest on the transect's 0-line are detected. To increase detection of caribou, beginning in 2000, aerial surveys employed helicopter flying slowly at low constant altitude and short length random transect lines with a narrow strip width while avoiding solar glare and considering observer fatigue. Consequently, more animals present on the transects flown were detected. The new logistics of the post-2000 survey optimized sample size, variance, detectability, observer concentration and with the result that estimates of population size far exceeded pre-2000 estimates. For the North region helicopter surveys were repeated in 2005 and 2010. Further background as well as detailed descriptions of design and methods for the aerial surveys from 2000 to 2010 follow Cuyler *et al.* (2002, 2003, 2005 & 2011). Since 2000, the KS caribou (Rangifer tarandus groenlandicus) population has been documented as the largest in Greenland (Cuyler *et al.* 2011).

Table 1. Late winter population parameters of the Kangerlussuaq-Sisimiut caribou population of the North region, West Greenland, taken from aerial surveys of 1993 to 2010 (Cuyler et al. 2002, 2005, 2011; Ydemann & Pedersen 1999 unpublished).

Parameter	**1993**	**1996**	**2000**	**2005**	**2010**
Population size estimate	3,788	7,727	51,600	90,464	98,300
90% Confidence Interval (CI) – lower	-	-	40,400	70,276	71,500
90% Confidence Interval (CI) – upper	-	-	62,800	113,613	132,400
Coefficient of Variance (CV)	-	-	-	-	0.19
Standard Error (SE)	-	-	-	-	18,500
Mean group size ± SD	1.95 ± 0.33	2.5 ± 0.48	2.8	4.63 ± 3.4	2.96 ± 2.14
Max group size	-	-	17	17	17
Density per sq km	0.16	0.33	1.2 to 2.8	2 to 6	2 to 7
Calf percentage	1.3 %	17.2 %	26.6 %	11 %	15.2 %
Recruitment (Calf /100 Cow)	-	-	68	16.2	27.7
Sex ratio (Bull /100 Cow) *	-	-	87	33	54

*Age classes; calves (age ≤ 10-months), adults (age > 1-year)

Survey methods altered somewhat from 2000 to 2005 (Cuyler *et al.* 2005). Further, the 2000 survey had significantly ($p < 0.001$) lower caribou detection on one side of every transect (Cuyler *et al.* 2002). The former makes it impossible to directly compare the 2000 and 2005 abundance and density values and the latter suggests the possibility that the 2000 survey underestimated both. The abundance and density of KS caribou appears to have remained unchanged in the 2005-2010 period (Table 1). Simultaneously, calf percentage and recruitment increased after an initial drop in the 2000-2005 period.

Given the large number and relatively high density of KS caribou in the 2000-2010 period, density-dependent forage limitation was considered a risk, which could cause population size instability and possibly decline. Therefore, wildlife management aimed at reducing caribou abundance and density to a target stocking rate of 1.2 caribou per sq km (Cuyler *et al.* 2007). The target density was based on studies elsewhere that document associations between observed densities and changes in 1) caribou productivity, 2) dispersal, and 3) condition of the range, as described in Cuyler *et al.* (2007). Therefore, initially there were higher quotas followed by unlimited harvests. The autumn season, which was originally 1-month was lengthened several times over the years. A winter hunting season with quota was added and it became permissible to harvest all sexes and ages. Details are available in Cuyler *et al.* (2016). Despite these management measures, by 2010 there was no reduction in KS abundance or density. Today, unlimited autumn harvesting continues, and in 2019 the autumn hunting season became the longest ever (01 August – 31 December). Meanwhile, the winter harvest was recently discontinued, however, not prior to the March 2018 survey.

Present survey

The international network of caribou knowledge holders, CARMA (Circumpolar Rangifer Monitoring & Assessment network), advises monitoring caribou population abundance every three years. Given the last survey of the KS caribou population was in March 2010, and there have since been eight unlimited autumn harvests, had abundance, density, or demographics of the Kangerlussuaq-Sisimiut caribou population changed? In early March 2018, GINR again examined the Kangerlussuaq-Sisimiut caribou population in the North Region of West Greenland by aerial helicopter survey. The 2018 survey methods for collecting herd structure data remained unchanged from earlier surveys. The 2018 survey, however, replaced the multiple short length random transect lines strip method used for KS caribou in 2000, 2005 and 2010, with systematic transect lines and Distance Sampling, in which distances from a line 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 report investigates the Distance Sampling data set collected during GINR's 2018 caribou survey of the KS population in the North region. It then presents the 2018 pre-calving caribou abundance and density. Further, this report presents information on the movement or lack thereof of caribou detected. The herd structure data set is also investigated, and we report the pre-calving demographics for the KS caribou population.

Note that an earlier analysis for 2018 caribou abundance and density was run on the same data (Marques 2018), however, the then known area (km^2) was incorrect. Marques' (2018) is an internal CREEM (Centre for Research into Ecological and Environmental Modelling (St. Andrews, Scotland)) report, which is available upon request.

Methods

Study area

The North region is within the Qeqqata municipality. Although the Qeqqata municipality has a 2020 human population of *ca.* 9,400 not all live within the boundaries of the North region. The only large settlement within the region is the city of Sisimiut, with *ca.* 5,600 inhabitants, followed by the *ca.* 500 residing at the Kangerlussuaq international airport. Together, the hamlets of Itilleq and Sarfannguit contain a further 200-300 people.

The North region is seasonally ice-free. Improvements in Geographic Information System (GIS) excluded lakes, rivers, sand, glaciers, and islands for a more accurate land area of 23,303 km^2. Previous surveys reported a less precise land area of *ca.* 26,000 km^2 (Cuyler *et al.* 2002, 2005, 2011). Located between 66-68° N Lat, the Arctic Circle passes through its middle. The northern border is provided by the Nordre Strømfjord, which has numerous turbulent maelstroms and thin, treacherous, incomplete winter ice. The southern border is framed by a combination of the Greenland Ice Cap, the Sukkertoppen Ice Cap, and the outer portion of the Kangerlussuaq fjord. The latter is ice-free year-round and dominated by cliffs of *ca.* 1000 m. The western border is the permanently ice-free seacoast of the Davis Strait, and eastern border is the Greenland Ice Cap.

The west coast topography is mountainous with peaks whose elevation can be 1000 to 1800 m and glaciers are common. Moving eastward the mountains gradually give way to rugged terrain generally ranging 10-900 m elevation. The wide and typically cliff sided Kangerlussuaq fjord penetrates the region stopping just short of the Greenland Ice Cap. It effectively separates the North region into two thirds above it and one third below it. In the southern third, the terrain immediately north of the Sukkertoppen Ice Cap is generally barren highlands >1000 m elevation. Moving north towards the Kangerlussuaq airport the terrain includes lowland valleys under 400 m elevation and highlands of generally under 1000 m elevation.

Common to West Greenland, the North region exhibits a climate gradient on a west-east axis. The western seacoast is wet maritime; however, the climate becomes dry continental as one moves east towards the Greenland Ice Cap. Climate and weather in the west are influenced by the ice-free Davis Strait and the low-pressure oceanic storm systems that sweep in from the southwest. The climate in the inland of the North region is influenced by the Sukkertoppen Ice Cap at its southern boundary. Sukkertoppen's elevation acts as a barrier to the oceanic storm systems above, creates a precipitation shadow on its northeastern side, and in combination with the dominating high pressure over the Greenland Ice Cap creates the inland's xeric continental climate. Loess/sandstorms are common in the vicinity of the Greenland Ice Cap and are caused by katabatic winds (often gale force and dry) descending off the Ice Cap (Cuyler *et al.* 2005).

The North region may be described as open or alpine tundra. At lower elevations, vegetation involves low arctic species of mainly dwarf shrub heath, which changes to predominantly steppe and grassland when moving east towards the Greenland Ice Cap (Tamstorf *et al.* 2005). Lichen heaths are rare, and further, higher elevations are often fell field, abrasion plateaus and bare ground (Tamstorf *et al.* 2005).

Aside from the caribou, the only native wild mammals present in the North region are arctic hare (Lepus arcticus Rhoads) and arctic fox (Vulpes lagopus Linnaeus). Large mammalian predators are absent. In the early/mid 1960's, muskoxen (Ovibos moschatus Zimmermann), were translocated from NE Greenland to a location close to the Kangerlussuaq international airport. Muskoxen are now firmly established in the southern third of the North region. The borders of the North region are semi-permeable permitting limited animal movement between adjacent regions, *i.e.*, Naternaq region to the north (above Nordre Strømfjord) and Central region to the south (below Sukkertoppen Ice Cap). Nevertheless, the borders are likely effective barriers preventing mass caribou movements (Linnell *et al.* 2000).

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. Meanwhile, snow cover is highly variable, and the terrain rugged (Appendix 4). Further, erratics (glacial boulder debris) are common and appear similar to caribou in size and colour. Singularly or in combination, these attributes of the habitat provide small groups of caribou with outstanding background camouflage and reduce detectability (Cuyler *et al.* 2005, 2011). Failure to detect caribou (often stationary, specifically even when on the 0-line) must be recognized as a source of negative bias (inaccuracy) for caribou surveys in Greenland. To mitigate the combinations of conditions that lower detectability of caribou, a helicopter is necessary to enable a constant altitude above ground level while flying low (40 m, *ca.* 120 feet) and slow (*ca.* 65 km/hour). The aerial survey of the KS herd occurred 01-15 March 2018 and a helicopter AS350 was the platform for observation.

Participants included three observers, all with previous survey experience: GINR's senior scientist Christine Cuyler, GINR's project coordinator Peter Hegelund, and professional hunter Aslak Jensen (Greenland Association of Professional Hunters (KNAPK)) from Nuuk. Jensen and Hegelund were seated in the rear of the helicopter and observed animals for all distances from the side they were sitting, which alternated. Cuyler always sat in front, observed the 0-line, including distances to either side up to 100 m, and was the data recorder. Verbal contact among the observers permitted the digital audio recording of all observations. 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. The audio recording included distance to, size, behaviour of each caribou group observed and name of the observer. Often flight and environmental conditions were recorded. Manual click-counters, logging the number of caribou seen by each observer, provided low-tech back-up for the digital audio observations from each line segment.

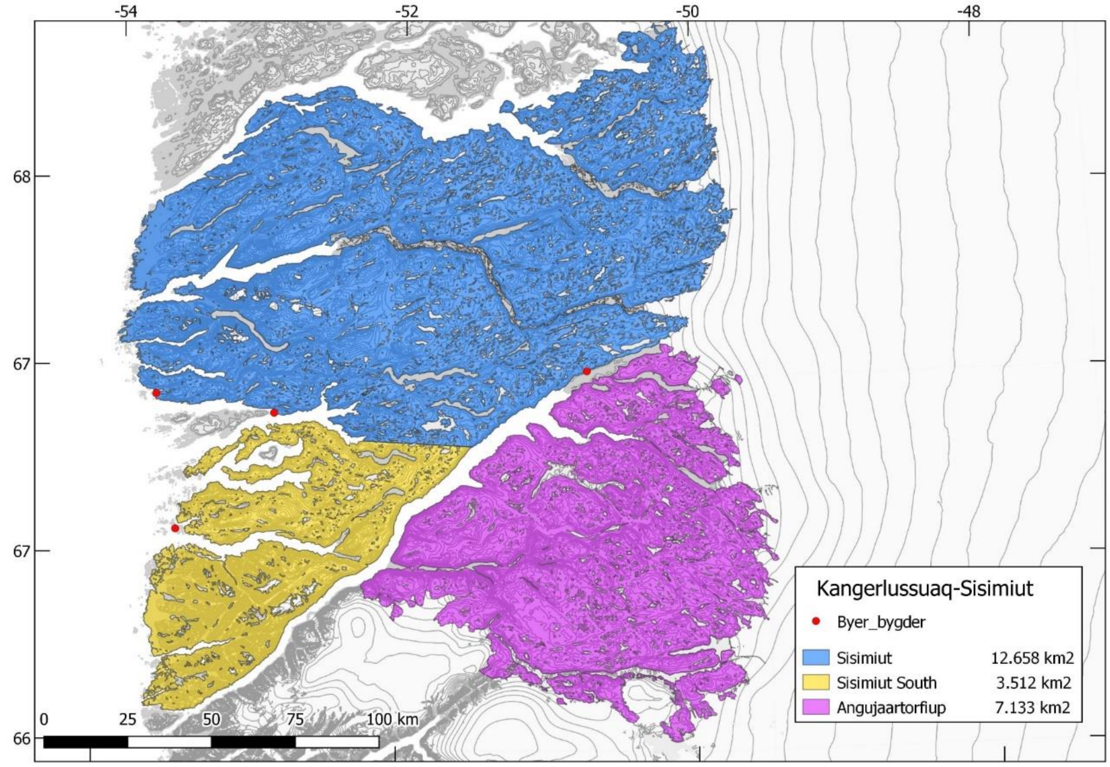

Figure 2. Area covered by the 2018 caribou survey of the North region (23,303 km²). Three different colours illustrate the three sub-areas, designated as Sisimiut (blue), Sisimiut South (orange) and Angujaartorfiup (purple). The term 'Byer bygder' identifies the four human settlements.

Survey design

The 2018 survey differed in design from the 2000-2010 random transect line strip-counts. The surveyed North region area, 23,303 km², was divided into three sub-areas, arbitrarily named Sisimiut (12,658 km²), Sisimiut-South (3,512 km²) and Angujaartorfiup (7,133 km²) (Fig. 2). The sampling design for the 2018 survey considered 19 systematic parallel line transects of variable length separated by 15 km and placed over the three sub-areas (Fig. 3). Those transects provide the maximum area coverage possible given the financial resources available. An initial line transect was computer generated at random, and the others followed 15 km apart. 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 was chosen as perpendicular to previously known animal distribution gradients in March. Lines 1 to 13 followed a west-east axis, which also reflects the climate gradient from wet maritime to dry continental. Line transects 14 to 19 followed a north-south axis, reflecting animal, climate, and topological gradients between Sukkertoppen Ice Cap and the Kangerlussuaq International airport.

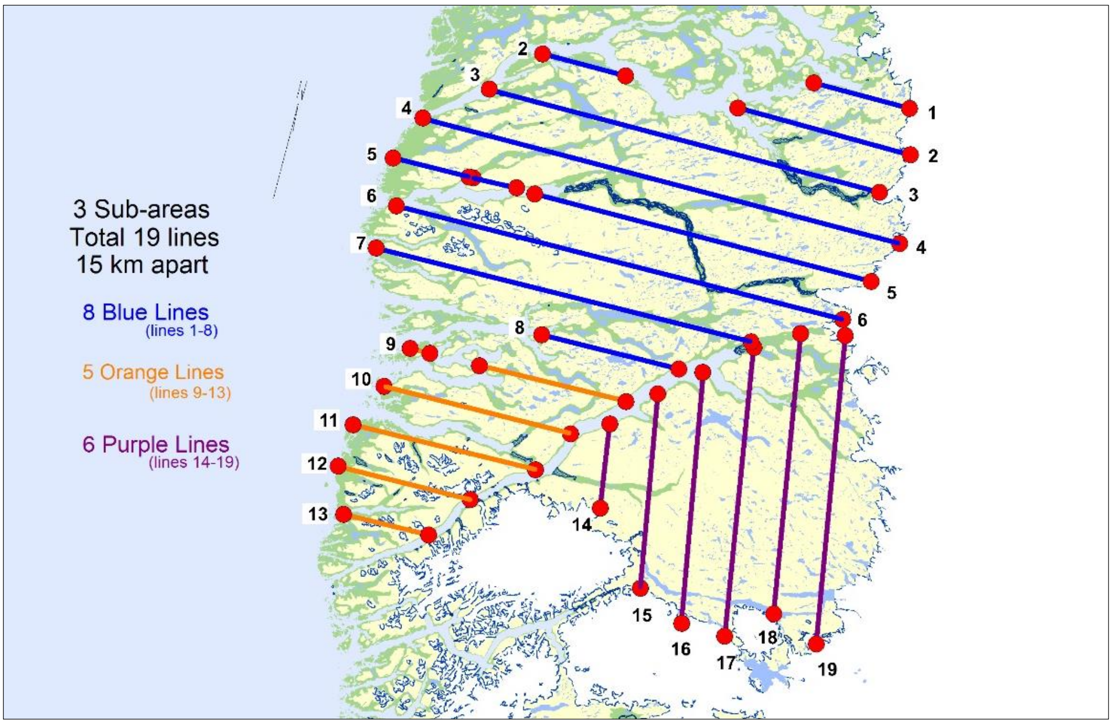

Figure 3. The 19 line transects used in the 2018 caribou survey of the North region, illustrating end points, and numbering of line transects and employing the same three colours as applied to the three sub-areas in above figure 2: Sisimiut (blue), Sisimiut South (orange) and Angujaartorfiup (purple). Elevations between 0 and 200 m are pale green, while any above 200 m are pale yellow.

Distance collected was the perpendicular distance from the helicopter's flown 0-line to a caribou group (object-of-interest). A caribou group was a relatively tight aggregation of animals. Since flight response to the approach of the helicopter was common, distance collected was the distance to the center of the caribou group from the 0-line before any movement by the caribou occurred. Exact distance measurements were not possible primarily because impractical, *e.g.*, maintaining flight speed, number of caribou groups encountered within a short time, the range finder too time consuming to use with errors occurring, plus time constraints on audio recordings, which could create confusion as to which distance applied to which group observation. Additionally, helicopter time was limited by financial constraints, which prevented stopping and flying out to individual groups before returning and continuing along the 0-line. Instead, distance measurement used the following distance bins: 0, 50, 100, 200, 300, 400, 500, 750 and 1500 meters perpendicular to the line transect. These values correspond to the upper limit for a specific bin that the caribou observation was included in. For analysis, these were recoded to the mid distance for a specific bin. Note, binning accuracy relies heavily on observer ability to correctly estimate distance to the observed animals. Thus, before starting the survey the helicopter hovered at the 40m altitude used during line transects, while each observer used a Leica laser range finder 1600 to gauge distances. Then they marked their window with masking tape delineating the approximate distances for each bin. When possible while flying line transects, the laser range finders were used to double-check reported bin distances to detected caribou.

Distance sampling

The caribou group was the selected sample unit for the Distance Sampling analysis of the 2018 survey. Neither the individual caribou within a group, nor individual line transects were considered as the sample unit.

The recorded distances to the caribou groups observed 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 (caribou group) given that it is at a distance y, from the centreline (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 Distance Sampling methods, the probability of detection is explained recurring to these observed distances (Buckland *et al.* 2001).

Prior to Distance Sampling 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, as per recommendations by several authors (Buckland *et al.* 2001; Marques *et al.* 2011; Thomas *et al.* 2010). To determine the detection function, several models were considered, since this is the standard approach introduced by Buckland (1992) and popularized by being available in the software Distance (Thomas *et al.* 2010). The model presenting the lowest AIC value was chosen. The subsequent analysis was based on Marques (2018). Details regarding Distance Sampling theory, methods and analysis are available in Buckland *et al*. (2001, 2015), and a briefer summary provided in Appendix 1. For analysis, we used R Statistical Software (https://www.r-project.org/).

Demographics

Herd structure and recruitment observations were obtained after most of the Distance Sampling survey was completed. On 11, 12 and 14 March, large areas of the North region were flown. 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 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.

Natural mortality

To avert alarm or hasty assumptions concerning population trend if caribou carcasses are observed, since 2000, all technical reports for Greenland caribou surveys have included, for that specific survey year, the expected number of 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. The KS region lacks predators and the xeric inland provides stable weather conditions. Although natural mortality rates vary among years (Bergerud *et al.* 2008), given the above, an assumed standard natural mortality rate of 8-10% (Kingsley & Cuyler 2002) for Greenland caribou likely yields a useable estimate of mortality. This rate is applied to the 2018 survey's abundance estimate to provide decision makers with a rough number of expected caribou deaths due to natural mortality within the survey year.

Results

Table 2. Summary of unprocessed results: Survey of the Kangerlussuaq-Sisimiut caribou population by helicopter in the North region, 03-15 March 2018.

Parameter	**North region sub-area**			**Total**
	Sisimiut	**Sisimiut South**	**Angujaartorfiup**	
Flight altitude (m)	40	40	40	**40**
Flight speed (km/hr)	60-70	60-70	60-70	**60-70**
Sub-area size (km^2)	12,658	3,512	7,133	**23,303**
Number of lines	8	5	6	**19**
Distance flown (km)	916.5	258.1	470.5	**1,645**
Strip width[1] (m)	1000-1500	1000-1500	1000-1500	**1000-1500**
Coverage[2]	14.5-21.7 %	14.7-22 %	13.2-19.8 %	**14.1-21.2 %**
Coverage after truncation[3]	10.9 %	11.0 %	9.9 %	**10.6 %**
Total caribou observed	4,158	343	565	**5,066**
# groups observed	1,679	133	267	**2,079***
Mean group size	2.48	2.58	2.12	**2.44**
Std Deviation group size	± 1.84	± 1.72	± 1.33	**± 1.33**
Median group size	2	2	2	**2**
Maximum group size	20	11	11	**20**
Minimum group size	1	1	1	**1**

[1] Strip width provided is to one side of helicopter only. Must double for total strip width.
[2] Coverage prior to truncation of strip width to 750 m.
[3] Coverage after truncation of strip width to 750 m each side helicopter for Distance Sampling analyses (see page 24).
*Correia (2020) used 2076 og these groups because three groups lacked the Latitude/Longitude coordinates required for modelling analyses.

Survey logistics & unprocessed data

In the period 01-15 March, we flew 11 of those days. Poor weather made three days non-flyable, as did the one Sunday airport closure (second Sunday the airport was open for another user, which by default permitted us too). Flight time totaled *ca.* 54 hours and 08 minutes. This is 20 hours and 26 minutes more than flown in the last North region survey, 2010. Typical of AS350 helicopters carrying three passengers and pilot, refueling was necessary after about 3 hours of flight time, an additional 15-20 minutes were possible when wind conditions and distance to nearest airport permitted. The 2018 survey used 19 line transects for a total distance flown of 1645 km, *i.e.*, Sisimiut 916.5 km, Sisimiut South 258.1 km and Angujaartorfiup 470.5 km (Table 2). It was necessary to ferry the helicopter from Nuuk to Kangerlussuaq airport for the survey and return it to Nuuk once the survey was completed. Ferry flight typically requires 1 hour and 45 minutes at an air speed of 110 knots (*ca.* 204 km/hour), however, added maneuvers to avoid fog and low cloud increased flight time on both trips in 2018. Given the 1645 km of line transects flown, an optimistic calculation of survey coverage of the North region's total area (23,303 km^2) would be 14.1-21.2%, *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 Distance Sampling analysis, page 24), the strip width was truncated to 750 m. Thus, coverage was 10.6% for the final abundance estimate. The raw total of observed caribou groups was 2,079, for a raw count of 5,066 caribou (Table 2). Mean group size was 2.4 ±1.33 caribou, and median group size was 2 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, survey characteristics such as glare, shade, snow covering and depth. Owing to inconsistent categorization and recording, most of the latter were not included in the analysis. Data pertaining to habitat changes were removed because these concerned habitats exclusively *i.e.*, there were no caribou observations associated. The remaining variables were properly restructured within R Statistical Software.

Table 3. The 2018 caribou survey observations lacking recorded distances occurred in two of the three sub-areas (stratum): Sisimiut and Angujaartorfiup.

Excel row	Sub-area	Transect no.	Group size
108	Sisimiut	1	3
174	Sisimiut	2	1
467	Sisimiut	2	2
543	Sisimiut	2	NA
985	Sisimiut	3	1
1065	Sisimiut	3	1
2617	Sisimiut	4	1
2779	Sisimiut	4	6
6307	Angujaartorfiup	16	1
6794	Angujaartorfiup	19	3

The data set was subject to some prior processing before analysis. Comment fields were deleted. Variable names were recoded to make them sensible in R. A small number (n=10) of caribou observations were missing their distance (Table 3). Given these are few relative to the large amount the data, the actual impact of using any given distance value is minor. Thus, the pragmatic solution was to use the average observed distance. For group size, only one observation had no value. Again, the average for group size was used.

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 2018 caribou survey of the North region met these recommendations, since the sample size was 2079 observations, i.e., detections of groups of (one or more) caribou, from a total of 19 parallel line transects separated by 15 km. Each transect took from as few as 30 minutes to several hours to be fully sampled. This depended on number of segments and total length. Caribou were detected on every line transect in the 2018 survey. Of the three sub-areas, the Sisimiut sub-area dominated in observation frequency, i.e., number of detections, i.e., caribou groups, per sub-area (Fig. 4). This was expected because Sisimiut was the largest sub-area (ca. 13,000 km^2) and had the longest line transects, relative to Sisimiut South and Angujaartorfiup Nunaa smaller areas (ca. 3,500 and ca. 7,100 km^2, respectively) and shorter line transects. These preliminary analyses are from Correia (2020).

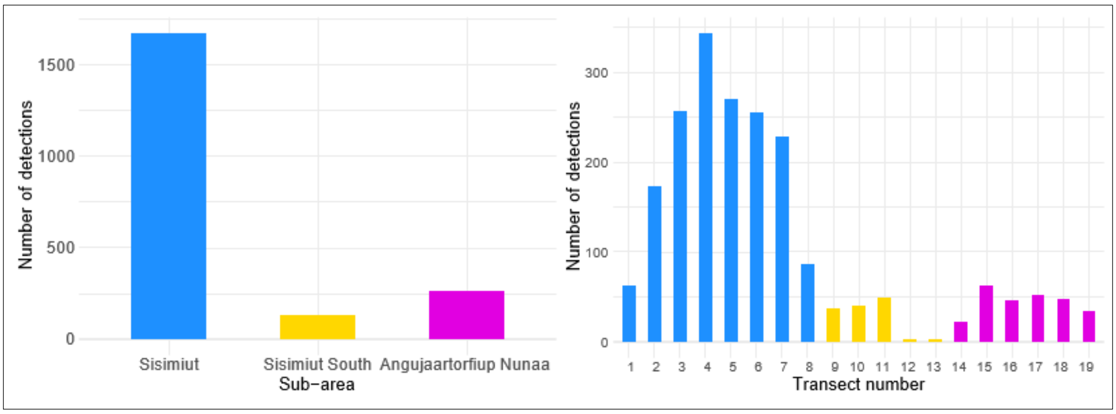

Figure 4. Kangerlussuaq-Sisimiut caribou survey 2018: exploratory analysis plots for the number of detections by sub-area (left), and number of detections per line transect by sub-area (right): Sisimiut (blue), Sisimiut South (orange) and Angujaartorfiup (magenta).

The detected objects of interest, *i.e.*, caribou groups, typically included no more than 6 animals, while the most observed group size was two animals (n=733 observations) (Fig. 5). Groups consisting of less than five individuals made up 90% of the observations, while groups counting less than ten individuals made up 99%. Groups from 11 to 20 caribou were observed nine times and usually beyond 1 km from the line transect. All nine groups were 'running away' from the helicopter and 'never stopping'. Cows with calves were involved. This suggests that large groups arose due to merging of scattered small groups, which individually had not been detected owing to being so far away. These groups were truncated at the analysis stage (see details below).

The number of detections per unit transect length is the encounter rate. The Sisimiut sub-area had a mean encounter rate of 1.84 caribou groups per km. Sisimiut South and Angujaartorfiup sub-areas had means of 0.45 and 0.63, respectively (Fig. 6). The remarkably similar encounter rates across all line transects within a sub-area, specifically the highest density stratum (Sisimiut), naturally will lead to a reasonable precision in the density estimates.

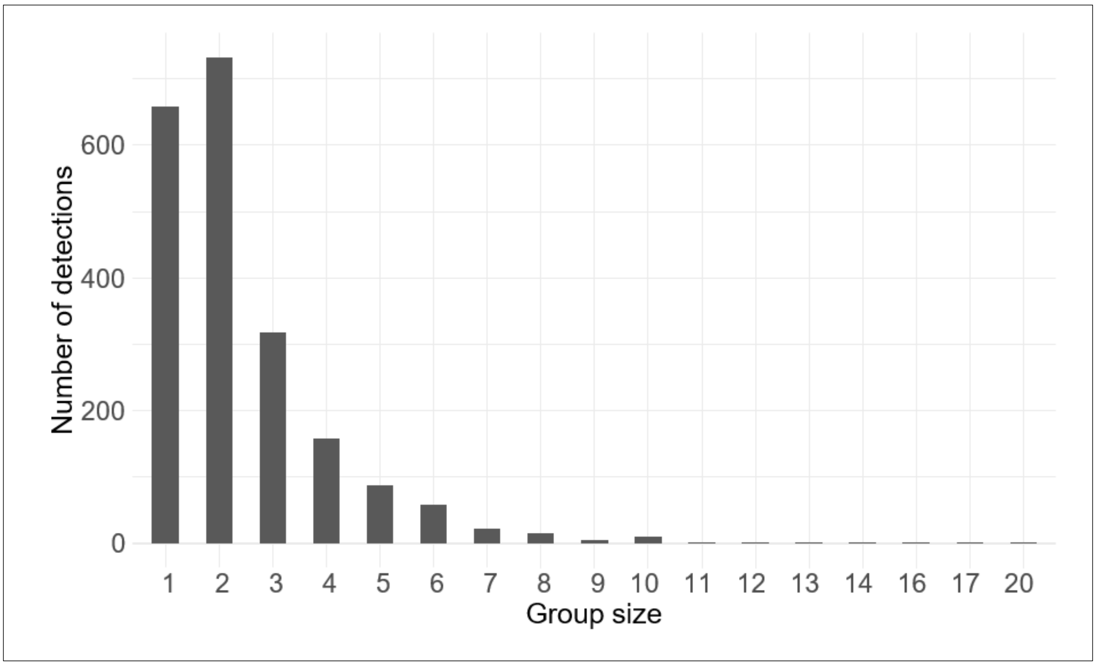

Figure 5. Kangerlussuaq-Sisimiut caribou survey 2018: exploratory analysis for caribou group size distribution.

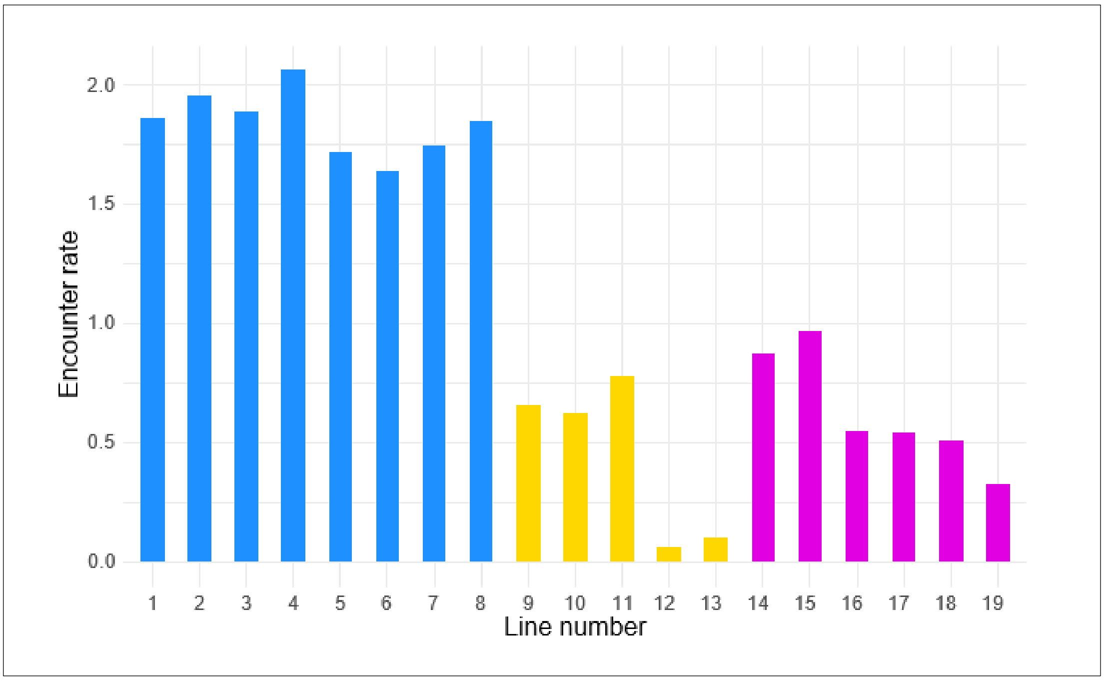

Figure 6. Kangerlussuaq-Sisimiut caribou survey 2018: exploratory analysis for caribou encounter rate (groups per km) per line transect and illustrating sub-area: Sisimiut (blue), Sisimiut South (orange) and Angujaartorfiup (magenta).

Histograms examining observer effects (Fig. 7) were similar and therefore this covariate contributed little to explanations for detectability. Other potential covariates, like sun glare or snow covering, were available but there were too many missing observations and/or inconsistency when referring to the categories for these to be used in the analysis.

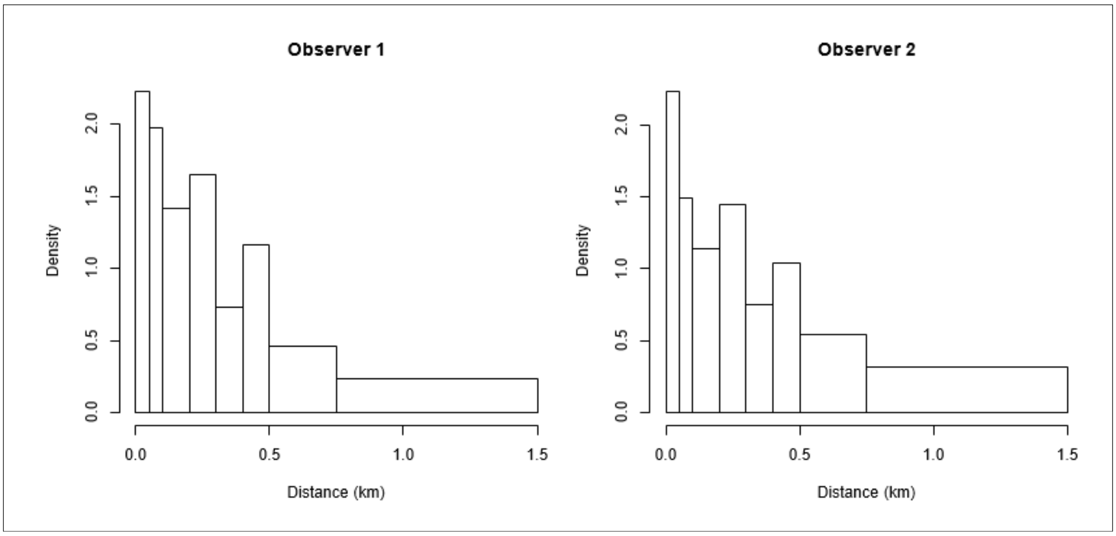

Figure 7. Observer effect: histograms illustrating detected distances for the two observers (a covariate with two levels). Density, y-axis, refers to the density of observations.

The preliminary analysis provides the expectation of good precision in further analyses of detections, because of data conformity within each sub-area and the information agreed well with anticipated a priori, *e.g.*, Sisimiut sub-area would have more caribou than the other two sub-areas.

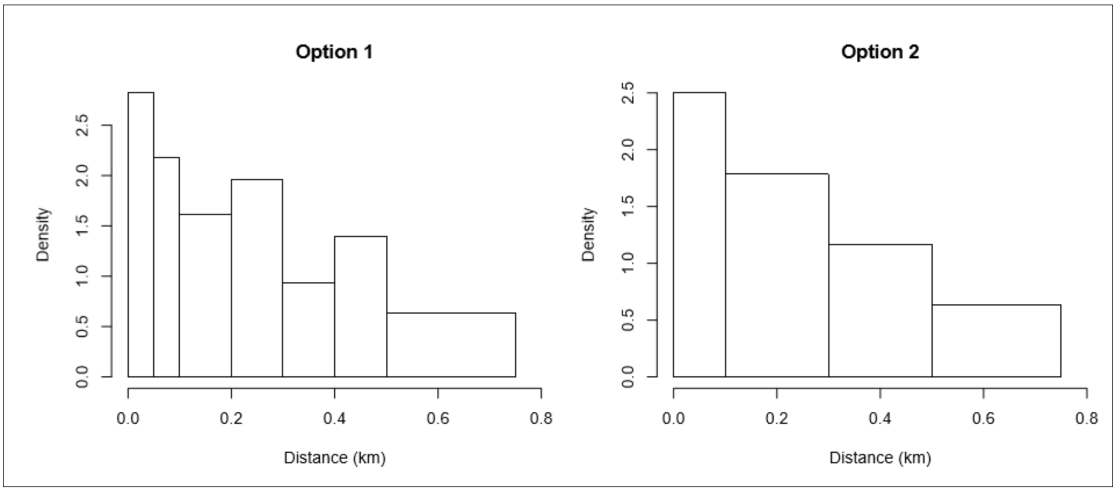

Figure 8. Histogram of two binning options for the caribou distance data. Left: the original bins as collected on the survey. Right: an alternative binning to reduce the effect of heaping. The area of the rectangles is proportional to the number of points within each bin.

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. These analyses are from Correia (2020). The histogram of observed distances with no defined truncation distance is similar to typical Distance Sampling data, perhaps showing some over-dispersion, with not-equally-spaced bins (Fig. 8). Given the histogram of binned distances, a strip half-width of w = 0.75 km was selected (*i.e.*, all observations at distances beyond 750 meters were discarded). This truncation reduced the sample size from 2079 to 1640 caribou groups for the Distance Sampling 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 0.75 km from each side of the line make a minimal contribution to the abundance estimate.

The alternative binning Option 2, less bins, reduces the influence of potential measurement errors in the observed distances. This alternative binning option includes bin cut points of 0, 0.10, 0.30, 0.50 and 0.75 km (Fig. 8).

With the original binning option, there seem to be less than expected observations on the 0.10-0.20 km and 0.30-0.40 km intervals, when compared to the 0.20-0.30 km and the 0.40-0.50 km bins. This might be evidence of heaping. This phenomenon occurs when observers tend to record some preferred values over others (Buckland *et al.* 2001). Here, the heaping would have occurred for distances 0.25 km and 0.50 km, which are round distances that are easily chosen in the absence of a rigorous distance measuring method.

Both binning options were considered in model fitting, albeit only Option 2 minimizes the effect of measurement error induced by heaping. Since binning Option 1 was not suitable for grouping, only the analyses whose fitted models consider the second binning option are illustrated below. The advantage for choosing the second binning option is that it results in more reliable detection functions. However, owing to fewer degrees of freedom, the small number of bins affects the $\chi 2$ Goodness-of-Fit tests following model fitting.

A scatter plot, with a GLM fitted between two variables, observed distance as explanatory variable, and group size as response variable, suggested a faint tendency for larger groups being associated with greater distances (Fig. 9).

Note that the maximum group size is no longer 20 as this data set has been truncated, considering a strip width of w = 0.75 km, therefore, the most distant observations, which corresponded to large group sizes, were excluded. This regression analysis suggests that distance is a statistically significant variable explaining group size (Table 4). Group size also seemed marginally related with the spatial coordinates (Correia 2020).

Table 4. Summary of the coefficient characteristics of the GLM between observed distance and the group size while considering a Poisson distribution.

Parameter	Estimate	Standard Error	z-value	p-value
Intercept	0.747	0.029	26.20	0.00000
Distance	0.311	0.080	3.88	0.00011

Note: AIC = 5613.7, Null Deviance = 1361.4, Residual Deviance = 1346.4.

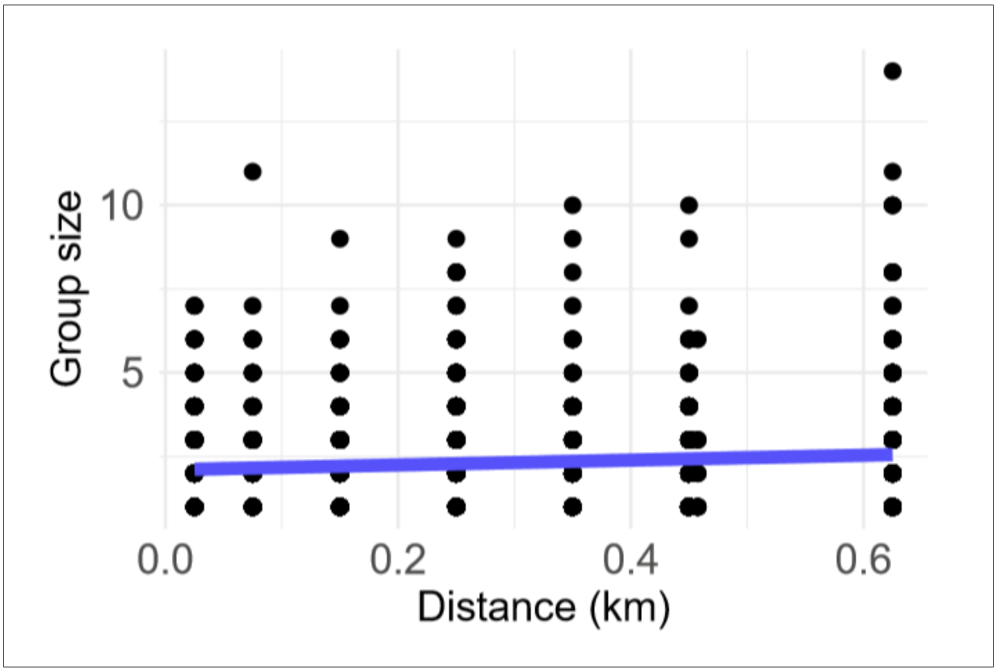

Figure 9. Relationship between group size and observed distances and respective regression fit using GLM.

Detection function models fitted with the first binning option did show poor fitting, including the best fit within this group, since these presented several adjustment terms, due to the heaping phenomena. Below, the detection functions are fitted to the data considering the second binning option.

For these models, every combination of key function and adjustment terms was tested. The only additional covariates assessed were observer and group size, considering w = 0.75 km. A summary of the information from each model fitted to the data (Table 5) 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)), 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 2018 caribou survey data, this model has the hazard rate function as a key function, no adjustment terms added and only group size as covariate (AIC = 4414.52). The hazard rate key function was selected because it was the most flexible key.

The second-best model includes the half-normal key with group size as a covariate (AIC = 4422.17, *i.e.*, ΔAIC = 7.66). This strongly suggests that group size is a relevant covariate in detectability. The best fitted detection function parameters' estimates indicate a slight positive relationship between group size and detectability, superimposed with the observed distances' histogram (Table 6, Fig. 10). The estimated averaged probability of detection for the North region was $\hat{P}$a = 0.541 (se = 0.025, Table 5). Remaining detection functions and summary table are found in Correia (2020). It is an averaged estimate since group size is included in the model. Consequently, each group size has its separate detection function, corresponding to different estimates for the probability of detection (Fig. 11).

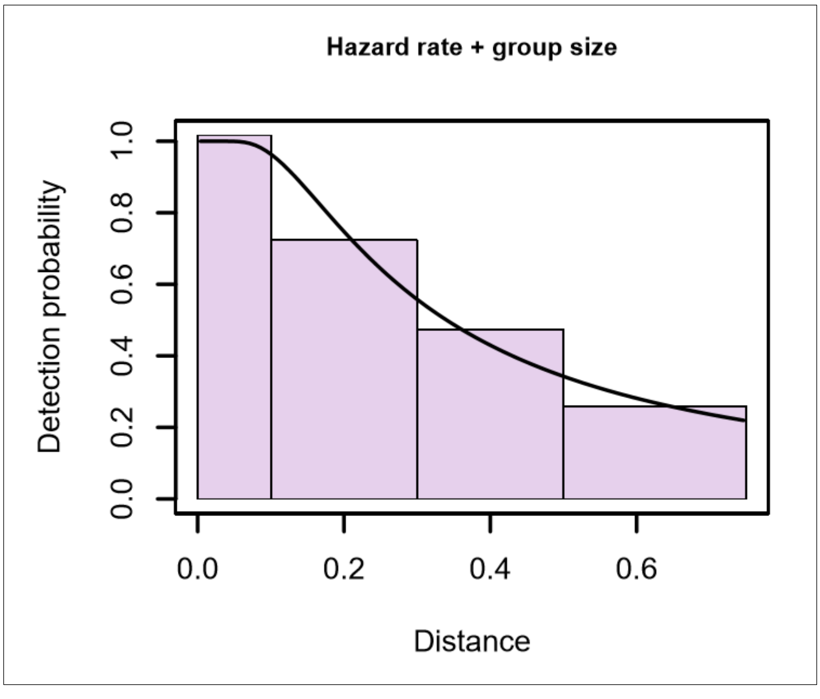

Figure 10. The detected distances with the estimated detection function overlaid, considering the binning option that reduces the effect of heaping.

Table 5. Model comparison across the three Conventional Distance Sampling models and models considering group size and observer as covariates.

Key function	**Formula**	**x^2 *p*-value**	**$\widehat{P}_a$**	**se ($\widehat{P}_a$)**	**ΔAIC**
Hazard-rate	Group size	NA	0.541	0.025	0.000
Half-normal	Group size	0.000	0.603	0.013	7.658
Half-normal with cosine adjustment terms of order 2,3	1	NA	0.512	0.026	8.582
Uniform with cosine adjustment terms of order 1,2,3	NA	NA	0.513	0.025	8.582
Hazard-rate with cosine adjustment term of order 2	1	NA	0.519	0.025	8.647
Hazard-rate with simple polynomial adjustment term of order 2	1	NA	0.533	0.032	10.123
Hazard-rate	Observer	NA	0.544	0.025	10.672
Hazard-rate with Hermite polynomial adjustment term of order 4	1	NA	0.535	0.032	10.679
Uniform with simple polynomial adjustment terms of order 2,4,6	NA	NA	0.577	0.029	15.371
Half-normal	Observer	0.000	0.605	0.013	15.635
Half-normal	1	0.001	0.606	0.013	19.097
Uniform with Hermite polynomial adjustment term of order 4	NA	0.000	0.643	0.010	30.245

Note: Under Formula, explanatory variables: Group size = group size as variable, 1 = for Uniform key, NA = no explanatory variables, Observer = observer as variable.

Under Chi-square *p*-value, NA = not enough degrees of freedom for the Goodness-of-Fit (GOF) test, thus the 'NA' values. (Degrees of freedom are calculated considering the model parameters and these vary considering which key function is used and how many/which explanatory variables are considered.).

For each key function, all three series expansions (Cosine, Simple Polynomial, Hermite (Appendix 1, Table 14) were applied.

Table 6. Detection function parameters' estimates.

	Estimate	**Standard Error**
Intercept	+1.681	0.154
Group size	0.152	0.048

Note: Estimates are on log scale.

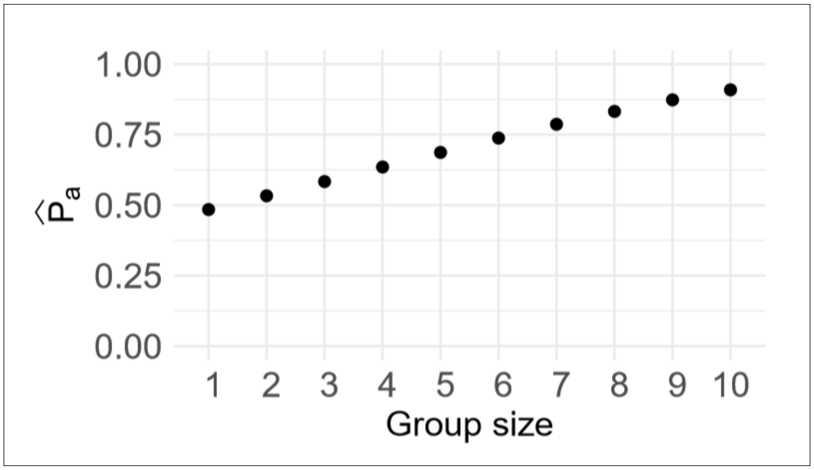

Figure 11. Estimated probabilities of detection for each observed group size obtained with the fitted model.

A group size of 2 caribou presents an estimated probability of detection of 0.533, while a group size of 10 has an estimate of 0.909 (Fig. 11). With increasing group size, the probability of detection also increases. This is consistent with the author's intuition as larger groups are easier to detect than smaller ones.

The estimates for encounter rates suggest the Sisimiut sub-area has the most caribou, since its estimate is larger than the other sub-areas (Table 7). Visualization of the detected caribou distribution shows this was almost continuous along the line transects of the Sisimiut sub-area, with a few 'hot' spots (Fig. 12). Meanwhile, caribou were seldom observed at elevations over 1000 m. This involved much of the Sisimiut South sub-area, south end Angujaartorfiup sub-area, and a couple of line segments in Sisimiut sub-area: line transect 6 for duration of the glaciated Qáqapalât (1200-1600 m); line transect 5 over the Akuliaruserssuaq Peninsula and associated Tugtoqarajôg (900-1500 m). Concerning the design-based estimates for caribou abundance and density, Sisimiut is also the sub-area presenting more caribou (Table 8, Fig. 13).

Table 7. Encounter rate estimates per sub-area (stratum) for caribou groups considering three strata, five bins, and a detection function fitted with group size as covariate.

Sub-area	Encounter rate	Standard Error (se)	Coefficient of Variance (cv)
Sisimiut	1.389	0.084	0.060
Sisimiut South	0.403	0.110	0.273
Angujaartorfiup	0.559	0.085	0.152
TOTAL	0.997	0.120	0.120

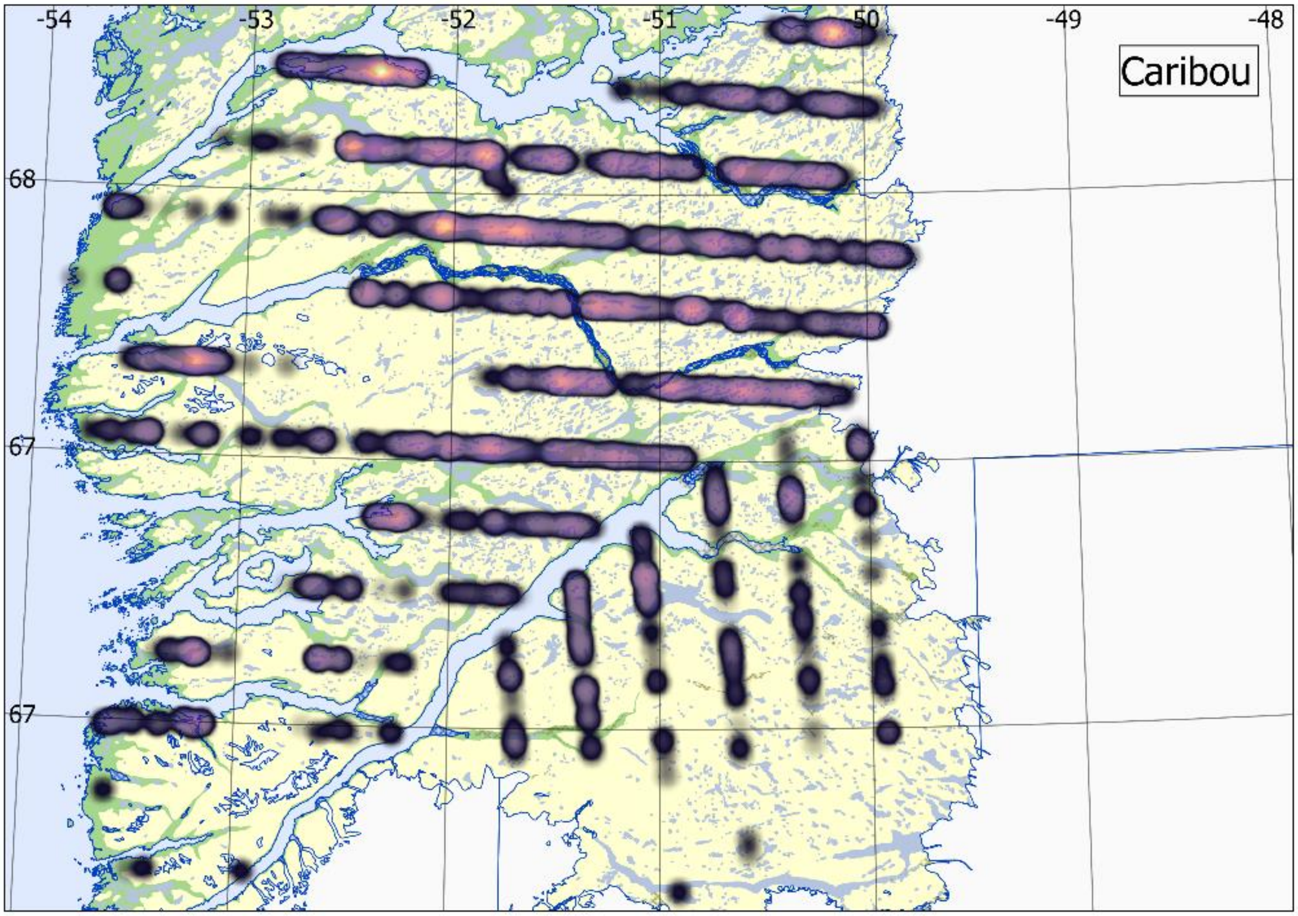

Figure 12. Relative distribution of caribou numbers along the line transects. Smudge shading indicates fewest caribou. This darkens until becomes black, turns into purple-violet, shifting to pink and ending with yellow, which is the most caribou. Underlying map: elevations between 0 and 200 m are pale green, above 200 m are pale yellow.

The $\chi 2$ Goodness-of-Fit test could not be performed to the selected model because there were not enough degrees of freedom (Appendix 1: Equation (19), $u - q - 1 = 4 - 3 - 1 = 0$ degrees of freedom, observed and expected values in Correia (2020)). Additionally, the Kolmogorov-Smirnov and Cramér-von Mises tests (Appendix 1) could not be applied since the distances were represented as a discrete variable.

In March 2018, the North region had an estimated population size of approximately 60,469 caribou (95% CI: 51,932 – 70,410), with a CV of 7.4% (Table 8). The latter is an exceptionally low value, which indicates relatively accurate caribou abundance estimates for 2018. The design-based density estimate for the whole survey region was 2.59 caribou per km^2, with 95% CI: 2.23 – 3.02 (Table 8, Fig. 13). Further details in Correia (2020).

Table 8. Kangerlussuaq-Sisimiut caribou abundance estimates and densities in the North region, March 2018, considering three sub-areas (strata), five bins and a Hazard rate detection function with group size as a covariate.

Sub-area	Population Estimate	SE	CV	95% Confidence Interval		Density (caribou / km^2)
				Lower	Upper	
Sisimiut	46,724	3,745	0.080	39,392	55,422	3.7
Sisimiut South	3,931	1,134	0.289	1,820	8,492	1.2
Angujaartorfiup	9,814	1,502	0.153	6,758	14,252	1.4
TOTAL	**60,469**	**4,501**	**0.074**	**51,932**	**70,410**	**2.6**

Note: SE = Standard Error, CV = Coefficient of Variance.

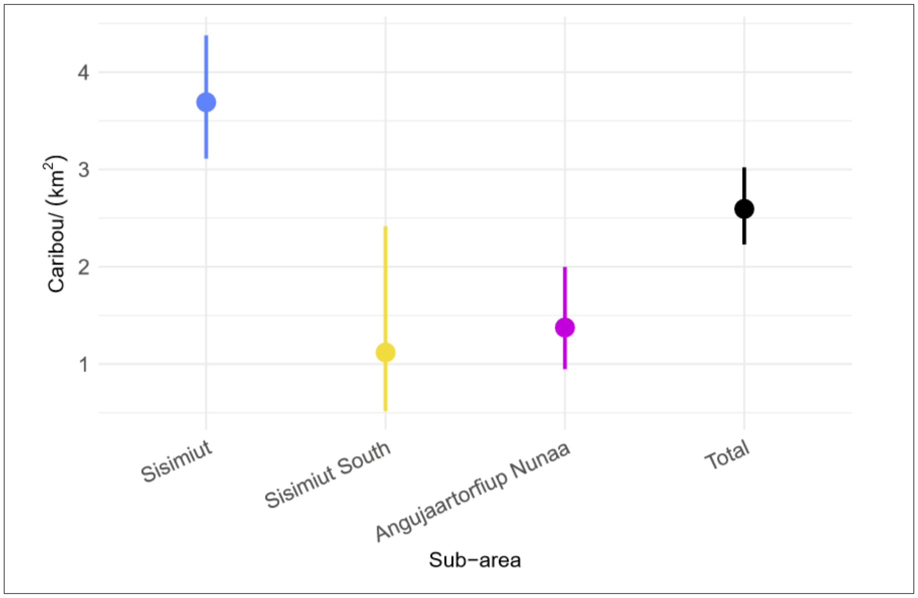

Figure 13. Caribou density estimates with corresponding confidence intervals for the three sub-areas, Sisimiut, Sisimiut South and Angujaartorfiup, and finally for the total North region.

Caribou detectability

As noted under all helicopter surveys since 2000, detecting caribou was again difficult owing to background conditions camouflaging the caribou from view. These included incomplete or patchy snow cover, substrate (including grass, low vegetation, ground) poking or showing through thin snow layer, rocky terrain, fog, and light/shadow conditions typical to latitudes around the Arctic Circle in early March. Detecting caribou was further compromised by the west-east orientation of most lines, which ensured that on the south-facing side of the helicopter in the absence of cloud cover, the sun was in observer eyes and reflecting off the snow surface causing solar glare. Despite observers using polarized sunglasses, this intense sunlight in the eyes may have reduced detectability of caribou. The flight altitude of 40 m reduced the amount of dead ground (land blocked from view by terrain features, *e.g.*, Appendix 4, Fig. 25), resulted in more ground to search and scan over for animals. When combined with a long line length, the subjective result was a feeling of there not being enough time to scan all terrain properly, and sometimes diminished observer concentration could occur. Both could lower caribou detection given the high camouflage conditions. Finally, the helicopter windows sometimes frosted, that frost and the time for physical removal (scrapping off using credit card) could have decreased caribou detection. Additionally, low caribou group size and specifically lack of movement by the caribou made sighting them difficult.

Table 9. Kangerlussuaq-Sisimiut caribou movement, or lack thereof, in reaction to helicopter flying line transect survey of North region, March 2018. The dataset for observations of caribou group size which included behaviour was n= 1880, while the dataset which included distance of the caribou group from the line transect was n = 1870.

	Kangerlussuaq-Sisimiut caribou		
Caribou Groups	**Exhibiting Movement**	**Lacking Movement**	***p* – value**
Number of groups	1288	592	
% observations	68.5%	31.5%	
Mean group size	2.54	2.14	< 0.0001
Confidence Level (95%)	0.106110162	0.112602502	
Standard Error	0.054087919	0.057333656	
Median	2	2	
Mode	2	1	
Standard deviation	1.941145995	1.394988056	
Sample Variance	3.768047773	1.945991677	
Maximum	20	10	
Minimum	1	1	
Distance from 0-line[1]	1283	587	
Mean distance	539.36 m	663.80 m	< 0.0001
Confidence Level (95%)	28.5451518127234	39.8522696732454	
Standard Error	14.5503705	20.29116828	
Median	300	500	
Mode	1500	1500	
Standard deviation	521.1795663	491.6161067	
Sample Variance	271628.1403	241686.3964	
Maximum	1,500 m	1,500 m	
Minimum	50 m	50 m	

[1] 0-line is the centre of the line transect flown by helicopter.

Caribou behaviour: flight reaction or lack thereof

The caribou survey of 2018 was the first to use digital audio recorders to collect the observation data. The digital recorders permitted including in the dataset what, if any, was the behavioural reaction of the caribou group to the helicopter flying a line transect past or over them. Behaviour could then be put in relation to group size and distance from the transect line (Table 9).

There was a significant difference between the size of caribou groups that exhibited movement and those that did not, mean 2.5 and 2.1, respectively (t Stat = 5.104806; two-tailed testing P < 0.0001, t = 1.961497638, df = 1548).

Non-moving caribou groups averaged *ca.* 125 m further away from the line transect flown by the helicopter than those caribou groups showing movement (Table 9). There was a significant difference between the mean distance for groups with movement, 539.36 m, relative to the groups lacking movement, 663.80 m (t Stat = -4.983728647; two-tailed testing P < 0.0001, t = 1.961944491, df = 1199).

Table 10. Kangerlussuaq-Sisimiut caribou details for movement, or lack thereof, in reaction to helicopter flying line transect survey of North region, March 2018. Dataset of observations that included caribou group size, behaviour, and distance from line transect. Dataset was n= 1,880 groups, which contained n = 4,545 individual caribou.

Kangerlussuaq-Sisimiut caribou				
Category	**Groups (n = 1,880)**	**%**	**Individuals (n = 4,545)**	**%**
Exhibiting Movement				
Running away	1000	53.19	2548	56.06
Running away high speed	111	5.90	345	7.59
Walking	92	4.89	188	4.14
Approach*	20	1.06	63	1.39
Confused, circling tightly	20	1.06	39	0.86
Running parallel to line transect	18	0.96	38	0.84
Running, later standing looking	17	0.96	29	0.64
Trotting away	7	0.37	14	0.31
Mixed: movement + lack of	3	0.16	13	0.29
TOTAL	**1,288**	**68.51**	**3,277**	**72.10**
Lacking Movement				
Standing still	459	24.41	992	21.83
Standing, later walk approach*	66	3.51	145	3.19
Lying down	32	1.70	51	1.12
Lying down, later stood up	17	0.90	39	0.86
Some lying, others standing still	10	0.53	28	0.62
Lying down, later walk movement	8	0.43	13	0.29
TOTAL	**592**	**31.49**	**1,268**	**27.90**

*Approach movement was towards the helicopter position.

Caribou groups reacting to the helicopter fly-by with movement made up 68.5% of all observations. Conversely, 31.5% of all caribou groups exhibited little or no movement. The results were similar when considering the absolute number of caribou involved (Table 10).

Of 4,545 individual caribou, 72.1% exhibited movement and lack of movement 27.9%. Almost a third of all caribou observed lacked movement.

Among the 1146 ‘running’ groups (Table 10), 939 of those groups exhibited unabated flight, *i.e.*, they never stopped while within view of the helicopter. Group composition (sex, age) was determined for 316 of those groups and 86% were composed of cows with calves. Only 7% were bull groups (juveniles, adults), with the remaining 7% being groups of cows only, calves only, cows and juvenile bulls or adults of unknown sex.

Considering only the 233 caribou groups whose original position was on or within 50 m of the 0-line, 140 of those groups (60%) never stopped running away. Six times such unabated flight began while a group was far distant on a section of the 0-line yet to be flown, *e.g.*, 0.5 to 1.5 km ahead of the helicopter. Meanwhile, 15 groups lacked movement, although five of those groups did move once the helicopter was directly over top of them. In ten of those groups the caribou were standing and in five they were lying down.

Table 11. Demographics for Kangerlussuaq-Sisimiut caribou, North region, March 2018.

Parameter	**Kangerlussuaq-Sisimiut caribou**			
Number of groups observed	894			
Mean group size	2.45			
Confidence Interval (95%)	0.1148			
Standard Error	0.0585			
Standard Deviation	1.75			
Sample Variance	3.0605			
Median group size	2			
Mode group size	1			
Maximum group size	12			
Minimum group size	1			
	Original data		**Removed 124 orphan calves**	
Total individuals sexed & aged (*n*)	2188	100 %	2064	100 %
Cow (age > 1 year)	1136	51.92 %	1136	55.04 %
Calves from previous spring	476	21.76 %	352	17.05 %
	(231 females)	10.56 %	-	-
	(228 males)	10.42 %	-	-
Bull (age > 1 year)	576	26.33 %	576	27.91 %
	(231 adults, age > 3)	10.56 %	(231 adults, age > 3)	11.19 %
	(202 juveniles, age 2½)	9.23 %	(202 juveniles, age 2½)	9.79 %
	(143 juveniles, age 1½)	6.54 %	(143 juveniles, age 1½)	6.93 %
Recruitment (calves / 100 cows)	41.90		30.99	
Sex ratio (Bull >1 year / Cow)	0.51		0.51	

Demographics & recruitment

Detailed herd structure data was collected in separate specific efforts that were not part of the line transect Distance Sampling dataset. Over three days, 11, 12 and 14 March 2018, using *ca.* 10 hours flight time, we sexed and aged 894 groups of caribou, for a total of 2188 animals, in the Kangerlussuaq-Sisimiut caribou population (Table 11). Cows were almost 52% of the population, followed by bulls (age > 1-year) at 26% and calves at 22%.

Calf lacking their dam

Cows were often completely absent when calves (age ≤ 10-months) were observed. During demographics data collection a total of 476 calves were observed (Table 11). Only 352 calves (74%) were in the company of cows, while 124 (26%) lacked their dam (mother). Of those calves lacking dams, 87 (18%) were in calf only groups (Table 12). Although typically observed as singles, groups of up to three orphan calves together occurred. A further 37 orphan calves (8%) were observed in the company of bull only groups (n=14). Of those 14 groups, 12 involved only juvenile bulls, and two only adult bulls. Among the 352 calves in the company of cows, there might yet be some additional orphan calves, because some groups contained more calves than cows. This involved a total of 26 groups consisting of 96 caribou, which included 34 cows and 62 calves, for a possible 28 further orphan calves. Most of these groups (n=21) consisted of a single cow followed by two calves. One group had a cow and three calves. The remaining four groups contained 2, 3, 3, and 4 cows which were accompanied by 3, 4, 5 and 5 calves, respectively. Orphan calves may have made of 26-32% of all calves observed.

Assuming the 124 orphan calves are unlikely to survive their first winter, owing to higher mortality than calves with dams, and are therefore removed from the dataset, results in the following demographic: cows 55%, bulls 28% and calves 17%, with a decreased calf recruitment of 31 calves per 100 cows (Table 11).

Group composition & group size

The sex and age composition of caribou groups may have influenced group size. Disregarding calf (age ≤ 10-months) groups, groups containing only adult bulls (age > 3-years) had the lowest mean group size, 1.34, and groups with only bulls (juveniles and adults combined) had the next lowest, 1.50 (Table 12). Highest mean group size observed, 5.10 caribou, applied to groups consisting of a combination of cows, calves and bulls. Cow groups had a mean size that was higher than bull groups. Groups containing bulls in association with barren cows had a mean group size similar to groups with just cows and calves, 3.19 and 3.17, respectively.

Table 12. Group size relative to group composition from the demographic dataset, Kangerlussuaq-Sisimiut caribou, North region, March 2018.

	Kangerlussuaq-Sisimiut caribou group composition						
Parameter	**Adult Bull**	**Adult and/or Juvenile Bull**	**Adult Cow & Bull, no calves**	**Cow & Bull, with calves**	**Cow, no calf**	**Cow & calf**	**Calf**
Number of caribou	164	206	290	469	372	622	87
Number of groups	122	137	91	92	214	196	66
Group size							
Mean	1.34	1.50	3.19	5.10	1.74	3.17	1.32
CI (95%)	0.12	0.13	0.29		0.13	0.23	0.14
Standard Error	0.05	0.07	0.15	0.24	0.06	0.12	0.07
Standard Deviation	0.60	0.79	1.40	2.30	0.94	1.63	0.59
Sample Variance	0.36	0.62	1.95	5.28	0.89	2.66	0.34
Median	1	1	3	4	1	3	1
Mode	1	1	2	3	1	2	1
Maximum	4	5	7	12	5	12	3
Minimum	1	1	2	3	1	2	1

Elevation use by Kangerlussuaq-Sisimiut caribou

Elevation use by KS caribou groups in early March was approximated from the GPS dataset for helicopter elevation and position and matching those timestamps with those of the digital audio recording of caribou group 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.

All elevation results for caribou groups indicate only approximate values (Table 13). 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 group's location. Even caribou groups on the 0-line flown did not necessarily receive correct GPS positions. Owing to flight behaviour, these caribou groups (always cow-calf pairs) were often digitally recorded while still *ca.* 1.0 km in front of the helicopter's position. Additionally, caribou not on the 0-line flown could be in terrain at a higher or lower elevation than the helicopter. From the author's experience, most caribou observed would have been at elevations below that recorded for the helicopter, even after subtracting the flight altitude of 40 m. Further error arose from the GPS device itself. At the start of each survey day, the GPS device was manually synchronized to the Kangerlussuaq airport elevation, but commonly by the end of the day the GPS devise's value had changed.

Table 13. Approximate elevations for caribou groups observed: Survey of the Kangerlussuaq-Sisimiut caribou population by helicopter in the North region, 03-15 March 2018.

Parameter	**North region sub-area**			**Total North region**
	Sisimiut	**Sisimiut South**	**Angujaartorfiup**	
Sample size*	1556	77	264	**1897**
Mean elevation	334	363	521	**361**
Standard Error (SE)	4.7	22.7	17.4	**4.9**
Median	312	413	500	**333**
Mode	349	96	471	**111**
Standard Deviation	± 186.9	± 199.6	± 282.5	**± 213**
Variance	34925	39822	79782	**45488**
Range	1056	754	1217	**1222**
Min	1.5	24	6.3	**1.5**
Max	1057	777	1224	**1224**
Confidence Level (95%)	9.29	45.29	34.23	**9.65**

*Low sample size for Sisimiut South sub-area was owing to malfunction of the GPS unit for most of that sub-area.

Late-winter antler possession Kangerlussuaq-Sisimiut caribou

The dataset for the 2,188 sexed and aged caribou included antler possession for most observations. Adult (age > 3-years) bulls lacked antlers and were *ca.* 40% of all males observed. Juvenile (age 1½-2½-years) bulls made up 60%. In contrast to adult bulls, 96.2% of juveniles possessed both of their antlers from the previous autumn, while 3,8% had just one antler. Meanwhile, adult cows possessing one or both antlers made up 54.1% of all females (two antlers 28.5%: one antler 25.6%). Polled (no antlers) cows were 45.9%. Female calves (age ≤ 10-months) were predominantly polled, 64.4%. In contrast, 86.2% of male calves (age ≤ 10-months) possessed antlers (two antlers 66.1%: one antler 29.2%).

Natural mortality estimate 2018

Using an assumed natural adult mortality of 8-10% for West Greenland caribou populations in general (Kingsley & Cuyler 2002) and the current estimated population size of *ca.* 60,469 caribou, the calculated natural mortality for the Kangerlussuaq-Sisimiut population would be between *ca.* 4,800 and 6,000 caribou annually. The assumed 8-10% natural mortality rate excludes catastrophic stochastic events and hunter harvest.

Discussion

Caribou detection and flight response of caribou groups

Normal survey conditions for the North region have been well illustrated in Cuyler *et al.* (2005, 2011) and include any one of the following or combinations thereof; incomplete or patchy snow cover, substrates (including grass, bushes, ground) poking or showing through a thin snow layer, rocky terrain, fog, and alternating light/shadow. Conditions were similar in 2018 (Appendix 4) and camouflaged the caribou present making detection difficult. Frosted windows hampering vision are also common to all surveys. The west-east orientation of most line transects used in 2018 almost guaranteed solar glare in the eyes of the observer on the south-facing side of the helicopter. Despite the use of polarized sunglasses, detectability of caribou may have been reduced. Additionally, low caribou group size and specifically lack of movement by the caribou made sighting them difficult. Since flight responses by the caribou may influence whether an observer detects them, in 2018 the line transect data included whether the helicopter fly-by elicited a flight movement response from the caribou group or whether they were stationary.

Only 68.5% of the caribou groups exhibited movement, while 31.5% did not, which included a few groups on the 0-line. This large proportion of stationary caribou groups underlines the importance of skilled observers able to detect non-moving animals despite rugged terrain and camouflage conditions. It demonstrates the necessity of flying low & slow because the former makes detection of caribou easier, and the latter provides the time necessary to do so. For caribou surveys in Greenland, skilled observers are standard, and since 2000, so are flying low and slow at constant altitude. Further, the 2018 survey's Distance Sampling methods and analyses corrected for undetected caribou (moving or non-moving) and provided a robust estimate for caribou abundance and density (below). 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. Additional results from two Greenland caribou surveys completed in 2019, will confirm whether the observed proportion in 2018, almost 1/3 non-moving caribou groups, is atypical or typical. If typical, this suggests that a survey dataset that included few stationary caribou observations would underestimate population size correspondingly. Detecting non-moving caribou is essential to avoid underestimating population size.

Although the difference was small, the non-moving groups had significantly lower mean group size than moving groups, and mean distance to the non-moving groups was further than those for groups that moved, and median distance was 200 m greater (Table 9). This attests to exceptional observer ability to detect caribou despite the behaviour displayed by the caribou. Explanations for lack of movement among caribou further away from the helicopter would include the likelihood of less fear, since at greater distances the helicopter may be perceived as less threatening. Additionally, group composition may be involved. Adult bull caribou typically exhibit the least vigilance to disturbance (Wolfe *et al.* 2000, Reimers *et al.* 2011). Meanwhile, the group size of non-moving groups was significantly lower than moving groups. Low group size characterized the KS bull groups observed, specifically those with only adult bulls, but also bull groups containing both adults and juveniles. This suggests that the groups exhibiting lack of movement were primarily bull groups. In contrast, groups that fled had larger mean size and highest group sizes were always associated with the presence of cows, which are noted for their vigilance (Wolfe *et al.* 2000, Reimers *et al.* 2011).

Among moving groups, unabated flight reaction (running away, never stopping) was common for cows with calves and even occurred at distances exceeding 1 km from the helicopter. Specifically, both applied to the nine large groups (11-20 caribou) observed and suggests that large groups arose due to merging of scattered small groups, which individually had not previously been detected owing to being so far away. Closer to the helicopter, sustained flight reactions may interfere with correct determination of distance to a group. Correctly ascertaining a group's original position with regards to the helicopter was compensated for by the approximate bin distances. Further, unabated flight by caribou groups ahead of the helicopter on the transect 0-line created the possibility of failing Distance Sampling's primary assumption, *i.e.*, that all objects-of-interest present on the 0-line are detected while on that line. Thus, the 0-line was vigilantly monitored, facilitated by the treeless terrain, which permitted unimpeded vision forward. Still, the rugged terrain sometimes prevented forward vision. Error in the number of caribou groups assigned to the 0-line is possible if some groups fled while still more than 1 km ahead and hidden by terrain features. Then groups could disappear into the terrain without ever becoming visible, or when visible were at a position far distant from the 0-line and inadvertently assigned into a distance bin. Possible errors are assumed minimal given alert observing and open landscapes, in combination with the large total number of groups observed, relatively constant group encounter rate, good survey area coverage, and exceedingly low coefficient of variance on the population estimate.

Elevation

Albeit elevation data was only approximate given the limitations of the GPS device and mismatch between helicopter and caribou positions, observed KS caribou were at relatively lower elevations, mean 361 m. This preference for low elevations in late winter is supported by GPS telemetry data for cows, mean *ca.* 200 m (Cuyler *et al.* 2017). The Sisimiut South and Angujaartorfiup sub-areas, where high elevations predominant, had the least caribou and the higher mean elevation used reflects the topography available.

Antler possession

As expected, adult (age > 3-years) bulls lacked antlers in March, however, most juvenile bulls retained theirs. Antler possession in Greenland cows is highly variable (Cuyler *et al.* 2002). In winter 1998, *ca.* 42% of KS cows were antlered, while in another population Akia-Maniitsoq, antler possession was much less, *ca.* 19% (Cuyler unpublished). In March 2018, among KS cows, 54.1% possessed antlers, while 45.9% were polled (no antlers). Polling also predominated among female calves. These values, and those from 1998 (Cuyler unpublished), are in sharp contrast to caribou cows elsewhere, *e.g.*, 98% antlered cows in North America, where 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). Decline in antlered cow number has been attributed to overgrazed range which results in poor cow body condition (Gaare & Skogland 1980, Reimers 1983, Thing *et al.* 1986, 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. Both apply to the KS caribou. Their mean group size is 2.45 caribou (median 2), and the North region is noted for its xeric habitat and shallow snow (Appendix 4, Figs. 19, 20, 21, 22, 25 & 26). Thus, polled KS cows may be the result of a reduced need for the dominance conferred by antlers.

Demographics

In early March 2018, the KS caribou population's herd structure suggested an improved composition, which initially appeared to be cows 52%, bulls 26% and calves 22%. Calf production/survival appeared to be recovering towards former levels (*e.g.*, 2000) given the late winter calf recruitment was initially *ca.* 42 calves per 100 cows. These values are better than those from the 2005 and 2010 surveys (Table 1) and suggest the expectation of increasing abundance (Bergerud *et al.* 2008). However, high incidence of orphan calves (n=124) suggested that to create those orphans a similar number of cows had been killed previously in the 2017 autumn hunting season. Further to the 124 orphan calves, there is the possibility of an additional 28 orphan calves, as suggested by groups containing more calves than cows. Orphans may have been 26% to 32% of all calves observed. Twinning among Greenland caribou is possible since cows accompanied by two calves and twoegged twin foetuses have occasionally been observed (Cuyler & Østergaard 2005). Nevertheless, twinning is considered uncommon in caribou (Skoog 1968, Bergerud 1969, Dauphiné 1976). Either twinning is more common than expected in the KS caribou population or the extra calves also had lost their dam. Considering the 124 orphans, their survival into March of their first winter is remarkable but not unexpected since large predators are absent in West Greenland. It indicates that food availability, quantity and quality were not a problem for KS caribou in the months leading up to March 2018. Unfortunately, the high number of orphan calves (*i.e.*, missing cows) indicates that the calf recruitment of 42 calves per 100 cows is artificially high. One option would be to remove the orphan calves from the dataset, since these may not survive, assuming these have a higher mortality rate than calves with dams (Bergerud *et al.* 2008). If just the known 124 orphan calves are removed from the dataset, then the revised demographics results are cows 55%, bulls 28% and calves 17%, with a late winter calf recruitment of 31 calves per 100 cows and a bull to cow ratio of about 0.51. Even the revised calf values are better than the low 2005 and 2010 values (Tables 1, 11). The March 2018 demographics, revised or not, describe a caribou population that appears capable of withstanding current harvests, while the calf recruitment is not high enough to suggest the possibility of rapid population growth. Conversely, the 2018 calf recruitment indicates a low risk for future population decline, while there is potential for possible stability or slow growth (Bergerud *et al.* 2008). Still, stochastic catastrophic events could bring abrupt changes in abundance (CAFF 2021).

2018 caribou population size & density

At 23,303 km^2, the North region is the largest of all the caribou regions in West Greenland. Due to the high cost of helicopter time in Greenland, the 2000, 2005 and 2010 strip count surveys covered only about 1% of the North region area. In 2018 and with increased funding, Distance Sampling methods with systematic transects were adopted. This increased area coverage to 10.6% (given truncation limiting strip width to 750 m either side), which contributed to improved estimate accuracy.

The 2018 KS population estimate was 60,469 caribou (95% CI: 51,932–70,410; SE = 4,501; CV = 0.074), with density of *ca.* 2.59 caribou/km^2 (95% CI: 2.23–3.02). The Distance Sampling estimate was exceptionally precise (CV = 7.4%), specifically in regards past less precise estimates.

On the surface the 2018 population estimate is *ca.* 38.5% lower than the estimated number of KS caribou in 2010, *i.e.*, *ca.* 60,500 versus 98,300 (Tables 1, 8). Before concluding that a large decline in abundance has occurred, caution is needed because several mitigating factors must be recognized. The 2010 survey had low area coverage (1%) and a high Coefficient of Variance (CV), (19%). Thus, the 2010 estimate was likely not as accurate and was certainly less precise than the 2018 survey. Also, unlike in 2018, the 2010 analyses used a less refined area, *i.e.*, included lakes, rivers, and islands. The larger area entailed would have inflated the 2010 estimate. These may account for the lack of overlap in the confidence intervals for the 2010 and 2018 estimates. Expanding to include the 2005 survey estimate and the overlap of the confidence intervals suggests a lack of significant difference between the 2005-2010 and 2018 population sizes.

Population trend can be predicted if the same methods are repeated over a time series of surveys. However, the 2018 survey adopted Distance Sampling methods and analyses to maximize estimate accuracy and precision. This change of methods precludes trend projections based on just the current and the 2010 strip transect count surveys. To predict a somewhat reliable population trend, a time series of at least three estimates is needed and these must be obtained while repeating the same methods. Albeit the 2018 Distance Sampling estimate of *ca.* 60,469 caribou suggests decline in KS caribou abundance and some decline could be expected given both the poor calf recruitment of the 2005-2010 period and almost two decades of harvest management aimed at reducing KS caribou abundance. Regardless, the 2018 late winter calf recruitment does not support future population decline.

The 2018 Distance Sampling design-based estimate, 60,500 caribou, was based on the selected 19 line transects, which may over-represent some features within the North region, while under-representing others. In an alternate approach, Correia (2020) applied Generalized Additive Model (GAM) and Density Surface Model (DSM) to the same 2018 survey data and thus considered the entire North region. Correia's GAM/DSM analyses resulted in a 2018 Model-based population size estimate of 73,895 (95% CI: 65,983-82,757) KS caribou, which had the exceptional CV of 0.037 (3.7%), lower than that for Distance Sampling. Given there are two estimates begs the question, which is most accurate and precise? Addressing that issue is beyond the scope of this technical report. Instead, it is currently being investigated, requires additional results from two other West Greenland caribou surveys completed in 2019, and conclusions regarding Distance Sampling and Model-based estimates will be published in a peer-reviewed journal.

Given the Distance Sampling estimate of 60,500 caribou and the Model-based estimate of 73,895 presented by Correia (2020), we can be certain that despite 18 years of harvest management to the contrary, the KS caribou population size remains large in relation to the area available, 23,303 km^2. The overall 2018 estimate for KS caribou density was 2.6 caribou per km^2. Given good calf recruitment, population decline is not expected in the immediate future. As with the 2000, 2005 and 2010 surveys, the 2018 KS caribou density exceeded the recommended management target density of 1.2 caribou per km^2, above which there is assumed an increased risk of overgrazing leading to caribou decline (Kingsley & Cuyler 2002, Cuyler *et al.* 2007). In North America, when overgrazing played a major role, caribou declines took place over 15 to 20 years (Schaeffer *et al.* 2016, Soulliere & Hammel 2015). Nevertheless, even after almost two decades have passed with high densities exceeding the target, there is no strong evidence of extensive overgrazing or decline in the KS caribou. Since in 2018 recruitment improved to at least 31 calves per 100 cows, despite an overall density of 2.6 caribou per km^2, it appears that range conditions in the North region support a higher density than expected. Pending additional results from two other West Greenland caribou surveys completed in 2019, the target density for caribou management will receive re-evaluation regarding what level is compatible with demographics that facilitate sustainable populations and harvests.

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Appendix 1

Statistical methods behind Distance Sampling

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

Fundamental concepts

Before entering into the detailed theory behind the Distance Sampling 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. 14). Some of these small plots are randomly chosen for sampling and the total number of individuals within these, n_{plot}, is recorded.

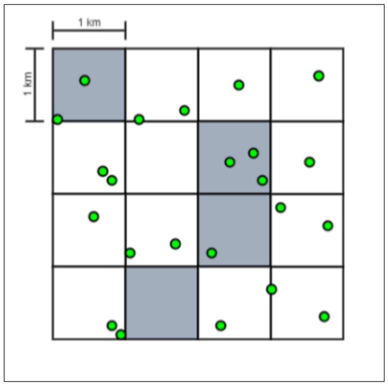

Figure 14. Plot sampling grid example of total area A divided into smaller plots of area a_{plot}.

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. 14) 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, $\widehat{N}$, can be obtained by simply multiplying $\widehat{D}_{\text{plot}}$ 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 Distance Sampling, 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 centreline, and the total transect length $L = \sum_{j=1}^{k} l_j$, where l is the length of transect j. Abundance can be determined using a reasoning analogous to that above (Equation 2). The truncation distance is defined as the distance beyond which distances are not recorded. This can be defined in the field or at the analysis stage.

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

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

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

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

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

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

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

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

where

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

and

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

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

Probability of detection

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

To illustrate the importance of this probability, consider that an observer walks across a large patch of tundra and detects 8 caribou (Fig. 15). While discussing with the local biologist, and considering the biologist's experience, he/she will state that, on average, only one third of all caribou present are detected (*i.e.*, $\widehat{P}_a = 1/3$) meaning that probably there were around 24 caribou within that patch of tundra and 16 have been missed. That is where Distance Sampling 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).

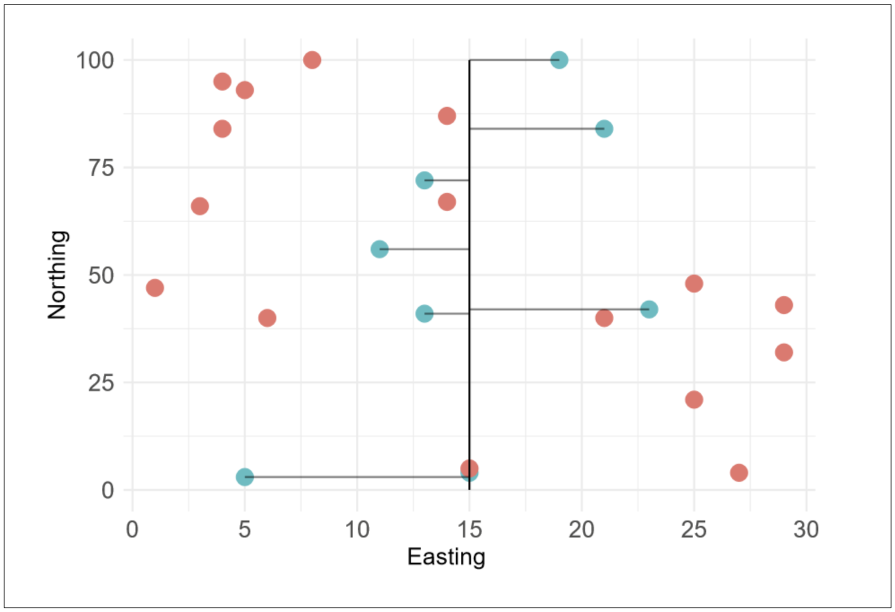

Figure 15. Example of a patch of tundra with the transect in the middle. Blue dots represent eight observed caribou, while orange dots represent the 16 undetected ones. The lines perpendicular to the transect represent the recorded distances.

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 centreline (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 Distance Sampling 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, $\hat{P}_\text{a}$ 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 14).

Table 14. 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. 16). 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. 17). These terms can be either cosine, simple polynomial or Hermite polynomial (Table 14).

It is important to note that these adjustment terms do not depend directly on y but on ys 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).

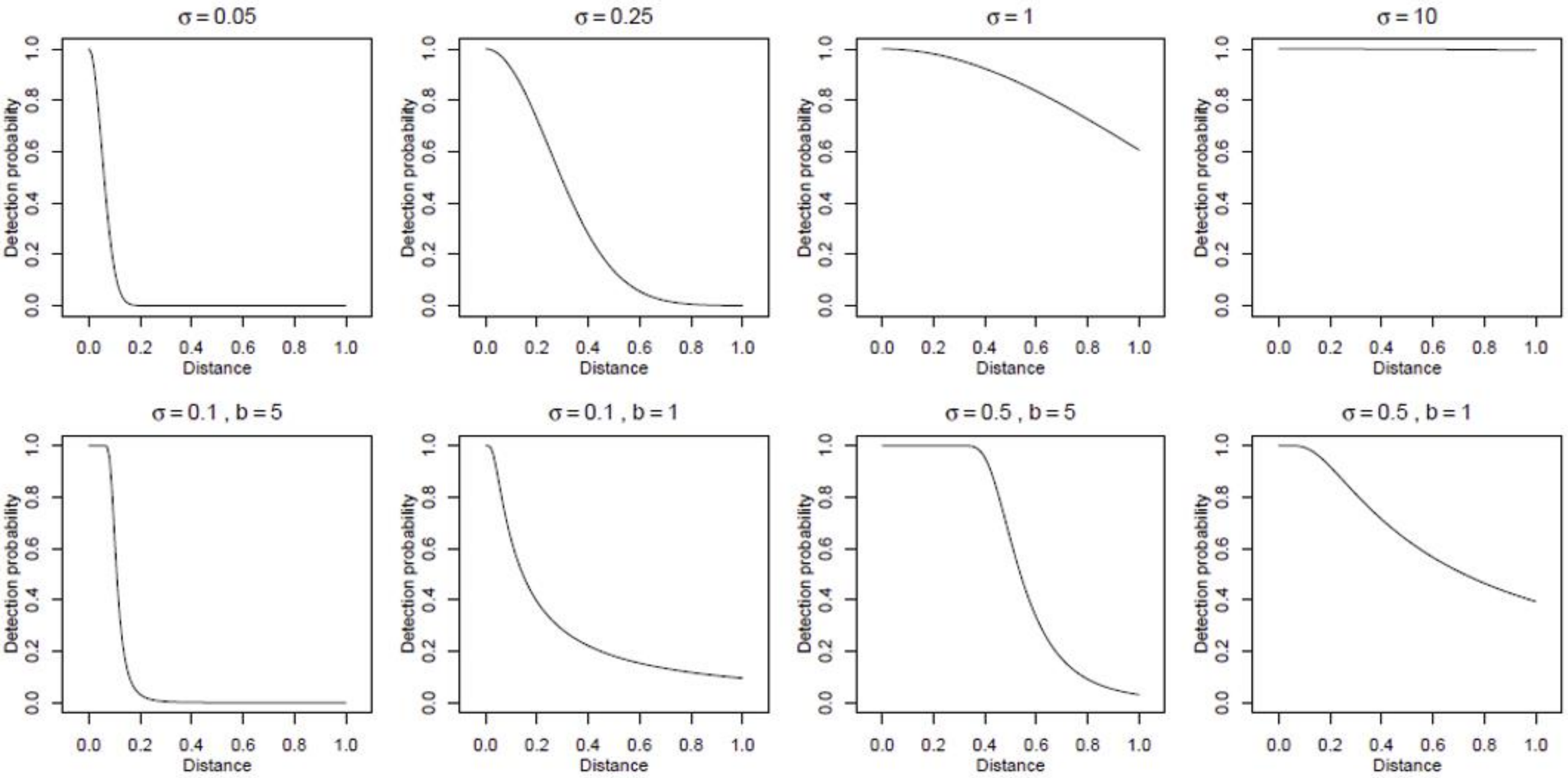

Figure 16. Half-normal (top row) and hazard-rate (bottom row) detection functions without adjustments, varying scale (σ) and, only for hazard-rate, shape (b) parameters. Values tested are presented above the plots. On the top row from left to right, the study species becomes more detectable (higher probability of detection at larger distances). The bottom rows show the hazard-rate model's more pronounced shoulder. Adapted from Buckland et al. (2001).

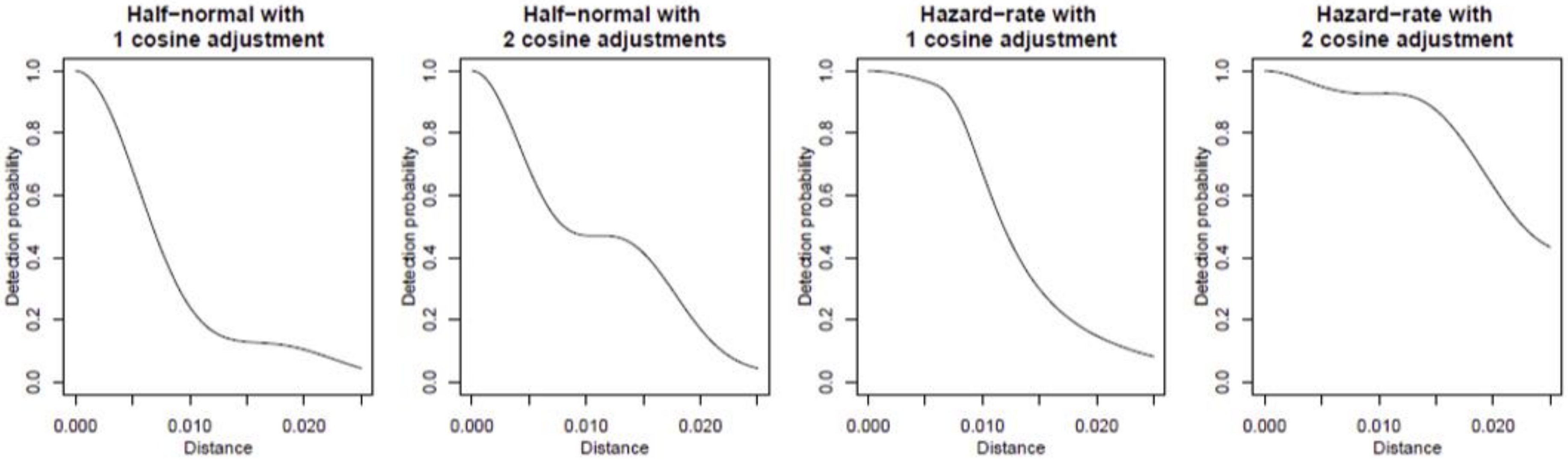

Figure 17. Possible shapes for the detection function when cosine adjustments are included for half-normal and hazard-rate models. Adapted from Buckland et al. (2001).

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 $g(y,\ \mathrm{z})$. These additional covariates can either 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 use a global estimate for the probability of detection, but this second introduces bias, for example, if one stratum favours the animals when compared to other strata which uses fewer parameters than a fully stratified detection function model;
2. where pooling robustness does not hold for CDS analyses, *e.g.*, when survey intensity varies according with pre-defined strata to increase efficiency, or when the detection probability faces extreme heterogeneity due to different object habitats or behaviours, 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. 18), *i.e.*, detection remains nearly certain at small distances from the sampling unit's centreline ($g'(0) = 0$). 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 zero distance line, which is especially important in the analysis of data where some heaping at zero distance is suspected.

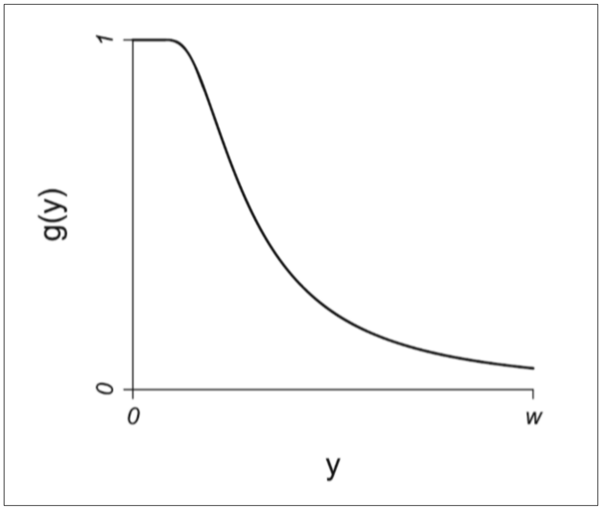

Figure 18. A good model for the detection function should have a shoulder, with probability of detection staying at or close to one at short distances from the centreline or point. At larger distances, it should fall away smoothly. The truncation distance ω corresponds to the strip half-width (for Line Transect Distance Sampling). 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. 18) (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 $\chi 2$ 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 $\chi 2$ 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

Similar 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 $\chi 2$ 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

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

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under the null hypothesis (H_0) of good model fitting, *i.e.,* the difference between the observed (n_i) and expected ($E(n_i)$) counts is close to zero. In Equation (19), n is the total number of observations, u is the number of groups (or bins) within the distance data, and q is the number of model parameters estimated. Reject H_0 if $X^2_{obs} > X^2_{1-\alpha;(u-q-1)}$, 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 2

Distance Sampling Assumptions – short summary

Line transect Distance Sampling assumptions and design are described in Buckland *et al.* (1993) and a summary of the assumptions for survey of large herbivores 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 transect lines 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 transect line 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 3
Recommendations for improving future surveys.

Aerial survey methods & design
The 10.6% survey coverage in 2018 promotes accuracy of abundance estimates and should be continued in future to facilitate evaluating population trends.

The flight altitude could be reduced to 30-35 m. The flight altitude of 40m while observers scanned the landscape out to 1000-1500m from the 0-line was mentally exhausting. This was because the amount of terrain to be scanned was too great for even the relatively slow speed flown (60-70 km/hour), given the high degree of background camouflage that hides caribou. Although an altitude of 30-35m likely will cause amount of 'dead' ground to increase, the Distance Sampling will mitigate for any caribou missed, provided that dead ground is not on the line (which there is no reason to expect it might be). Meanwhile, observer ability to judge correct distance bin may improve. It is the author's experience that without practice people commonly misjudge distance. Looking down from above can exacerbate this tendency. A lower angle to the terrain could provide a more (normal) horizontal line-of-sight to the animals and may increase binning accuracy.

The timing for aerial surveys could remain early March because it 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.

Demographics
When flying line transects, distance and other factors often make identification of calves impossible, resulting in an underestimate of calf number. Herd structure data must continue to be collected in efforts separate from flying the line transects for Distance Sampling.

Logistics
Check whether other helicopter options are available. To date, the smallest helicopter available is the AS350 from Air Greenland (Charter). The AS350 permits limited vision for rear observers, owing to the small window size containing several bar/struts, and which under cold ambient temperatures always fog with ice-frost. These factors reduce visibility of terrain.

Appendix 4
Photographs of KS caribou survey conditions March 2018

Figure 19. Rugged terrain with good sunlit conditions (above), and excellent, almost complete snow cover with shadows (below). Photos C. Cuyler.

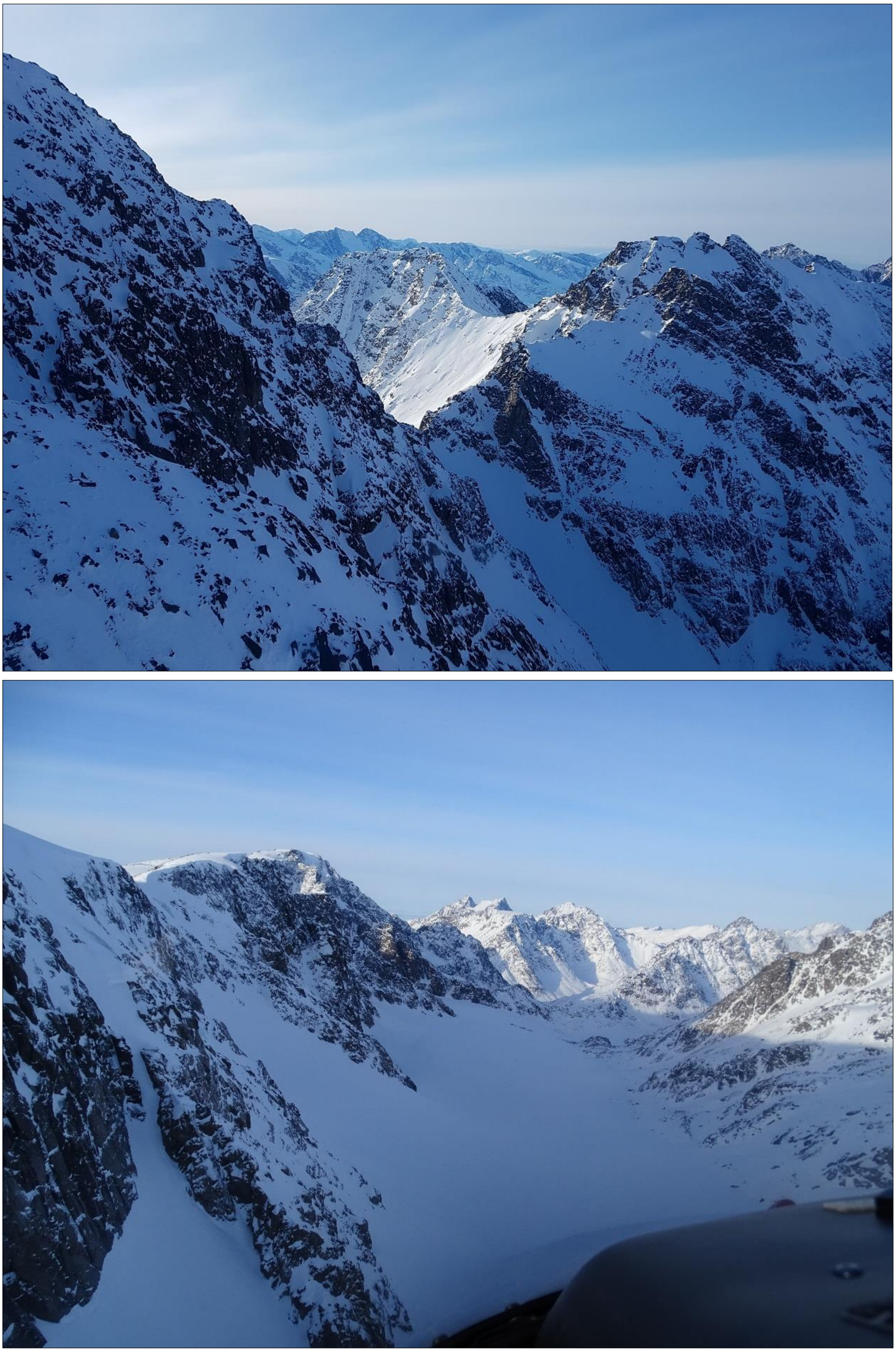

Figure 20. Portions of line transects flown across high elevations, Sisimiut South sub-area. Photos C. Cuyler.

Caribou survey conditions March 2018

Figure 21. Flat light combined with ground showing through thin layer of snow. Photos C. Cuyler.

Caribou survey conditions March 2018

Figure 22. Vegetation poking through thin snow layer in flat light (above) or with shadows (below). Photos C. Cuyler.

Caribou survey conditions March 2018

Figure 23. Thin snow layer with ground showing through (above), or rocks and vegetation (below). Photos C. Cuyler.

Figure 24. Thin snow layer with vegetation showing through combined with flat light conditions (above) and similar conditions (below) now including thick willows in the creek bed. Multiple caribou are present in this photograph, at distances > 100 m. All are well camouflaged. Photos C. Cuyler.

Caribou survey conditions March 2018

Figure 25. Dead ground to the left of a line transect. Photo C. Cuyler.

Figure 26. Fog with flat light and ground showing through thin snow layer. Photo C. Cuyler.

Caribou survey conditions March 2018

Figure 27. Thin snow layer combined with ground showing through the snow and in flat light. Photos C. Cuyler.

Caribou survey conditions March 2018

Figure 28. Variable snow cover in rugged terrain, with and without shadows/flat light. Photos C. Cuyler.

Appendix 5

Past and recent Greenland caribou population estimates & minimum counts

Table 15. *Population estimates and minimum counts of caribou in Greenland, 1977-2018, given in order from north to south latitudes[1].*

Caribou Population	Region No.	Region Name	1977 / 78	1993	1994	1995	1996	1999	2000	2001	2002	2005	2006	2010	2012	2018
Inglefield Land	10	-	-	-	-	100	-	2,260	-	-	-	-	-	-		60,469 (73,895[4])
Olrik Fjord	9	.	-	-	-	-	-	-	-	38*	-	-	-	-		
Nuussuaq Halvø	8	-	170	-	-	400	-	-	-	400	1.164*	-	-	-		
Naternaq	1	Naternaq	100	80	-	271	-	-	-	-	-	-	-	-		
Kangerlussuaq-Sisimiut	2	North	17,900	3,788	7,727	6,196	10,869	-	51,600[3]	-	-	90,464[3]	-	98,300		
Akia-Maniitsoq	3	Central	5,300	3,506	3,080	6,408	6,806	-	-	46,236	-	35,807		24,000		
Ameralik	4	South	-	1,341	1,458	4,553	4,458+	-	-	31,880	-	-	9,680	-	11,700	
Qeqertarsuatsiaat	5	South	-					-	-	5,372	-	-	5,224	-	4,800	
Qassit	6	Paamiut	-	-	-	-	-	-	196*	-	-	-	-	-		
Neria	7	Paamiut	-	-	181	407	-	-	1,600 (332*)	-	-	-	-	-		
Total Greenland Approximate Estimate			-	**9,000**	**13,000**	**18,000**	**22,000**	**-**	-	**140,000[2]**	-	-	**141,000[2a]**	-	**139,000[2b]**	

[1]Estimates between 2000 and 2010 were obtained using survey methods and design unlike those employed from 1993 to 1999. Therefore, conclusions about trends in population size are inappropriate because the population size differences between these two time periods are not assumed readily comparable. Similarly, the 2012 survey of the South region used new survey methods as compared to the 2000-2010 period.

[2] Rough sum of population estimates obtained in 1999, 2000 and 2001.

[2a] Rough sum of population estimates obtained in 2005 and 2006.

[2b] Rough sum of population estimates obtained in 2010 and 2012.

[3] 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.

[4] Model-based population estimate derived by Correia (2020).

* Minimum counts.

Sources: Ydemann & Pedersen 1999, Linnell *et al.* 2000, Landa *et al.* 2000, Cuyler *et al.* 2002, 2003, 2004, 2005, 2007, 2011 and current study.

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