

2022 and 2023 western Kitikmeot Region grizzly bear survey

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Summary

1. We surveyed grizzly bears (*Ursus arctos*) using DNA hair snagging methods within the western mainland of the Kitikmeot Region in 2022 and 2023 to obtain baseline density estimates and population abundance data for grizzly bears residing in high use caribou (*Rangifer tarandus groenlandicus*) areas for long-term population monitoring. Coupled with a 2021 survey of the far western Kitikmeot Region around Kugluktuk (western sector), our surveys enabled an overall estimate of grizzly bear abundance for most of the western mainland of the Kitikmeot Region. We used tripod hair-snagging structures clustered in subgrids instead of evenly dispersed across the landscape. We sampled an approximately 51,500 km² central sector west of Bathurst Inlet in 2022, and a 50,750 km² eastern sector around and south of Bathurst Inlet in 2023. The 2022–2023 study area roughly encompasses calving and annual range of the Bathurst caribou herd and summer ranges of the Bluenose-East and Beverley caribou herds.
2. Overall population density of grizzly bears in the central (5.5 bears/1,000 km²) and eastern (6.2 bears/1,000 km²) sectors were slightly lower but statistically similar to the estimate for the western sector (6.6 bears/1,000 km²) with overlapping confidence intervals (CI). We estimated the population of grizzly bears in 2021–2023 in the western Kitikmeot Region study areas at 542 females (CI = 443–641) and 380 males (CI = 280–480), for a total of 927 bears (CI = 785–1,069; the estimate for all bears does not add up to the total of female plus male estimates due to differences in models used for sex-specific and combined sex estimates).
3. When surveyed in July–August 2022 and 2023, grizzly bear densities varied among subgrids within each sector. Bears were more associated with shrub land cover areas than grassland/barren areas. Density differences did not appear to relate to caribou occurrence based on caribou collar data. Various factors likely influenced bear distribution including caribou in the survey area, marine resources near the coast, and presence of remains from local harvest of terrestrial and marine wildlife.
4. We installed 2 motion-triggered digital cameras in each subgrid in 2022 and 2023 (for a total of 12 camera-sites). Seven of these cameras captured images of 23 individual bears, all of which were also identified from DNA. Grizzly bears visited the tripods on average 6.5 days after tripod deployment or re-lure, spending an average of 10.6 minutes around the site.
5. The mean total known harvest of bears in the central and eastern sectors between 2008 and 2024 was about 1 bear per year (about 80% males), less than 0.2% of the current estimated populations. The average annual harvest was significantly greater in the western sector (4.2 males and 1.1 females annually, a 1.6% average harvest rate).
6. The 2022–2023 design with 3 larger subgrids within each sector (6-km spacing in an 8 x 8 pattern, compared with sub-grids with 5-km spacing in a 5 x 5 pattern used in 2021) and 3 sampling sessions in a single year proved robust and precise density and abundance estimates (relative standard errors ~11%) with reduced field work compared to previously used uniform grid sampling designs.

**AGHAT IDJUHINGINIK NAUNAITKUHIQHIMAJUT-
ANGUFFAAQHUGIT HAMANI**

**UATAANI KITIKMEOT AVIKTUNGNIANI HAMANI NUNAVUNMI,
2022–2023**

Naittuq

1. Naunaijaqtavut ghat (Marlungajut aghat) atuqhugit IDJUHINGIT mitquit pinirmun atuqtaujut uataani nunanni Kitikmeot Aviktungniani uvani 2022mi unalu 2023milu pijaangini amigainirit itqungniarutait amigainirillu naunaitkutait *aghat* najugaqaqtut tuktugarnirmi (Tuktut) najugaini hivitujumik-najugaqaqtut amigainirit munaridjutait. Aadjikutait uvani 202mi naunaijautit unghahiktuani uataani Kitikmeot Aviktungniani hamani Kugluktuk (uataani najugaani), naunaijautivut pipkaidjutaujut tamainun itqungniarutit aghat amigainirit tamavjaini uataani Kitikmeot Aviktungniani. Atuqhugit mitquinik pijautit qanituriktunun aadjikiingitumik mitquqtautit avatiini nunap. Uuktuqtavut naamavjaktut 51,500 km² qitqani uataani Qingaup uvani 2022mi, unalu 50,750 km² kivataani haniani Qingaup uvani 2023mi. Uvani 2022–2023 naunaijaiqviani haniani nuriviit ukualu ukiutigut hanguviit Qingaup tuktut ukualu aujami amigainirit Bluenose-Kivataani ukualu Beverley tuktut amihuaqjut.
2. Tamaini amigainirit aghat qitqani (5.5 aghat/1,000 km²) hamanilu kivataani (6.2 aghat/1,000 km²) najugait ikitqiat kkihimi kihiqtautikkut aadjikiivjaktut itqungniarutinun uataani najugainir (6.6 aghat/1,000 km²) qaliriiktut (CI). Itqungniaqtavut amigainirit aghat uvani 2021–2023 hamani uataani Kitikmeot Aviktungniani naunaijaijut najugaini 542 arnalut (CI = 443–641) ukualu 380 anguhaltut (CI = 280–480), atautimut 927 aghat(CI = 785–1,069).
3. Humi naunaijaqtaujut uvani Taaqhivalirviani–Niqiliqiik 2022 unalu 2023, aghat amigainirit aalakiiktut atautini najugaini. Aghat najugaqaluaqtut avaalaqiaqarnirmi nunani hamaninin iviqarnirmi/iviituni nunani. Amigainirit aalakiiktut pidjutiaqtut itut tuktugarnirmi pihimajut tuktut qunguhinirmiaqaqtut naunaitkutaini. Aalakiit pidjutiqarungnaqhijut aghat amigainirit ilaujut tuktut naunaijaqtauviini, tariumi haniini hinaini, takujauhijut anguniaqtunin ukualu tarumi huradjat.
4. Iliuraqtavut ingutaarnirmun piksaliurutinik atautini najugaini uvani 2022 unalu 2023 (atautimut 12 piksaliutit). Saivat piksaliurutit piksaliuqtut 23nik atautinik aghanik, tamaita naunaijaqtauhimajut NAUNAJAUTIKKUT IDJUHIIININ. Aghat upautihimajait piksaliurutit amigaitilaangit 6.5 ubluit kinguani iliuragaunikkut ukualuuniin piffaariangininihiakut, najugarijait amigaitilaangit 10.6 minutesmik najugaani.
5. Atautimut ilihimajaujut anguniaqtaujut aghat qitqani unalu kivataani qitqani 2008 unalu 2024 imaatun atauhiq aghaq ukiumi (imaatun 80% anguhaltut), ikitqiaq 0.2% tadjamin ituqngiarutainin amigainirit. Amigaitilaangit ukiutigut anguniarutikhat anginirhakkut amigaitqijaujut hamani uataani najugaini (4.2 anguhaltut unalu 1.1 arnalut ukiumi, a 1.6% amigaitilaangit anguniagahat).
6. Hamani 2022–2023 ihuaqhaidjutait pingahut amigaitqiat atautini najugaini (6-km inikhait 8 x 8 atuqtaujut, aadjiliurutigiblugit unghahiktilaangit imaa 5 x 5 inikhait atuqtaujut uvani 2021) ukualu pingahut uukturnirmun havaakhat atauhirmi ukiumi itquumadjutaujut amigainirit itqungniarutait (ilaujut atuqtaujut ihunaarutit ~11%)

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ikiklijuumirnirmun maniqami havaakhat aadjiliurutigiblugu kinguani atuqtaujuq atugahaq uuktuutit idjuhiinun.

**ÉCHANTILLONNAGE DE L'ADN DU GRIZZLI À L'AIDE DE LA MÉTHODE
DE MARQUAGE ET DE RECAPTURE DANS L'OUEST DE LA RÉGION
DE KITIKMEOT, AU NUNAVUT, EN 2022 et 2023**

Résumé

1. Nous avons procédé à un relevé des grizzlis (*Ursus arctos*) à l'aide de méthodes de prélèvement de poils aux fins d'analyses d'ADN dans l'ouest de la partie continentale de la région de Kitikmeot en 2022 et 2023. L'objectif était d'obtenir des estimations de base de la densité de la population de grizzlis évoluant dans des zones de grande utilisation du caribou (*Rangifer tarandus groenlandicus*) et des données sur son abondance dans le cadre d'une démarche de surveillance des populations à long terme. En les recoupant à un relevé réalisé en 2021 dans l'extrême ouest de la région de Kitikmeot, dans les environs de Kugluktuk (secteur ouest), nos relevés ont permis d'établir une estimation globale de l'abondance des grizzlis pour la majorité de l'ouest de la partie continentale de la région de Kitikmeot. Nous avons mis en place des structures de prélèvement des poils sur trépied rassemblés en cellules de quadrillage plutôt que dispersées également sur le territoire. Nous avons échantillonné un secteur central d'environ 51 500 km² à l'ouest de Bathurst Inlet en 2022, et un secteur oriental de 50 750 km² aux environs de Bathurst Inlet et au sud de cette zone, en 2023. La zone étudiée en 2022 et 2023 englobe approximativement le territoire de mise bas et l'aire de répartition annuelle de la harde de caribous de Bathurst, ainsi que les aires de répartition d'été des hardes de caribous Bluenose-Est et de Beverley.
2. La densité globale de la population des grizzlis dans les secteurs central (5,5 ours/1 000 km²) et oriental (6,2 ours/1 000 km²) était statistiquement semblable à l'estimation pour le secteur occidental (6,6 ours/1 000 km²), quoique légèrement inférieure, avec des intervalles de confiance (IC) croisés. Pour la période de 2021 à 2023, nous avons estimé la population des grizzlis dans les zones d'étude de l'ouest de la région de Kitikmeot à 542 femelles (intervalle de confiance de 443 à 641) et 380 mâles (intervalle de confiance de 280 à 480), pour un total de 927 ours (intervalle de confiance de 785 à 1 069).
3. Lors des études réalisées en juillet et août 2022 et 2023, les densités de grizzlis variaient d'une cellule de quadrillage à l'autre dans chaque secteur. Les ours étaient plus étroitement associés aux zones d'arbustaie qu'aux zones recouvertes de terre herbeuse ou de terre dénudée. Les différences de densité ne semblaient pas être influencées par la présence de caribous, selon les données recueillies à l'aide des colliers des caribous. Plusieurs facteurs semblaient avoir influencé la répartition des ours, y compris la présence de caribous, les ressources marines près de la côte et la présence de restes d'animaux sauvages terrestres et marins récoltés localement.
4. Nous avons installé 2 caméras numériques sensibles au mouvement dans chaque cellule de quadrillage en 2022 et 2023 (pour un total de 12 caméras filmant les sites). Sept de ces caméras ont capté des images de 23 ours individuels, qui ont aussi tous été identifiés à l'aide de leur ADN. Les grizzlis ont visité les trépieds en moyenne 6,5 jours après le déploiement des trépieds ou une nouvelle tentative d'appât, demeurant en moyenne 10,6 minutes autour du site.
5. La moyenne totale connue d'ours récoltés dans les secteurs central et oriental entre 2008 et 2024 s'établissait à environ 1 ours par année (environ 80 % de mâles), ce qui représente moins de 0,2 % des populations actuellement estimées. La moyenne de récolte annuelle était

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sensiblement plus élevée dans le secteur ouest (4,2 mâles et 1,1 femelle annuelle, pour un taux moyen de récolte de 1,6 %).

6. Le modèle de 2022 et 2023 comportant 3 grandes cellules de quadrillage plus grandes dans chaque secteur (espacement de 6 km dans un schéma de 8 x 8, en comparaison avec les cellules de quadrillage espacées de 5 km sur un schéma de 5 x 5 utilisées en 2021) et 3 séances d'échantillonnage au cours d'une même année a permis de réaliser des estimations robustes et précises de la densité et de l'abondance (erreur type relative d'environ 11 %) tout en réduisant le travail sur le terrain par rapport aux plans d'échantillonnage à quadrillage uniforme employés précédemment.

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Introduction

Grizzly bear (*Ursus arctos*) is listed as a species of Special Concern in Canada under the Canadian *Species at Risk Act* (SARA) and bears are regularly harvested in the western and central Arctic for subsistence, defense of life and property, and a relatively small amount of revenue through trophy hunting and the sale of hides and parts. The Inuit of the western mainland Kitikmeot Region traditionally have harvested grizzly bears for hides and food (Case and Buckland 1998). Habitat fragmentation and loss due to development and anthropogenic mortality were considered the primary threats during the SARA listing process (COSEWIC 2012). While this is true for most parts of the species' Canadian range, the range fragmentation and habitat loss issues that affect southern or western grizzly bear populations do not apply to barren-ground grizzly bear in Nunavut. Barren-ground grizzly bears occupying the central Arctic tundra roam over large areas and experience relatively little contact with humans (McLoughlin et al. 2003a, 2003b; Jessen 2017), and directional climate change has been improving habitat for bears in Nunavut (McLoughlin and Stenhouse 2021). Local knowledge, harvest records and research indicate an increase in numbers and range expansion eastward and northward (Clark 2007, Dumond et al. 2015, Jessen 2017, Awan et al. 2019, Barrueto et al. 2023, Harding et al. 2025). This is considered a true range expansion, as opposed to recolonization occurring in other parts of Canada (Harding et al. 2025) where the species is expanding into portions of their historical range (Lamb et al. 2023). However, there are limited baseline data on grizzly bear distribution and density within Nunavut, in part due to the cost and challenge of surveying bears at low densities in vast and remote areas.

Hunters from different Kitikmeot communities have reported an increase in grizzly bear-human conflicts, primarily property damage at cabins (Awan 2021). The number of cabins has increased significantly over the past 30 years, likely increasing conflicts compared to temporary tent camps. Much of the mainland Kitikmeot is part of the Slave Geological Province, a geological formation containing many rich mineral deposits (Bromley and Buckland 1995). Mineral development can lead to displacement, food conditioning and increased human-bear conflicts, and road development increases hunter access and harvest (Department of Environment 2017). Grizzly bear-human conflicts are expected to escalate in the region with the number of development projects likely to grow over time, including construction of the proposed Grays Bay Road and Port project (<https://www.nirb.ca/project/126002>). Improved access and infrastructure will also likely result in the development of more mineral reserves (Johnson et al. 2005). Some companies have conducted studies as part of wildlife baseline programs across their mine and exploration sites to estimate the number of grizzly bears that use their project area (Rescan 2012, 2014; Barrueto et al. 2023). However, there is concern that most areas lacked current information on bear density, especially to assess the cumulative effects of various human-caused mortalities. Due to limited food resources, barren-ground grizzly bears in the central Canadian Arctic have very large spatial requirements (McLoughlin et al. 2002a) and later ages of maturation than elsewhere, making them more susceptible to over-harvest and disturbance, given their overall low productivity and slow recovery potential (McLoughlin et al. 2003b, McLellan et al. 2017).

Recent barren-ground caribou (*Rangifer tarandus groenlandicus*) calving ground surveys in the Kitikmeot Region have reported high and increasing numbers of grizzly bear sightings (Poole et al. 2014, GBWBMFWG 2021, Adamczewski et al. 2022, Boulanger et al. 2024). Inuit hunters have suggested predation as a potential cause of the current caribou decline (Kugluktuk Angoniatic

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Association 2019) and an increasing grizzly bear population has been identified as a threat to caribou recovery (Kugluktuk Angoniatit Association 2019, GBWBMFWG 2021). Sighting rates for grizzly bears recorded during calving ground surveys have consistently been high on the Bluenose-East and Bathurst herds calving grounds compared to other calving grounds (Poole et al. 2014, GBWBMFWG 2021, Adamczewski et al. 2023). The decline of caribou herds throughout the central Arctic has led to management actions such as limiting caribou harvest and incentivizing wolf (*Canis lupus*) harvest (WRRB 2019, NWMB 2020, Wilson et al. 2024). Understanding of grizzly bear abundance and population dynamics and its potential impact on caribou populations is required for caribou management.

The grizzly bear population in the western Kitikmeot Region around Kugluktuk was sampled intensively in 2008–2009 using a nearly uniform grid of posts for DNA hair sampling, resulting in an estimate of ~5.0 bears/1,000 km² (95% CI = 3.5–9.1 bears/1,000 km²; Dumond et al. 2015). Re-analysis and modeling of the Dumond et al. (2015) data resulted in a revised but similar estimate of 5.6 bears/1,000 km² (95% CI = 4.5–7.0 bears/1,000 km²; Awan et al. 2023). To examine grizzly bear population trend since 2008–2009 and to provide a more precise estimate of bear abundance within the western Kitikmeot Region, in collaboration with the Kugluktuk Angoniatit Association, we sampled grizzly bear hair in 2021 using clusters of sampling stations and a different design of hair snagging structure (Awan et al. 2023). The 2021 project provided a precise and non-significantly higher population estimate for the area near Kugluktuk, as detailed in a previous Government of Nunavut report (6.6 bears/1,000 km²; 95% CI = 5.1–8.7 bears/1,000 km²; Awan et al. 2023).

Regions to the east of the 2021 study area were sampled in 2022 and 2023 to allow an overall estimate of grizzly bear abundance for most of the mainland western Kitikmeot Region, including specifically the area encompassing calving/post calving grounds of the Bluenose-East and Bathurst caribou herds. The main objectives of the 2 years of this study were to obtain baseline density estimates and population abundance data for grizzly bears residing in high use caribou areas for long-term population monitoring. Results from 2022 and 2023 are outlined in this report, along with some results from 2021 for comparison.

Study area

As an overall design for sampling grizzly bears, we arbitrarily divided the western mainland portion of the Kitikmeot Region into 3 approximately equal-sized ‘sectors’ corresponding to sampling areas in 2021, 2022 and 2023 (Figure 1). The boundaries of the study area were somewhat arbitrary except for the seacoast to the north, and extended into the Northwest Territories (NWT) border to the southwest because of the layout of the sampling grid and alignment with sampling conducted in 2008–2009 (Dumond et al. 2015). The 2022 and 2023 field work occurred in the central and eastern sectors, respectively; logistical and resource constraints required sampling to be split between years with 3 of the subgrids (1, 2, 6) sampled in 2022 and 3 subgrids (3, 4, 5) sampled in 2023 (Figure 1). Grizzly bears were typically active from the second half of April–early May (den emergence) to mid-late October (den entrance; McLoughlin et al. 2002b).

The study area is a mix of low and high Arctic landscape features from near tree line in the southwest to the coast and Bathurst Inlet in the north. The area is within the Southern Arctic ecozone and 4 ecoregions (Bathurst Hills, Queen Maud Gulf Lowland, Takijuj Lake Upland, Gary Lake Lowland (Ecological Stratification Working Group 1996). Winters in this ecozone pass in near darkness and

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snow may fall any month of the year and usually remains on the ground from September to June. The area is classified as having a low Arctic ecoclimate with a mean annual temperature between -11 and -13°C . Seasonal mean temperatures are about 4 to 6°C in summer and -27 to -28°C in winter. Much of the landscape is typified by barren plains covered in frost-patterned soils and the occasional rock outcrop (Ecological Stratification Working Group 1996). Typical vegetation includes a discontinuous cover of tundra plant communities dominated by dwarf birch (*Betula nana*), Arctic willow (*Salix arctica*), alder (*Alnus* spp.), northern Labrador tea (*Rhododendron tomentosum*), mountain avens (*Dryas integrifolia*), *Vaccinium* spp. and sedge (*Carex* spp.). Lichen-covered rock outcroppings are prominent throughout these ecoregions.

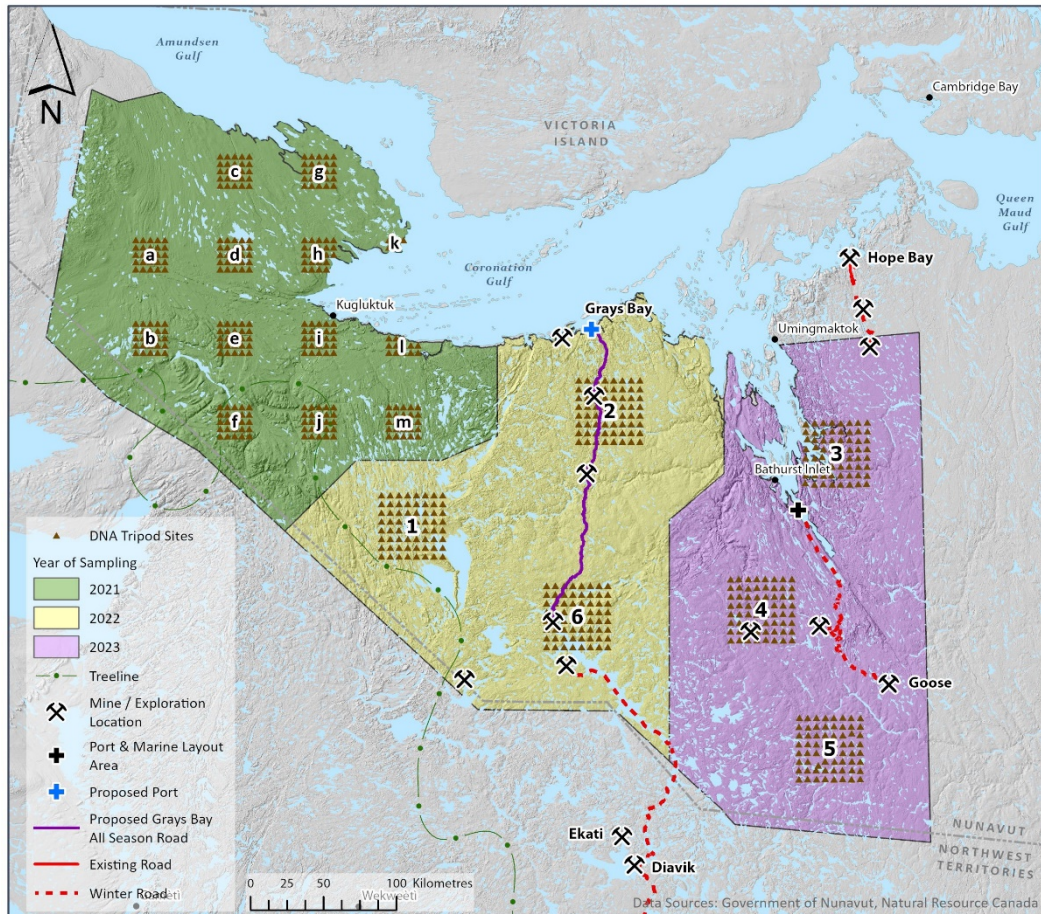


Figure 1. Division of the western portion of mainland Kitikmeot Region into sectors sampled for grizzly bears in 2021 ('western'; 54,275 km²), 2022 ('central'; 51,470 km²), and 2023 ('eastern'; 50,745 km²). Subgrid identification numbers or letters are indicated.

The 2022–2023 study area roughly encompasses calving and annual range of the Bathurst caribou herd and summer ranges of the Bluenose-East and Beverley caribou herds (Nagy et al. 2011; Adamczewski et al. 2022, 2023; Boulanger et al. 2024), and winter range of the Dolphin and Union caribou herd (Environment and Climate Change Canada 2018). Low densities of moose (*Alces alces*) and variable densities of muskoxen (*Ovibos moschatus*) live year-round in the area (Leclerc 2018, Leclerc et al. 2024). Smaller prey species included Arctic hare (*Lepus arcticus*), Arctic ground squirrels (*Spermophilus parryii*), voles and lemmings (Muridae), ptarmigan (*Lagopus* spp), and migratory bird species (Gau et al. 2002, L'Hérault et al. 2016). Carnivores in the area included wolf, Arctic fox (*Vulpes*

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lagopus), red fox (*V. vulpes*), wolverine (*Gulo gulo*), occasional reports of black bears (*U. americanus*) around the tree line and rare occurrence of polar bears (*U. maritimus*) along the coast.

Methods

Sampling designs for 2022 and 2023

Design of the 2022 and 2023 field sampling was based upon results of the 2021 field effort (Awan et al. 2023). A spatial algorithm was used to divide the study area into 6 subregions ('strata') of equal area (Walvoort et al. 2010). One sampling grid was centred in each stratum (Figure 2).

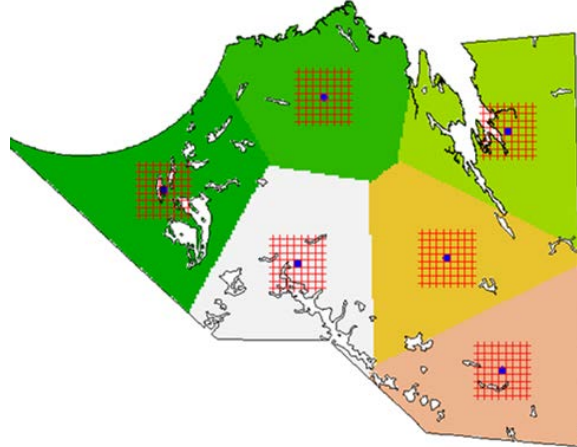


Figure 2: Placement of subgrids within equal-area strata numbered clockwise from the westernmost.

The general objective in 2022 and 2023 was to obtain estimates for the larger region with similar or reduced effort than the 2021 survey. To do this we applied an “independent” subgrid approach with each subgrid being large enough to obtain a representative sample of detections and re-detections of male and female grizzly bears. This approach contrasted with the 2021 survey which relied on re-detections of individual bears across multiple small subgrids. As detailed in Awan et al. (2023) a simulation study was used to determine optimal subgrid size under the general constraint of approximately 190 tripods employed for 3 sampling sessions. We tested subgrid sizes ranging from a grid of 5 x 5 to 10 x 10 tripods with spacing between tripods ranging from 4 to 10 km. Spatially explicit detection parameters from the 2021 study were used for the simulations. Simulation results suggested that subgrid sizes of 8 x 8 to 10 x 10 tripods with spacing of 4 to 6 km would result in the most precise estimates (Figure 3). The chosen subgrid design for 2022 and 2023 employed 1 subgrid within each stratum with 6-km spacing among tripods in an 8 x 8 pattern, and 3 strata within each sector.

There were similarities and differences in each yearly design employed (Table 1). One noteworthy difference was that fewer stations were sampled in the later years (2022 and 2023). Clustering of stations in small, dependent subgrids (2021) or larger, independent subgrids (2022 and 2023) reduced travel time while providing adequate recaptures for analysis.

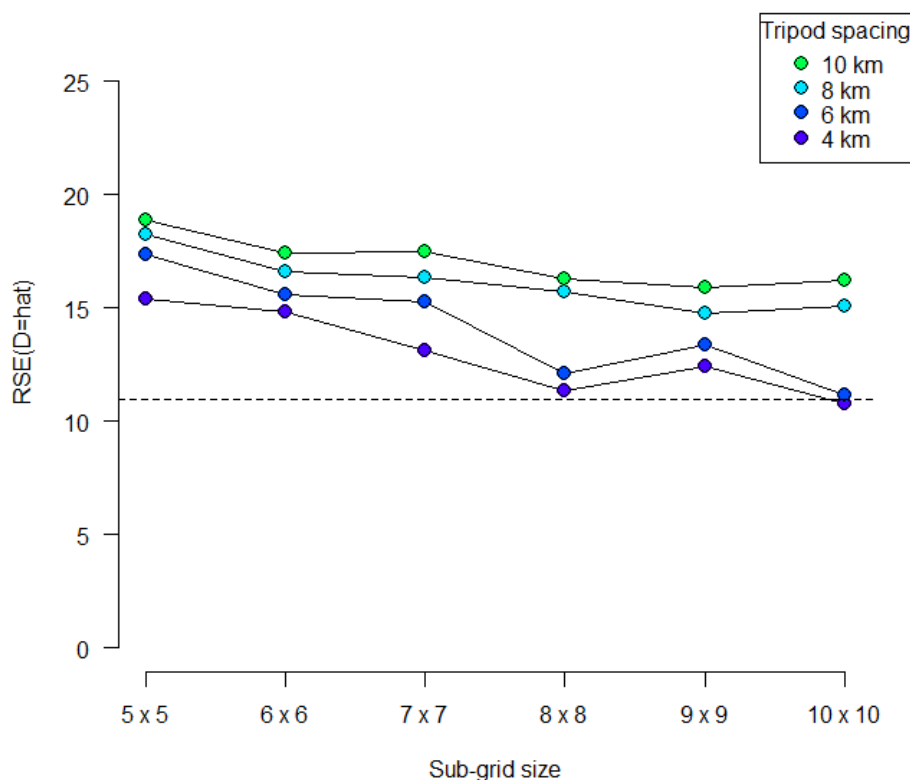


Figure 3: Simulation results to determine optimal tripod spacing and subgrid size.

Table 1. Comparison of the 2008–2009, 2021, 2022, and 2023 western Kitikmeot Region grizzly bear sampling designs.

Attribute	2008–2009	2021	2022	2023
Stations	393	291	187	192
Spacing	10 km	5 km	6 km	6 km
Coverage	Uniform	Clustered	Clustered	Clustered
Layout	1 post per grid square	13 subgrids (5 x 5)	3 subgrids (8 x 8)	3 subgrids (8 x 8)
Sampling sessions	2 x 2 years	3 x 1 year	3 x 1 year	3 x 1 year
Detector checks	1,572	873	561	576
Sampling interval	~14 days	~14 days	~14 days	~14 days
Sample retrieval	Jul–Aug	22 Jul – 27 Aug	21 Jul – 31 Aug	21 Jul – 27 Aug
Detector design	Post	Tripod	Tripod	Tripod
Lure	Commercial Long Distance Call and Beaver Castor	Commercial fish oil, Long Distance Call and Beaver Castor	Commercial fish oil, Long Distance Call and Beaver Castor	Commercial fish oil, Long Distance Call and Beaver Castor

Hair snagging method

We adapted a hair-snagging tripod design from earlier studies conducted on the Arctic tundra (Izok Lake – K. Poole, Aurora Wildlife Research, unpublished data and Boulanger 2013; Hope Bay – Rescan 2012), and updated the sampling design used by Awan et al. (2019). We produced a video to illustrate

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the methodology (<https://www.youtube.com/watch?v=uZ5FEFVrMas>). Each tripod comprised six 2" x 4" pieces of rough lumber 5' 3" (160 cm) in length and secured at the corners with 3/16th inch (0.47 cm) aircraft cable. We wrapped the 3 upright 2" x 4" legs with double-stranded 15 gauge high-tensile barbed wire (5" (13 cm) barb-spacing) to trap hairs from grizzly bears interacting with the tripod. We assembled the tripods and subsequently collected hair samples using a Bell 206B-LR helicopter for transportation (Figure 4).



Figure 4. Tripod deployment and check on the subgrids, western Kitikmeot Region, 2021.

We placed non-reward commercial trapping lures (Long Distance Call and Beaver Castor; O’Gorman Lures, Montana, USA) on a piece of felt attached to the top of the tripod and poured ~200 ml commercial fish oil (Forsyth Lures, Alix, AB) on top to attract the bears. We recorded the GPS position of each tripod. We checked the tripods approximately every 14 days. During the sampling, we collected all visible hairs with forceps from the tripod and from the surrounding ground. We cleaned the barbed wire using a propane torch to burn any remaining hair and moved the tripod about 10 m to avoid cross-contamination between sampling sessions (e.g., to avoid resampling hair on the ground). We installed a fresh set of lures after every check. We air-dried collected hairs in labelled (station number, tripod leg and date) individual paper envelopes and stored them at room temperature.

We installed 2 motion-triggered digital cameras (Reconyx PC-800 Hyperfire Professional IR, Holmen, WI) in each subgrid in 2022 and 2023 (for a total of 12 camera-sites) at selected stations facing hair snagging tripods to capture grizzly bear activity and composition and to compare with hair detections and individual identification. We mounted cameras on a 2" x 4" piece of rough lumber 160 cm in length, anchored vertically in a crack in the bedrock or between boulders. We programmed cameras for high sensitivity, 5 images per trigger, 1 second apart. We changed the batteries and SD-card as needed during station checks. The cameras documented grizzly bear visit date and time at the site, and captured images of other animals. We inspected all images manually. We defined 1 station visit as the start of the series of pictures until the bear left the area or knocked down the camera. Only 3 stations recorded >1 visit of a bear in a sampling session. These multiple visits in a sampling session were separated by 1 to 4 days. Therefore, we defined independent visits as those separated by ≥ 1 day in each session.

Genotyping

Analysis of microsatellite DNA allows individuals to be identified from hair (from remote hair snagging) and tissue (from harvested bears). Hair and tissue samples were genotyped and assigned individual identities by Wildlife Genetics International (WGI; Nelson, BC) using 8 microsatellite markers and a sex marker, and passed through 3 phases of scrutiny: first pass, cleanup and error-check. Potential genotyping errors were rigorously checked as described by Paetkau (2003, 2004).

We used sub-selection rules to optimize the number of hair samples extracted. From the hair samples, we analyzed up to 2 samples per tripod leg (X, Y, Z), plus up to 2 from the ground per session/tripod. If the maximum of 8 samples was not reached, we selected up to 2 additional samples (e.g., from the ground or tripod top). We conducted 2 rounds of DNA extraction. In the first round we used a stringent quality threshold as used in other barren-ground grizzly projects (Awan et al. 2019, 2023), limiting analysis to samples with 30 underfur or ≥ 2 guard hair roots. In the second round we revisited collection events from which no sample had yet been extracted, or from which all samples from the first round of extraction had failed the first pass of genotyping. We purified DNA from the remaining samples using QIAGEN DNeasy Blood and Tissue kits with the tissue protocol. We preferentially used 10 clipped guard hair roots, as available, or 30 whole underfur hair if needed to supplement the available guard hairs.

Estimation of density and abundance

We used spatially explicit capture–recapture (SECR) analysis, an extension of conventional capture–recapture methods, specifically to estimate the density of spatially distributed populations (Efford 2004, Borchers and Efford 2008, Royle et al. 2014). SECR avoids most of the concerns about geographic closure that featured in earlier analyses using conventional closed-population methods (Boulanger and McLellan 2001).

The data used for SECR are spatial detection histories; each history is a record of the particular sites (stations) at which each individual was detected. The detected individuals are a sample of those centred in the surrounding area – the chance of being detected declines with distance from the activity centre. By fitting a curve for the decline in detection probability with distance from the activity centre, we were able to estimate both (i) the parameters of the curve, and (ii) the density of activity centres (including animals that were not detected; Figure 5).

For SECR, the population is thought of as a distribution of animal activity centres in 2 dimensions (open circles in Figure 5A). We can ignore centres that are very far from detectors because these animals stand negligible chance of detection, and this has computational benefits. The criterion for ignoring distant animals is usually a buffer of a certain width around the detectors (represented by the perimeter line in Figure 5A). The area within this boundary becomes the area of integration for maximum likelihood or the ‘state space’ of centres in Bayesian models (e.g., Royle et al. 2014; the term ‘habitat mask’ is used in R package ‘secr’).

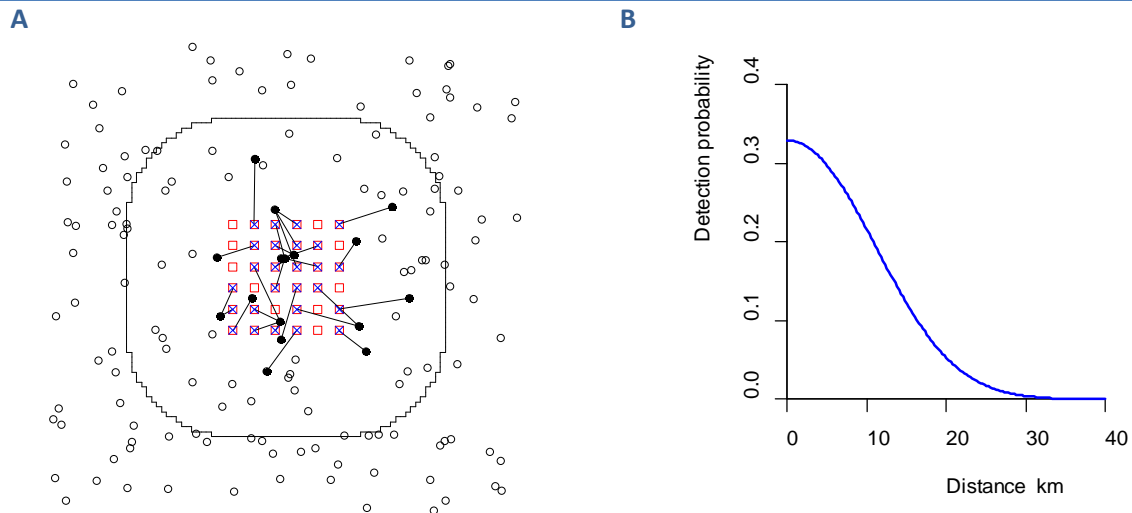


Figure 5. 5A: Spatially explicit capture–recapture conceptual model. Animal activity centres (dots) are distributed across the wider landscape. Animals centred near a station (red squares) have a high probability of detection (blue crosses; see also hypothetical distance–detection function in Figure 5B). The activity centres of animals detected at least once are shown as filled dots (a single sampling interval is shown). Animals centred beyond an arbitrary outer perimeter (solid line) have such low probability of detection that they can be ignored in model fitting.

Where habitat extends indefinitely in all directions, as appears to be the case for grizzly bears, the placement of the boundary is arbitrary. The area should merely be large enough that enlarging it further has no effect on density estimates because only un-detectable animals are added. This is achieved by using a buffer around the stations that is large compared to the radius of home ranges during the sampling period. Annual home ranges of male grizzly bears in the central Arctic averaged approximately 7,250 km² (~48 km radius circle; McLoughlin et al. 2003a), however, the buffer area corresponded to the summer season when sampling occurred. Whether the buffer is large enough can be tested once pilot values are available for σ , the spatial scale (width parameter) of the blue detection curve in Figure 5B. The habitat mask included all land within a 60-km radius of any tripod. The mask was discretized as 2-km x 2-km pixels. Lakes, as defined by the Northern Canada Geodatabase (Natural Resources Canada 2017), were excluded from the mask but were not considered to provide a barrier to movement. Lakes that were excluded from the mask (mean area = 138.0 km², SD = 275.0, min = 12.3, max = 1,193.9, $n = 46$) amounted to 3.3% of total land area in the sectors sampled in 2022 and 2023. We modelled detection hazard as a negative exponential function of distance between a bear’s activity centre and a tripod. Detection parameters were modelled as sex-dependent.

We fitted SECR models by maximum likelihood using the R package ‘secr’ 5.1.0 (Efford 2024). Various models for spatial variation in density were assessed to determine the most effective use of the multi-year dataset. Population size (abundance) for each sector was estimated by multiplying the relevant density estimate by the land area of each sector. When density was modelled as a function of land cover in each mask cell, as described below, an intermediate calculation was required to estimate the average density across each sector. Further details including the R coding are presented in Appendix 1.

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Land cover data

There is limited information on the spatial distribution of bear habitat across the Kitikmeot Region. We used the 30-m resolution 2020 land cover data published by Natural Resources Canada (2020) that is based on information from the Operational Land Imager (OLI) Landsat sensor. We smoothed the 30-m cover data by replacing the value in each pixel by the dominant (modal) cover class in a 250-m radius circular window around each point. Our description is based on the smoothed cover value at the centroid of each 2-km x 2-km cell of the habitat mask.

Eighty-one percent of the region was mapped as lichen or moss in association with grassland, shrubland or barrens, and a further 13% was water bodies not classed as 'lakes'. To define a habitat covariate for grizzly bear density we distinguished 2 lichen-moss associations (shrubland lichen-moss = 'shrub' and grassland lichen-moss = 'open'). Minor classes, including barrens, forest and wetland, were assigned to 1 of the 2 dominant associations on the basis of vegetation stature (e.g., barrens included in 'open').

Table 2. Sector areas and land cover. The 'binary' cover classification allocated non-lake 'water' to the nearest terrestrial class.

Sector	Area (km ²)	Area excl. lakes (km ²)	Percent cover excl. lakes			Percent binary cover	
			shrub	open	water	shrub	open
Western	54275	53395	41.9	46.8	11.3	46.2	53.8
Central	51470	48090	46.3	40.1	13.7	53.6	46.4
Eastern	50745	49721	55.3	32.0	12.7	63.5	36.5
Total	156490	151206	47.7	39.8	12.5	54.2	45.8

Note: Areas are for GIS polygons and differ slightly from those by summing mask pixels

Sampling of the central sector in 2022 and the eastern sector in 2023 confounded possible spatial and annual variation in bear density. Spatial covariates were associated with each pixel. These represented either geographic units or pixel-level variation. The geographic units were sectors (central 2022 vs eastern 2023; Figure 1) and strata (Figure 2). Pixel-level covariates were distance to the coast and the aggregated land cover class. Variation in the frequency of cover classes near each subgrid is shown in Table 3a. Non-lake water bodies were a minor land cover class that was nearly constant across strata; these pixels were assigned the aggregated cover class of the nearest terrestrial pixel (Table 3b, Figure 6).

Table 3: Percent land cover of 30-km zone around each subgrid in 2022 and 2023.

Cover class	S1	S2	S3	S4	S5	S6
<u>a) Three class coverage</u>						
shrub-lichen	47.5	27.7	53.5	43.5	67.5	64.7
open-lichen	33.8	57.2	32.0	45.9	21.6	23.5
water	18.7	15.1	14.4	10.7	10.8	11.8
<u>b) Two class coverage</u>						
shrub-lichen	59.2	32.0	61.2	48.9	75.7	73.5
open-lichen	40.8	68.0	38.8	51.1	24.3	26.5

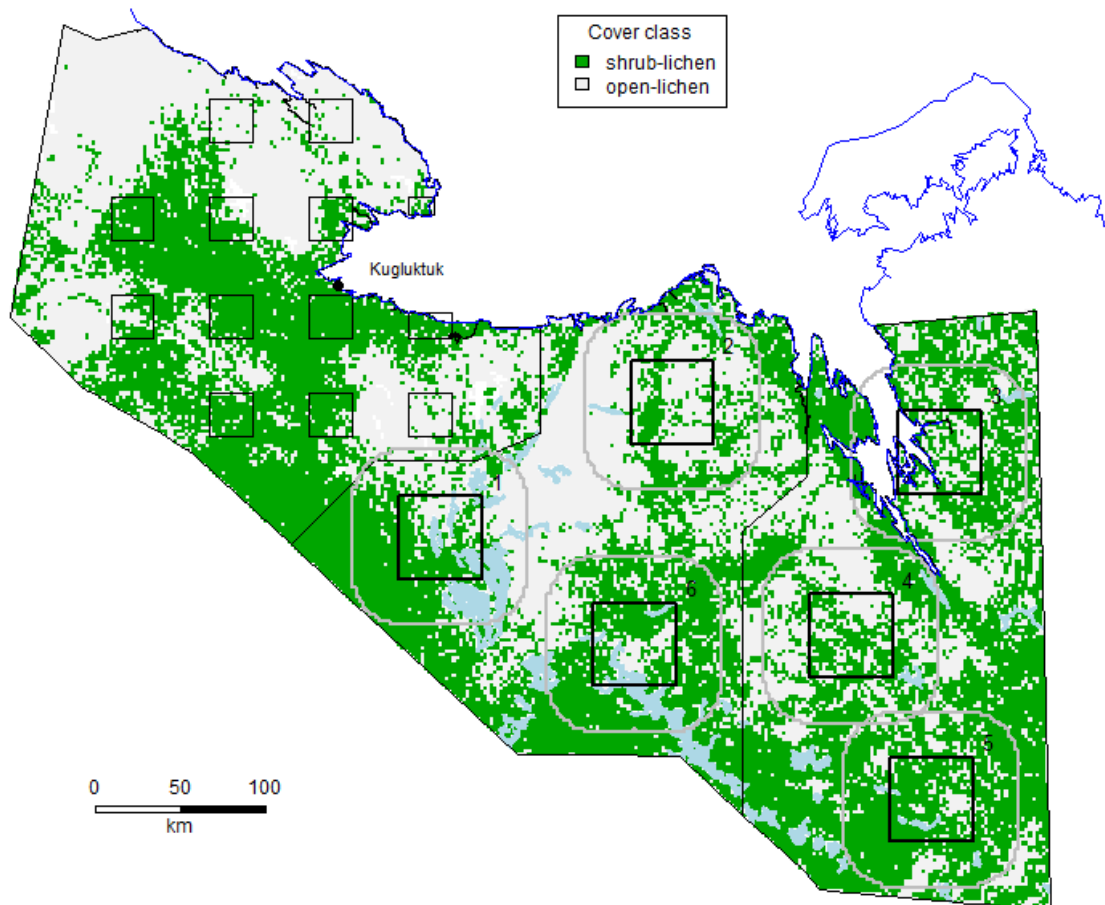


Figure 6: Binary land cover classification of the western Kitikmeot Region. Numbered bold squares are the hair-snag subgrids sampled in 2022 and 2023. Grey lines indicate 30-km buffered zone around each subgrid. Also shown: western, central and eastern sector boundaries.

Grizzly bear harvest data

Kitikmeot region hunters voluntarily provided tissue samples and reported the day and location of kill from harvested bears via their local conservation officers. Harvest by sport hunters or for the purpose of selling the hide must be reported, while subsistence harvest reporting was voluntary with likely high compliance (Awan 2021). There is also a requirement under the Nunavut *Wildlife Act* to report accidental/defense of life and property kills. Awan (2021) analyzed grizzly bear harvest data from the period 2013–2019, and some additional samples were obtained from 2020 to 2024. The harvest year was assigned as the year at the end of the regulations' harvesting season, for example, 1 July 2022–30 June 2023 was the 2023 harvest year.

Results

Detections and re-detections

We collected 905 and 983 hair samples during the 3 sampling sessions in 2022 and 2023, respectively. Summing both years, WGI excluded 9 samples (0.5%) as non-grizzly bear, 64 (3%) because of inadequate material, 179 (10%) hair samples based on our sub-selection rules (limiting the number of

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samples examined by WGI from each station), and 312 samples (30%) that failed multilocus genotyping.

Overall, 55 bears (30 females and 25 males) were detected in 2022 and 60 bears (38 females and 22 males) were detected in 2023 (Table 4). The number of new bears detected decreased from one sampling session to the next within a year for males and females in both 2022 and 2023, suggesting that sampling was effective in targeting bears within the survey areas. In addition, detection frequencies (the number of sessions an individual bear was detected) demonstrated that many bears were detected in more than one sampling session suggesting that the designs were effective in re-detecting bears.

Table 4: Summary statistics by session (1,2,3) and year (2022, 2023).

Year/statistic	Males and Females				Females				Males			
	1	2	3	Total	1	2	3	Total	1	2	3	Total
2022												
Bears detected	20	30	40	90	15	18	21	54	5	12	19	36
New bears	20	17	18	55	15	9	6	30	5	8	12	25
Detections	30	48	57	135	22	33	31	86	8	15	26	49
Detection frequency ^a	30	15	10	55	14	8	8	30	16	7	2	25
Tripods visited	29	43	49	121	21	31	28	80	8	15	23	46
Tripods employed	187	187	187	561	187	187	187	561	187	187	187	561
2023												
Bears detected	36	32	38	106	24	24	27	75	12	8	11	31
New bears	36	11	13	60	24	8	6	38	12	3	7	22
Detections	59	51	70	180	42	40	52	134	17	11	18	46
Detection frequency	27	20	13	60	13	13	12	38	14	7	1	22
Tripods visited	46	40	60	146	35	32	47	114	17	11	17	45
Tripods employed	192	192	192	576	192	192	192	576	192	192	192	576

^a Detection frequency refers to the number of sessions (columns 1, 2, and 3) that individual bears were detected. For example, in 2022, 14 females were detected in only 1 session, 8 in 2 sessions, and 8 in all 3 sessions, for a total of 30 females.

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Estimates of detection parameters for females ($\lambda_0 = 0.15$, $\sigma = 4.21$ km) and males ($\lambda_0 = 0.07$, $\sigma = 6.23$ km) indicate that females were more detectable at their home range center than males (λ_0) but moved less during sampling (σ). Detection probabilities are best illustrated in the context of sampling (Figure 7). A female whose activity centre lay at the edge of a subgrid had approximately 97% chance of detection at least once, whereas a male in the same location had 84% chance of detection. Bears with home range centers in the middle of the grid had a very high probability of detection.

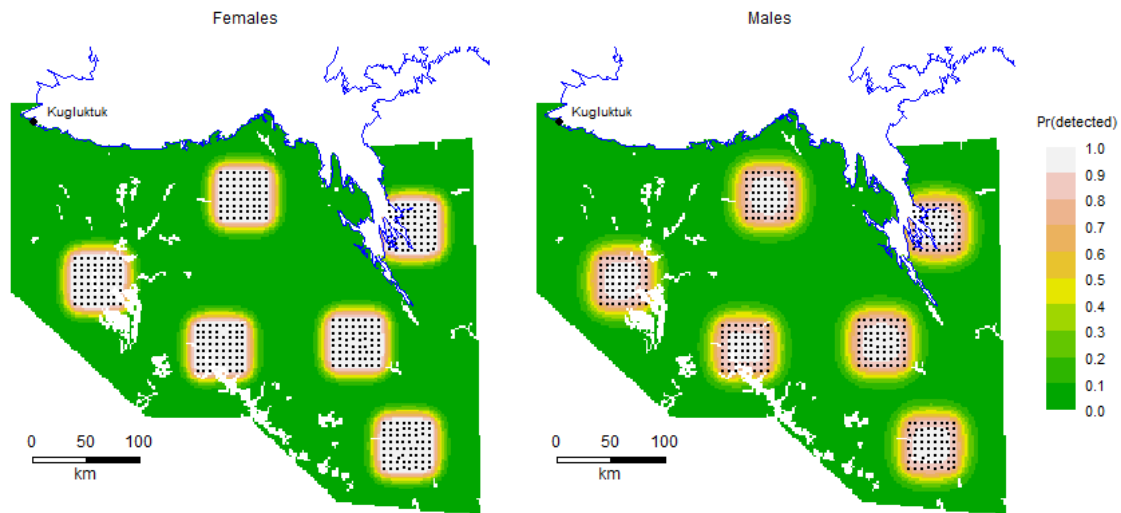


Figure 7: Probability of being detected at least once on the Kitikmeot subgrids surveyed in 2022 and 2023. The probability depends on location of the activity centre relative to each subgrid.

Summary of spatial detections

A map of individuals detected per subgrid reveals variation, especially in 2021 where subgrid 'h' detected 60 individuals which was notably higher than other subgrids (Figure 8). In contrast, the number of bears detected in each subgrid in 2022 and 2023 was relatively even except for subgrid 2 in 2022, where only 9 bears were detected. Subgrid 2 was located in an area of lower productivity (Figure 6, Table 3), primarily rocky and rugged habitat, with comparatively few observations of caribou and muskoxen during field work (M. Awan, pers. obs.).

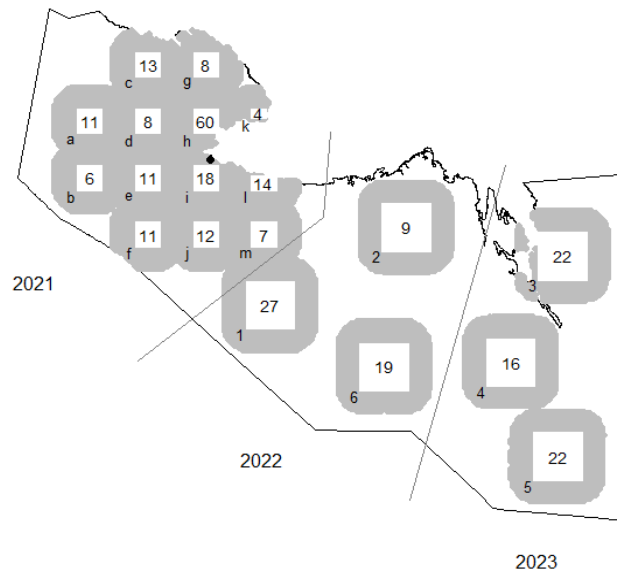


Figure 8: Individuals detected per subgrid (small subgrids 25 tripods, large subgrids 64 tripods).

The number of individual bear detections per tripod per session provides an index of density since it accounts for different numbers of tripods in each subgrid (Figure 9). Indices suggest relatively similar density in most of the subgrids sampled in 2022 and 2023, except for subgrid 2 sampled in 2022 that had markedly fewer detections per tripod (as noted above, an area of lower productivity). Most subgrids in 2021 also had similar indices of density with the exception of subgrids h and l in 2021 which had higher numbers of detections per tripod (adjacent to the coast), and subgrids b and g with lower detections (rugged areas with poor vegetation and likely very few large prey in mid- to late summer). The distribution of detections in 2021 is discussed further in Awan et al. (2023).

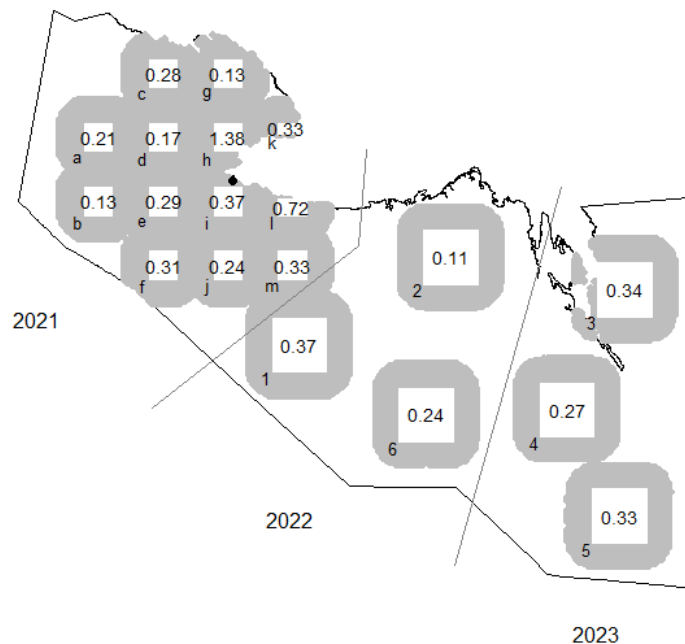


Figure 9: The number of bear detection per tripod per session for each subgrid.

Movements of bears during sampling

There were no observed movements of individual bears among subgrids in 2022 and 2023, in comparison to 2021 when subgrids were closer and movements were detected (Figure 10: subgrids roughly 35 km apart in 2021 compared to 70 km apart in 2022 and 2023). The lack of observed movement among subgrids in 2022 and 2023 was anticipated and the larger subgrids provided enough within-grid spatial re-detections of individual bears for SECR analysis.

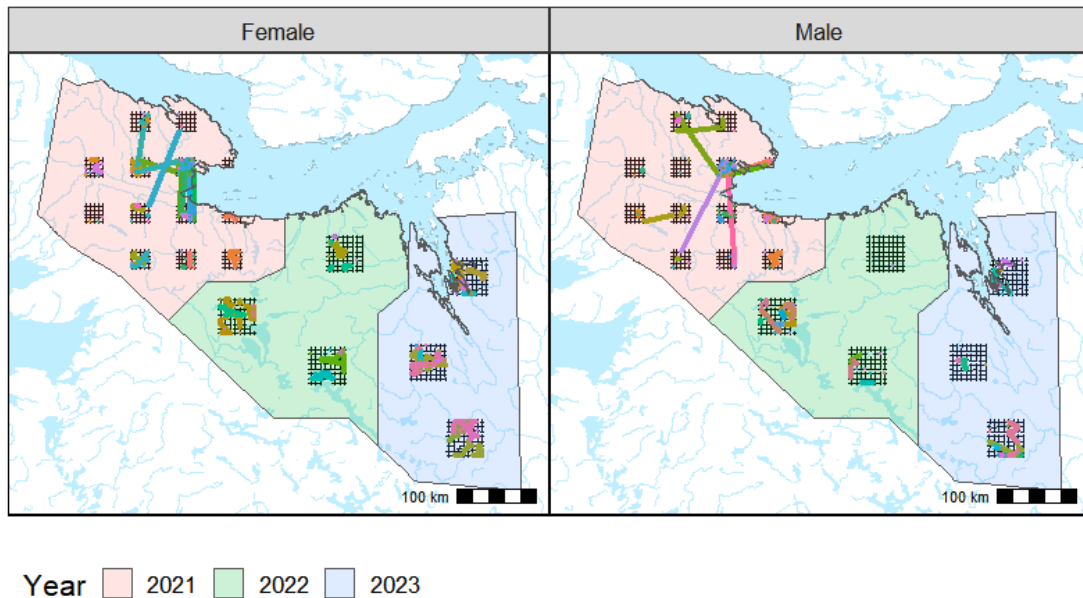


Figure 10: Movements of bears within each sampling year for 2021, 2022, and 2023.

Only male bears moved long distances between years. Three such movements were detected between 2021 and 2022–2023 and one between 2022 and 2023 (Figure 11).

- Male 2-13A2-X5 was detected on subgrid m (tripod 13A2) on 2021-08-12 and 42 km away on subgrid 1 (tripod 1H1) on 2022-08-31.
- Male 2-9B1-X2 was detected on subgrid i (tripods 9B1 2021-08-13, 9A2 2021-08-27) and the following year on subgrid 1 (1F5 2022-08-31, 1D6 2022-09-01). The between-year movement was 131 km.
- Male 1-9C2-TOP was detected on subgrid i (tripods 9C2,9C5) on 2021-07-30 and 2 years later on subgrid 5 (5A3 2023-07-21, 5A8 2023-08-05). The between-year movement was 448 km.
- Male 2-6D4-X1 was detected on subgrid 6 (tripod 6D4) on 2022-08-08 and 196 km away on subgrid 3 (tripod 3A3) on 2023-08-28.

We suspect these movements were of subadult males undergoing natal dispersal. Long-distance movements likely occurred outside of the sampling window (July–August) and therefore have negligible effect on the density estimates.

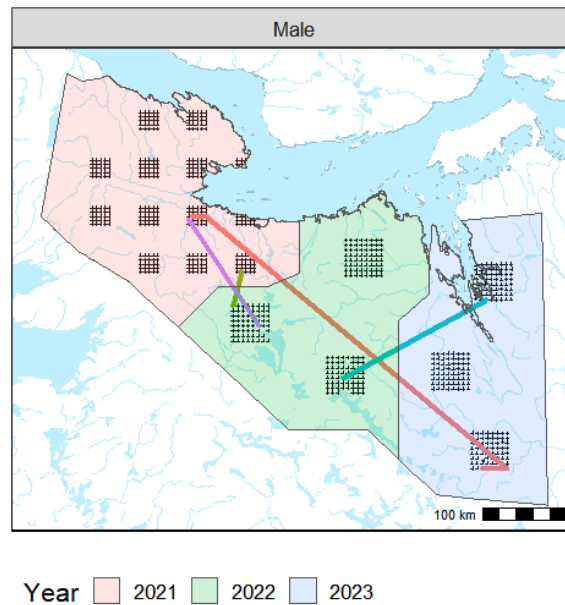


Figure 11: Movements of male bears detected in more than 1 year of sampling.

Detections of bears from previous studies

In 2022 and 2023, 3 males were detected from the 2008–2009 survey (which occurred in the area of the 2021 survey area). In addition, 1 male was detected from the Izok 2012 project that occurred in the southern border of the 2022 subgrid 6. Three males were detected from the Hacket River 2012–2013 project that occurred in the southern portion of the 2023 subgrid 4. One male was detected from the 2012 Ekati project that occurred approximately 60 km south of the 2022 subgrid. Finally, 5 bears (3M:2F) were detected from the Napaktulik Lake wolverine project conducted in 2019 (Awan et al. 2020) that occurred in the western portion of the 2022 study area (subgrid 1).

Sample sizes of bears detected and the sporadic nature of sampling prevented survival analysis using data from previous projects with the 2022–2023 data. A detailed survival analysis was conducted using the 2008–2009 and 2021 data sets (that sampled the same study area) which estimated female annual apparent survival at 0.90 (CI = 0.86–0.93) and male survival at 0.79 (CI = 0.71–0.86), as detailed in Awan et al. (2023).

Estimation of density and abundance

We analysed the 2022 and 2023 data together (Table 5), separately from the 2021 analysis reported by Awan et al. (2023). Fitting a single model to the 3 years of data would be feasible, but we did not consider it desirable because of the radical change in subgrid design and because peculiarities of the 2021 data would be hard to accommodate in a combined model. Specifically, large-scale movements to subgrid ‘h’ in 2021 (Figures 8 and 9) were unusual and not representative of movements across all the regional areas. Analysing 2022–2023 separately ensures that the unusual movements in 2021 do not affect the estimates from the 2022–2023 analysis.

Table 5: Comparison of SECR models for spatial variation in grizzly density in the central and eastern sectors sampled in 2022 and 2023, respectively. ‘AIC’ Akaike’s information criterion, ‘ Δ AIC’ difference in AIC from ‘best’ model, ‘AICwt’ AIC model weight, ‘npar’ number of parameters, ‘logLik’ maximized log likelihood.

Density Model	AIC	Δ AIC	AICwt	npar	logLik
Land cover	1977.3	0.0	0.621	7	-981.6
Stratum (subgrids)	1978.4	1.1	0.351	11	-978.2
Constant (null)	1984.8	7.5	0.015	6	-986.4
Distance to Coast	1986.1	8.8	0.008	7	-986.0
Sector	1986.7	9.4	0.006	7	-986.3

We compared models for spatial variation in grizzly bear density on the central and eastern sectors (Table 5). We interpret Table 5 as follows:

1. There was no evidence for an overall difference in density between the central (2022) and eastern (2023) sectors.
2. However, there was some evidence for spatial variation in density: a model with a distinct density in each stratum (subgrid) was better than the null (constant) model (Δ AIC = 7.5).
3. Density differences among strata (subgrids) were modelled slightly more efficiently (with fewer parameters) using the 2-level land cover covariate (Δ AIC = 1.1) compared to a stratum-specific model.

The fitted coefficients of the binary land cover model implied a density contrast between the 2 cover classes. The density estimate for the shrub-lichen habitat was 8.8 bears per 1,000 km² (95% CI 6.5–11.8) whereas that for open-lichen habitat was only 1.6 bears per 1,000 km² (95% CI 0.4–6.9). It is unclear whether these are actually habitat-specific estimates; the cover covariate may merely serve as a surrogate for a difference in density between stratum 2 (mostly open-lichen cover) and the rest (Figure 12).

The tables below provide density (Table 6) and population size (Tables 7 and 8) estimates for each of the sectors. The estimates from 2021 assume a uniform density throughout the western sector; they are slightly different than those listed in Awan et al. (2023) due to changes in analysis methodology and variance estimation. The estimates for the central and eastern sectors in 2022–2023 use the binary cover class model, weighted by the cover composition of each sector.

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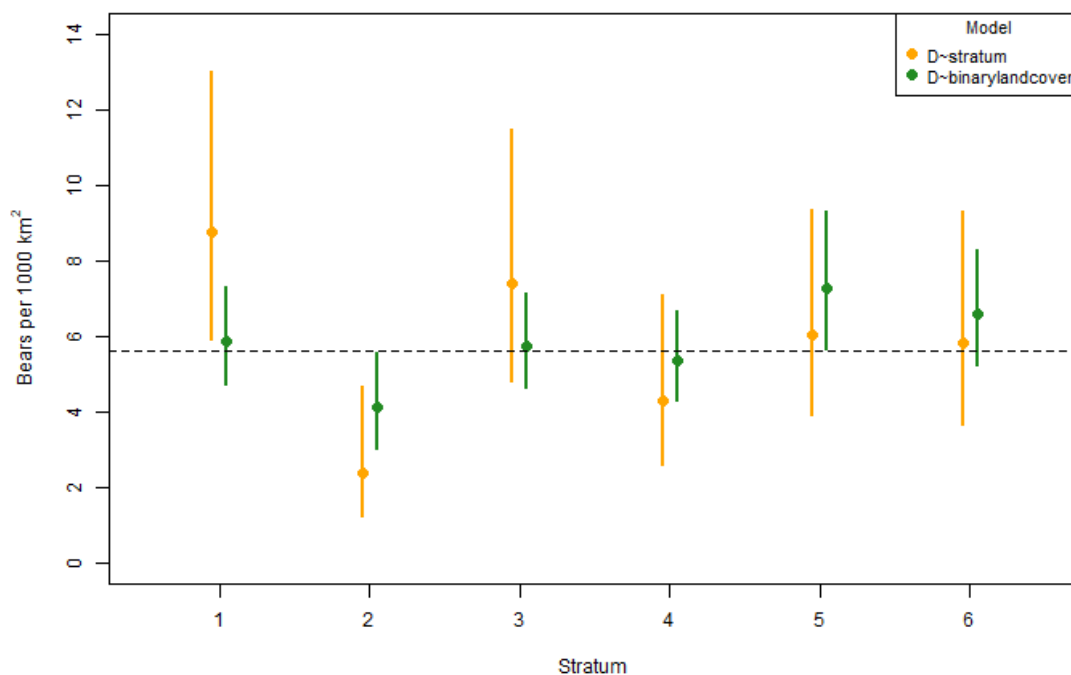


Figure 12: Estimated grizzly bear densities for each of the strata (subgrids) surveyed in 2022 and 2023 (Figure 2). Estimates are from 2 spatial models with nearly equal support: density specific to each grid ($D \sim \text{stratum}$), and density varying with binary land cover ($D \sim \text{binarylandcover}$). Bars show 95% CI. Dashed line is density estimated from constant model.

Table 6: Density estimates by sector (bears/1,000 km²). Estimates of density for 2021 are from Awan et al. (2023). RSE is the standard error of the estimate divided by the estimate.

Sector (year)	Sex	Density	SE	95% CI	RSE
Western (2021)	F	4.04	0.52	3.13–5.20	0.130
	M	2.59	0.38	1.94–3.45	0.148
	F+M	6.62	0.65	5.47–8.02	0.098
Central (2022)	F	3.14	0.40	2.44–4.03	0.129
	M	2.24	0.43	1.54–3.27	0.194
	F+M	5.45	0.61	4.38–6.77	0.112
Eastern (2023)	F	3.46	0.46	2.67–4.47	0.132
	M	2.65	0.51	1.82–3.86	0.194
	F+M	6.15	0.70	4.92–7.67	0.114
Central + Eastern (2022–2023)	F	3.30	0.43	2.57–4.24	0.129
	M	2.45	0.48	1.68–3.57	0.194
	F+M	5.80	0.65	4.67–7.21	0.111

Estimates of the number of bears in each sector (Table 7) were obtained by multiplying densities (Table 6) by the area excluding lakes (Table 2). For comparison, an estimate of the total population in the central and eastern sectors using the model assuming constant density was 552 bears (95% CI 443–687), which is close to the land cover model estimate. As discussed later, this suggests the subgrid design provided an adequate sampling of grizzly bear density with the 2022 and 2023 sectors.

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Different models were used for sex-specific and combined sex estimates and therefore male and female estimates do not exactly add up to the combined sex estimates.

Table 7: Estimates of grizzly bear population size for the central (2022) and eastern (2023) sectors. Estimates for males and females do not add up to total F+M estimates due to differences in models used for sex-specific and combined sex estimates.

Sector (year)	Sex	N	SE	95% CI
Central (2022)	F	151	19.4	117–194
	M	108	20.9	74–157
	F+M	262	29.2	211–326
Eastern (2023)	F	172	22.7	133–222
	M	132	25.6	90–192
	F+M	306	34.7	245–381
Central + Eastern (2022–2023)	F	323	41.6	251–415
	M	240	46.5	164–349
	F+M	567	63.2	456–705

Table 8: Estimates of grizzly bear population size for the western (2021) sector from Awan et al. (2023).

Sex	N	SE	95% CI
F	219	28.4	170–282
M	140	20.7	105–187
F+M	359	35.0	297–434

The combined population estimate for all sectors was over 900 grizzly bears (Table 9). Overall estimates show reasonable precision as indicated by RSE values. Density for the entire region was then estimated as the abundance estimate divided by the sum of regional areas with large lakes excluded (151,206 km²) and included (156,490 km²). The relative difference in estimates with and without lakes was 3.4%.

Table 9: Estimates of total grizzly bear population size and density (bears per 1000 km²) in all western Kitikmeot Region sectors (2021–2023). Estimates for males and females do not add up to total F+M estimates due to differences in models used for sex-specific and combined sex estimates.

Sex	Abundance				Density			
	N	SE	95% CI	RSE	D (no lakes)	95% CI	D (lakes)	95% CI
F	542	50.4	443–641	0.093	3.58	2.93-4.24	3.46	2.83-4.10
M	380	50.9	280–480	0.134	2.51	1.85-3.17	2.43	1.79-3.07
F+M	927	72.3	785–1069	0.078	6.13	5.19-7.07	5.92	5.02-6.83

Grizzly bear harvest

Grizzly bear harvest was lower in most years in the central (2022) and eastern (2023) sectors in comparison to the western (2021) sector (Figure 13 and Table 10). The mean total known harvest of bears in the central and eastern sectors between 2008 and 2024 was about 1 bear per year which

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amounted to less than 0.2% of the current estimated populations for bears in these 2 sectors. One exception was in 2022 when 5 male bears were harvested from the eastern sector which amounted to 3.8% of the male abundance estimate and 1.6% of the total abundance estimate for this population (estimated from 2023 sampling). Approximately 29% of grizzly bear harvest from 2008–2024 were taken in sport hunts, 95% of which were males (M. Awan, unpubl. data). Grizzly bear harvest is tightly linked to hunter accessibility; in late winter/early spring hunters use snowmachines to access areas further from communities, and in summer ATVs are used to access areas around communities as well as boats to extend hunting off water channels. Areas north of the eastern sector are within the Cambridge Bay community hunting area and often had higher numbers of bears harvested (e.g., on the Kent Peninsula in 2022; Figure 13). A detailed assessment of harvest for the western sector is given in Awan et al. (2023).

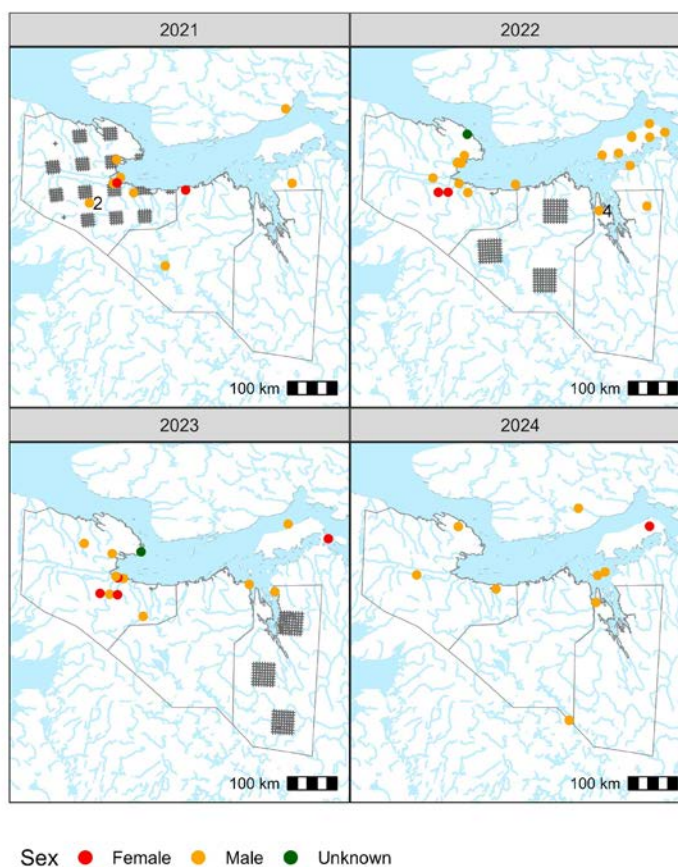


Figure 13: Locations of grizzly bears harvested by calendar year within the western Kitikmeot Region. The number of bears harvested is indicated next to the location if more than 1 bear was harvested.

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Table 10: Summary of grizzly bear harvest by sex, sector, and hunting year.

Harvest Year ¹	Western (2021)				Central (2022)			Eastern (2023)		
	F	M	Unk	total	F	M	total	F	M	total
2009	2	3	0	5	0	0	0	0	1	1
2010	0	1	0	1	0	0	0	0	0	0
2011	0	3	0	3	0	0	0	0	0	0
2012	0	1	0	1	0	1	1	0	2	2
2013	0	2	0	2	0	0	0	1	1	2
2014	1	3	0	4	0	0	0	0	0	0
2015	1	5	0	6	0	0	0	0	0	0
2016	0	4	0	4	0	0	0	0	0	0
2017	1	2	0	3	0	0	0	0	0	0
2018	0	4	1	5	0	2	2	0	1	1
2019	0	7	0	7	0	0	0	0	0	0
2020	3	5	0	8	0	0	0	0	0	0
2021	4	14	1	19	0	2	2	0	0	0
2022	2	4	1	7	1	0	1	0	5	5
2023	3	8	0	11	0	0	0	0	0	0
2024	2	5	1	8	0	0	0	0	1	1
Mean	1.2	4.4	0.3	5.9	0.1	0.3	0.4	0.1	0.7	0.8

¹ Harvest year is assigned at the end of the regulations' harvesting season, e.g., 1 July 2008–30 June 2009 = 2009 harvest year.

Distribution of caribou

Three mainland caribou (*Rangifer tarandus groenlandicus*) herds were in the vicinity of the subgrids in 2022 and 2023 (Figures 14 and 15). The relative size of each herd should be considered when viewing these figures. The Beverly herd was estimated in 2018 at over 100,000 caribou (Campbell et al. 2019), whereas the Bathurst herd was estimated in 2021 at approximately 7,000 caribou (Adamczewski et al. 2022) with the Bluenose-East herd estimated in 2023 at approximately 39,000 caribou (Boulanger et al. 2024). Given these differences, the Beverly herd is most likely to have the largest potential impact on bear distribution with the Bathurst having the least impact. Although the vast majority of Dolphin and Union caribou summer on Victoria Island, hunters have seen repeatedly that in the spring some caribou attempt to cross back to Victoria Island when the sea-ice is no longer adequate, trapping them along the coast of the mainland in the summer until they go back to their wintering range (Haniliak et al. in press). These likely represent relatively few individuals, primarily clustered close to the coast west of Bathurst Inlet.

Estimated densities for subgrids (from the strata/subgrid model in Figure 12) are shown in Figure 14 for 2022. Higher densities of bears were in the 2 southern subgrids that had Bluenose-East caribou in the vicinity with low densities in the northern subgrid. However, this subgrid also was mainly in the more barren open-lichen land cover area (Figure 6) and therefore it is not possible to relate density difference to caribou occurrence.

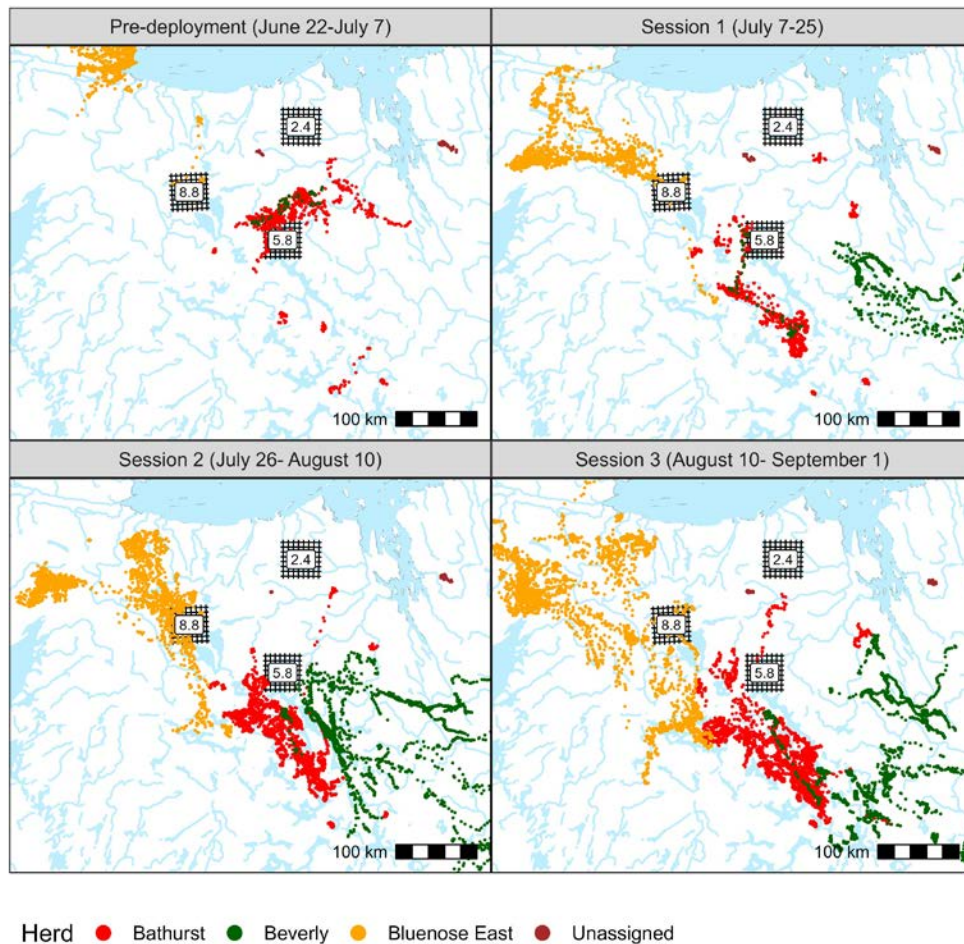


Figure 14: Locations of caribou herds relative to subgrids in the central sector in 2022. Estimated grizzly bear densities from the strata (subgrid) model are shown for each subgrid.

Beverly caribou were mainly associated with the most southern subgrid in 2023 which displayed moderate bear densities (Figure 15). However, the most northern subgrid in the eastern sector also had higher densities with no caribou in the vicinity of the subgrid. Muskox densities during a March 2022 survey were low in this area (Leclerc et al. 2024), but field staff observed numerous moose during 2023 grizzly bear hair sampling. We speculate that resources such as moose, seals (*Pusa hispida* and *Erignathus barbatus*) and Arctic char (*Salvelinus alpinus*) may influence bear densities in this area.

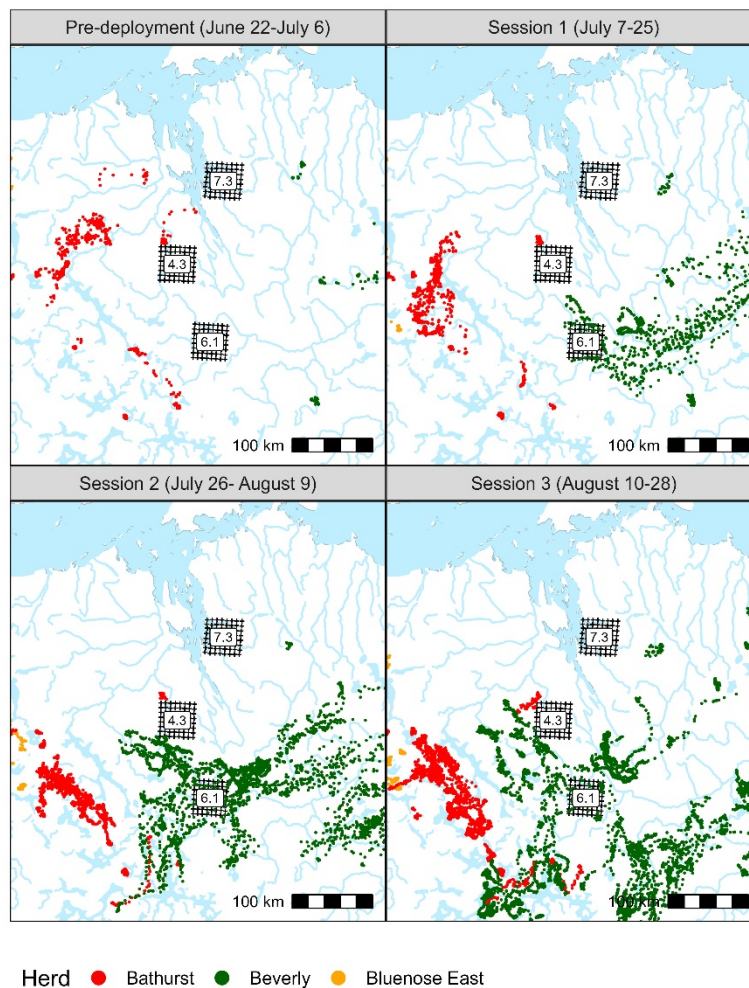


Figure 15: Locations of caribou herds relative to subgrids in the eastern sector in 2023. Estimated grizzly bear densities from the strata (subgrid) model are shown for each subgrid.

Camera data

Cameras at 7 of the 12 tripods captured images of bears during 2022–2023 sampling. We captured images of 23 individual bears: a single bear at 1 camera, 2 bears at 1 camera, 3 bears (female and 2 cubs) at each of 2 cameras, 4 bears at each of 2 cameras and 6 bears at 1 camera, all identified by DNA analysis. All bear visits detected on camera at tripods left a hair sample with viable DNA. In 2023, 2 family units (female with 2 cubs) were identified from camera images on subgrid 4 and a family unit (female with 2 cubs) was identified on subgrid 3. The camera data indicated that grizzly bear visited the tripods on average 6.5 days (SD = 3.5, $n = 19$) after tripod deployment or re-lure. Removing a single visit where a grizzly bear spent 2.9 hours at the site, bears spent on average 10.6 minutes (SD = 11.4 minutes) around the tripod.

Discussion

Overall, this study was successful in obtaining precise density and abundance estimates for grizzly bears in the 3 sectors within the western Kitikmeot Region sampled from 2021 to 2023 as well as an overall regional abundance estimate. Relative standard errors were below 0.1 for total estimates and below 0.15 for sex-specific estimates. The subgrid sampling designs employed were able to produce

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robust estimates with reduced field effort compared to previously used uniform grid sampling designs. The tripod hair-snagging detector design appeared robust with the lures or structure triggering curiosity response, with all bears captured on camera rubbing against the tripods or nearby on the ground (likely as communication behaviour; Kendall et al. 2009, Morehouse et al. 2021). All bear visits detected by cameras were also identified from viable DNA, supporting the use of remote cameras to confirm bear numbers from hair sampling. The mean number of days after deployment or re-lure that bears visited tripods was similar during 2008–2009 (Dumond et al. 2015) and 2022–2023 studies (an estimated average of 6.6 days, and 6.5 days, respectively). Camera data can provide supplemental information for DNA surveys, however, challenges with cross-referencing camera and genotype identifications limit its utility as a replacement for DNA sampling (Morin et al. 2022).

Simulation studies have examined the effect of detector (hair snagging structure) layout on the precision of density estimates for a given overall sampling effort. The best precision is achieved when the expected number of bears detected is roughly equal to the expected number of re-detections (Efford and Boulanger 2019). In 2022 there were 55 bears detected with 80 re-detections, and in 2023 there were 60 bears detected and 120 re-detections. Numbers of detections and re-detections were nearly equal for males. This suggests that the design target was nearly met in 2022 (similar numbers of bears were detected and re-detected) with a higher number of re-detections than detections in 2023. There may have been a slight benefit (more individuals, fewer re-detections) from increasing the spacing of tripods within subgrids; against this must be weighed the increased travel costs among more widely spaced tripods.

The land cover analysis for the 2022–2023 data set suggested bears were less associated with barren lichen land cover compared to the shrub-lichen land cover areas. During mid- and late summer grizzly bears generally show preference for eskers and riparian tall shrub habitat (McLoughlin et al. 2002a). Areas with shrub likely provide more productive plant forage for bears as well as more optimal prey habitat. This analysis provided further inference on factors affecting bear distribution, however, mean estimates of abundance were similar to constant density models further suggesting that the subgrid design adequately sampled land cover in regional areas. The general robustness of SECR sampling to variation in density within regions has been demonstrated for representative designs that have equal coverage across a study area (Efford 2014). Other studies using subgrid designs for black bears have also coupled analyses with land cover to produce robust estimates (Humm et al. 2017, Humm and Clark 2021).

One challenge in the analysis was combining the 2021 data sets which utilized a different sampling design than the one used for the 2022–2023 data sets. In theory, it should be possible to combine data sets with different sampling configurations under the assumption that detection parameters are independent of site layout. However, some studies have suggested that detection parameters are influenced by trap layout (Fleming et al. 2021). In the case of our study the main issue was high densities and large movements relative to subgrid h north of Kugluktuk during the 2021 study (Figures 8 and 9). These movements and densities were atypical of other subgrids in 2021 or in 2022–2023. We speculate that gut piles from hunting camps in this area may have attracted bears to this area, which was also influenced by the presence of the Bluenose-East caribou herd in this area prior to the first sampling session (Awan et al. 2023). Hunting mortality in this area is also higher (Figure 13) which may also create an attractive sink for grizzly bears. Regardless, the simplest approach to confront this issue was to analyse the 2021 data set independently. Estimates for 2021 will still be unbiased as the sampling of movements and densities was representative of the 2021 study area.

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Visual comparison of the association between caribou presence and subgrid densities did not suggest a high level of association, despite a high dependence on caribou in their diet especially in spring and fall (Gau et al. 2002, Mowat and Heard 2006). There was evidence for variation in bear density among subgrids, but higher density did not coincide with caribou presence. Subgrid 3 (2023 sampling, Figure 15) had higher bear densities with no collared caribou in the vicinity. This subgrid is relatively close to Bathurst Inlet, where Rescan (2013, 2014) reported grizzly bears hunting seals on the sea ice in spring. Caribou calves are most vulnerable to grizzly bear predation during June when calves are young (<2 weeks of age), less mobile and in high densities (Adams et al. 1995, Brockman et al. 2017). Calves during sampling would have been at least 4 weeks old and at that age can generally evade predation by grizzly bears (Adams et al. 1995, Brockman et al. 2017). It is likely that grizzly bear density variation is driven by land cover (as suggested in this analysis) but also marine resources, muskox densities, seasonally available caribou, and smaller-scale habitat and prey attributes (Gau et al. 2002, Mowat and Heard 2006).

Analysis of reported harvest for the central and eastern sectors from 2008–2023 suggests low overall harvest pressure for these areas. It is difficult to assess historical harvest pressure relative to population trend for the central and eastern sectors given that only 1 abundance estimate has occurred in these areas. However, assuming relatively similar abundance of grizzly bears, the relative harvest pressure was low compared to the western sector. Although the grizzly bear harvest in the western sector is comparatively high, the population density estimates of all sectors (western, central and eastern) are statistically similar. In the western Kitikmeot, harvest of bears depends on the human access and harvest was concentrated in the vicinity of Kugluktuk, Cambridge Bay and along the traditional travel route from the Cambridge Bay to the Bathurst Inlet area (Awan 2021). The western sector is around the community of Kugluktuk and the central/eastern sectors are far from communities, so harvest from the Cambridge Bay occurs primarily north of the central and eastern sectors (Figure 13). Despite the higher harvest, the relatively stable population in the western sector is likely due to overall higher productivity of the landscape. Grizzly bear densities in the north generally decline from west to east (e.g., Awan et al. 2019, Barrueto et al. 2023, Boulanger and D'Eon-Eggertson 2024,) and may be influenced by marine resources (Edwards et al. 2010). Source-sink dynamics may influence grizzly bear distribution at local scales within our study areas (e.g., subgrid h north of Kugluktuk in the western sector (Awan et al. 2023)), but there is no evidence that this is occurring at the broader scale.

Jessen (2017) reported 4.6 bears/1,000 km² (95% CI = 3.9–5.3 bears/1,000 km²) in 2012–2014 in the central Arctic around the diamond mines, an increase in grizzly bear density compared with the mid to late 1990s (“minimum density” of 3.5 bears/1,000 km², based on counts of collared and observed bears; McLoughlin and Messier 2001). However, densities in the northern portion of the study area around the Ekati and Diavik mines (5.8 bears/1,000 km²) were more than twice the densities in the southern portion (2.7 bears/1,000 km²; Jessen 2017). Barrueto et al. (2023) re-examined these data and estimated 5.9 bears/1,000 km² (95% CI = 5.2–6.7 bears/1,000 km²) for the combined northern and southern study areas analyzed by Jessen (2017); one likely reason for the higher estimate was the removal of “inland lakes and rivers” from the SECR mask in the Barrueto et al. (2023) analysis. In 2016 and 2017, Awan et al. (2019) sampled 4 grids (49 km × 49 km) in the Kivalliq Region of Nunavut using DNA-hair tripods and estimated a density of 3.5 bears/1,000 km² (95% CI = 2.1–6.1 bears/1,000 km²). Boulanger (2013) estimated 8.7 bears/1,000 km² (95% CI = 5.1–14.8 bears/1,000 km²) in 2012 in the Izok Lake area overlapping the NWT border and the southern portion of the central sector study area.

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Boulanger and D'Eon-Eggerston (2024) estimated 8.6 grizzly bears/1,000 km² (95% CI = 7.7–9.2 bears/1,000 km²) in the Inuvik-Tuktoyaktuk region in 2019–2020. Thus, our estimate of 6.13 bears per 1,000 km² (95% CI = 5.19–7.07 bears/1,000 km²) for all western Kitikmeot Region sectors is within the range of documented grizzly bear densities within the central Canadian Arctic. It is likely that older studies included lakes in their density calculations. If lakes are included, then the overall density estimate from our 2021–2023 study is 5.92 bears per 1,000 km² (CI = 5.02–6.83).

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Appendix 1: R Markdown

Western Kitikmeot Grizzly Bears Surveys 2022–2023

Murray Efford and John Boulanger

23 March 2025

Introduction

This R Markdown vignette describes analyses in R of grizzly bear surveys in the central and eastern sectors of Western Kitikmeot in 2022 and 2023. The results are included in the report of Awan et al. (2025) which follows the report of Awan et al. (2023) on 2021 sampling in the western sector.

Initial settings

First, load required packages.

```
# Load required packages
library(terra)
library(sp)
library(sf)
library(geobr)
library(RColorBrewer)
options(scipen = 2, digits = 6)
terraOptions(progress = 0)
dir0809 <- 'd:/bears/nunavut 2019/From John/' # hydro file
setNumThreads(18) # adjust to available cores

## [1] 18
```

List of required files

File	Contents
sectors.RDS	sector boundaries
stratamsk.RDS	original strata defined for the central and eastern sectors
KIsf.RDS	Western Kitikmeot boundary as sf object
landcover-2020-classification.tif	land cover
coverclass.txt	cover class descriptions
hydro_land_p.shp	lakes etc.
coast.RDS	coastline (generated previously from Canada coverage)
landcover5.tif	landcover subset (generated)
easternmaskall.RDS	mega mask (generated)
splitgrids21.RDS	all 2021 subgrids (generated previously, plotting only)
fits2021.RData	fitted models 2008-2009, 2021 (incl. x sex)
fits2223bygrid.RDS	fitted models
fits2223all.RDS	fitted models

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File	Contents
sexfit2223.RDS	fitted models

Set switches to control whether chunks should be processed etc.

```
renewlandcover <- FALSE
renewmask <- FALSE
pngoutput <- FALSE
usepreviousfits <- TRUE
```

Retrieve data

```
# original spcosa stratum mask defined for the central and eastern sectors
stratamask <- readRDS(file = 'stratamask.RDS')
# coordinates of Kugluktuk
Kugluktuk <- data.frame(x = 321966, y = 7532252)
# Western Kitikmeot outline (sf)
KIsf <- readRDS('KIsf.RDS')
# as terra SpatVector
KIvect <- terra::vect(KIsf)
# coastline of mainland Canada (sfc)
coast <- readRDS(file = 'coast.RDS')
# cover class names
coverclass <- read.table('coverclass.txt', h = TRUE)
```

Find land in KIsf excluding lakes

```
options(warn = -1)
hydro_land_p <- st_read(paste0(dir0809, 'hydro_land_p.shp'), quiet = TRUE)
hydro_land_p_utm <- st_transform(hydro_land_p, st_crs(KIsf))
lakes_utm <- hydro_land_p_utm[as.data.frame(hydro_land_p_utm)$FEAT_E=="lake",]
lakes <- st_as_sfc(st_intersection(lakes_utm, KIsf))
lakes <- st_union(lakes) # must union before intersection or difference!
land <- st_difference(KIsf, lakes)
options(warn = 0)

sectors <- readRDS(file = 'sectors.RDS')
sectorland <- st_difference(sectors, lakes)
sectorlandarea <- st_area(sectorland) / 1e6 # sq km
units(sectorlandarea) <- NULL
sectorlandarea

## [1] 53394.8 48090.4 49720.6
```

Define some functions

```
# convert covariate to factor and create new covariate with grouped levels
fact <- function(mask, cov, newcov, oldlevels, newlevels) {
  if (ms(mask)) {
    out <- lapply(mask, fact, cov, newcov, oldlevels, newlevels)
    class(out) <- class(mask)
    out
  }
  else {
    values <- covariates(mask)[,cov]
    values <- factor(round(values), levels = oldlevels)
    levels(values) <- newlevels
    covariates(mask)[,newcov] <- values
  }
}
```

```

    mask
  }
}
# infer nearest habitat to water
copynearest <- function (mask, cov, newcov, old = NA) {
  oldcov <- covariates(mask)[,cov] %in% old
  OK <- subset(mask, !oldcov)
  i <- nearesttrap(mask, OK)
  covariates(mask)[,newcov] <- covariates(mask)[,cov]
  covariates(mask)[,newcov][oldcov] <- covariates(OK)[i[oldcov], cov]
  covariates(mask)[,newcov] <- factor(covariates(mask)[,newcov])
  mask
}
# distance-to-coast covariate 'dtc' and
# distance-to-Kugluktuk covariate 'dtk'
addDTC <- function (mask, crs = st_crs(KIsf), coast = coast) {
  pts <- st_geometry(st_multipoint(as.matrix(mask), dim="XY"))
  st_crs(pts) <- crs
  pts <- st_cast(pts, 'POINT')
  edge <- st_geometry(obj = coast) %>% st_cast(to = 'POLYGON') %>%
    st_cast('LINESTRING') %>% st_union
  covariates(mask)$dtc <- as.numeric(st_distance(edge, y = pts))/1000
  covariates(mask)$dtk <- as.numeric(edist(mask, Kugluktuk))/1000
  mask
}

# summarise matrix
pctbycol <- function (x, digits = 3) round(sweep(x, 2, colSums(x), '/'), digits)*100

# shortened AIC table
terseAIC <- function (fits) {
  tmp <- AIC(fits)
  tmp[,1] <- sapply(strsplit(tmp[,1], ' '), '[', 1)
  tmp[,c(1,3,4,5,7,8)]
}

# summarise raster Landcover
pct <- function (freqs) {
  freqs <- merge(freqs, coverclass, by.x='value', by.y='Value',
    sort = FALSE)[,c(1,3,4)]
  freqs$pct <- round(100*freqs$count/sum(freqs$count),1)
  freqs
}

```

Land cover classification

Read land cover from downloaded tif file

```

landcover <- terra::rast('landcover-2020-classification.tif')
# how many 30-m pixels are needed to span Kitikmeot map?
apply(matrix(st_bbox(KIsf),byrow = TRUE, nrow=2),2,diff) / 30

```

Construct raster of Kitikmeot region

```

# do not cache - SpatRaster cannot be serialised
KIrast <- terra::rast(KIvect, ncols = 20223, nrows = 17198)

```

```
KIrast <- terra::rasterize(KIvect, KIrast)
KIrastlc <- terra::project(KIrast, "epsg:3979")
```

Crop landcover to Kitikmeot to make tractable

```
# do not cache - SpatRaster cannot be serialised
# initial projection EPSG 3979
landcover2 <- terra::crop(landcover, KIrastlc) # rectangular window
landcover2 <- terra::as.int(landcover2)
```

Transform

```
# 'near' ensures class remains an integer code
landcover3 <- terra::project(landcover2, KIrast, method = "near")
```

Summarise landscape: dominant landcover in surrounding 250-m radius circle

```
w <- matrix(1, 17, 17)
w[sqrt((row(w)-9)^2 + (col(w)-9)^2)>8] <- NA
landcover5 <- focal(landcover3, w = w, fun = "modal")
writeRaster(landcover5, "landcover5.tif", overwrite = TRUE)
```

Review composition; 30-m x 30-m pixels

```
landcover5 <- terra::rast("landcover5.tif")
# overall Kitikmeot
pct(freq(landcover5, zones = vect(land)))
```

##	value	count	zone	pct
## 1	1	81909	1	0.0
## 2	2	4634721	1	2.8
## 3	8	69	1	0.0
## 4	11	75334098	1	44.8
## 5	12	60460205	1	36.0
## 6	13	5642937	1	3.4
## 7	14	51430	1	0.0
## 8	16	1083874	1	0.6
## 9	17	1859	1	0.0
## 10	18	20708812	1	12.3

```
# by sector
freqs <- freq(landcover5, zones = vect(sectorland))
freqs$value <- factor(freqs$value, levels = c(1,2,8,11,12,13,14,16,17,18))
freqlist <- split(freqs, freqs$zone)
lapply(freqlist, pct)
```

##	\$`1`	value	count	zone	pct
## 1	1	76085	1	0.1	
## 2	2	3733258	1	6.3	
## 3	8	54	1	0.0	
## 4	11	20862569	1	35.2	
## 5	12	24094188	1	40.6	
## 6	13	3132101	1	5.3	
## 7	14	707	1	0.0	
## 8	16	944927	1	1.6	
## 9	17	1692	1	0.0	
## 10	18	6478704	1	10.9	
##					
##	\$`2`				

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```
##      value      count zone  pct
## 1         1       5364    2  0.0
## 2         2     900659    2  1.7
## 3         8         15    2  0.0
## 4        11 24000637    2 44.9
## 5        12 20257261    2 37.9
## 6        13   940895    2  1.8
## 7        14   22667    2  0.0
## 8        16   16235    2  0.0
## 9        17     167    2  0.0
## 10       18  7291133    2 13.6
##
## $`3`
##      value      count zone  pct
## 1         1       460    3  0.0
## 2         2       804    3  0.0
## 3        11 30470892    3 55.2
## 4        12 16108756    3 29.2
## 5        13  1569941    3  2.8
## 6        14   28056    3  0.1
## 7        16  122712    3  0.2
## 8        18  6938975    3 12.6
```

Load capthist and summarise

```
# data objects prepared previously
loaded <- load(file = 'CH.RData')
loaded

## [1] "ch0809" "ch2021" "ch2022" "ch2023" "ch2123" "ch2223"

# chall treats all 2022, 2023 sampling as simultaneous across central and eastern subgrids
chall <- append.capthist(ch2223)

# chall.sex splits into female and male sessions
chall.sex <- split(chall, f = covariates(chall)$Sex)

# tabulate counts by sampling occasion within each year
ch2223.sex <- split(ch2223, f = lapply(covariates(ch2223), '[[', 'Sex'))
sumF <- summary(ch2223.sex$F)
sumM <- summary(ch2223.sex$M)
sumFM <- summary(ch2223)
# female
do.call(cbind, lapply(sumF, '[[', 'counts'))

##           2022.1 2022.2 2022.3 2022.Total 2023.1 2023.2 2023.3
## n              15    18    21          54    24    24    27
## u              15     9     6          30    24     8     6
## f              14     8     8          30    13    13    12
## M(t+1)         15    24    30          30    24    32    38
## losses          0     0     0           0     0     0     0
## detections     22    33    31          86    42    40    52
## detectors visited 21    31    28          80    35    32    47
## detectors used   187   187   187         561   192   192   192
##           2023.Total
## n              75
## u              38
## f              38
## M(t+1)         38
```

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```
## losses          0
## detections      134
## detectors visited 114
## detectors used   576

# male
do.call(cbind, lapply(sumM, '[[' , 'counts'))

##           2022.1 2022.2 2022.3 2022.Total 2023.1 2023.2 2023.3
## n           5     12     19         36     12     8     11
## u           5     8      12         25     12     3     7
## f          16     7       2         25     14     7     1
## M(t+1)      5     13     25         25     12     15    22
## losses      0     0       0          0     0     0     0
## detections   8     15     26         49     17     11    18
## detectors visited 8     15     23         46     17     11    17
## detectors used 187   187   187         561    192    192    192
##           2023.Total
## n           31
## u           22
## f           22
## M(t+1)      22
## losses      0
## detections  46
## detectors visited 45
## detectors used 576

# total
do.call(cbind, lapply(sumFM, '[[' , 'counts'))

##           2022.1 2022.2 2022.3 2022.Total 2023.1 2023.2 2023.3
## n           20     30     40         90     36     32     38
## u           20     17     18         55     36     11     13
## f           30     15     10         55     27     20     13
## M(t+1)      20     37     55         55     36     47     60
## losses      0     0       0          0     0     0     0
## detections  30     48     57        135     59     51     70
## detectors visited 29     43     49        121     46     40     60
## detectors used 187   187   187         561    192    192    192
##           2023.Total
## n          106
## u           60
## f           60
## M(t+1)      60
## losses      0
## detections  180
## detectors visited 146
## detectors used 576
```

Summarise by grid:

```
ch2022bygrid <- split(ch2022, covariates(traps(ch2022))$Grid, bytrap = TRUE)
ch2023bygrid <- split(ch2023, covariates(traps(ch2023))$Grid, bytrap = TRUE)
ch2223bygrid <- MS.caphist(ch2022bygrid, ch2023bygrid)
summary(ch2223bygrid, terse = TRUE)

##           S1 S2 S6 S3 S4 S5
## Occasions  3  3  3  3  3  3
## Detections 69 22 44 65 51 64
```

```
## Animals      27  9 19 22 16 22
## Detectors   62 64 61 64 64 64
```

Build mega mask for entire KIsf, clipping out lakes

```
gridpts <- st_make_grid(KIsf, cellsize = 2000, what = "centers", square = TRUE)
landgridpts <- gridpts[land] # intersection
df <- as.data.frame(st_coordinates(landgridpts))
names(df) <- c('x','y')
easternmaskall <- read.mask(data = df, spacing = 2000)
```

Add covariates

- coverw is 3-level cover class covariate with 'water'
- coverf merges the 'water' class into the nearest non-water class

```
covariates(easternmaskall) <- NULL
# Land cover by 1-km square and 500-m circle
easternmaskall <- addCovariates(easternmaskall, landcover5, replace = FALSE)
names(covariates(easternmaskall)) <- 'landcover5'
# aggregate as 3 classes, with non-lake water as distinct class (coverw)
easternmaskall <- fact(easternmaskall, 'landcover5', 'coverw', oldlevels = 1:18,
  newlevels = c(rep('shrub', 11), rep('open',6), 'water'))
# aggregate as 2 classes, water assigned to nearest land (coverf)
easternmaskall <- copynearest(easternmaskall, cov = 'coverw', newcov = 'coverf',
  old = c(NA,'water'))
# stratum from 2019 spcosa split
covariates(stratamsk)$stratumf <- factor(covariates(stratamsk)$stratum)
easternmaskall <- addCovariates(easternmaskall, stratamsk,
  columns = c('stratum','stratumf'),
  strict = TRUE, replace = TRUE)
# distance to coast (dtc) and Kugluktuk (dtK)
easternmaskall <- addDTC(easternmaskall, coast = coast)
# sector
easternmaskall <- addCovariates(easternmaskall, sectors, columns = "sector", replace = TRUE)
# save
saveRDS(easternmaskall, file = 'easternmaskall.RDS')
```

Summarise land cover of Kitikmeot region

```
easternmaskall <- readRDS(file = 'easternmaskall.RDS')
# all land cover classes
freqs <- data.frame(table(covariates(easternmaskall)$landcover5))
freqs$Var1 <- as.numeric(as.character(freqs$Var1))
tmp <- merge(freqs, coverclass, by.x = 'Var1', by.y = 'Value')
tmp$Pct <- round(tmp$Freq/sum(tmp$Freq)*100,1)
print(tmp[,c(1,3,2,7)], row.names = FALSE)
```

##	Var1	Class	Freq	Pct
##	1	Temperate or subpolar needleleaf forest	20	0.1
##	2	Subpolar taiga needleleaf forest	1054	2.8
##	11	Subpolar or polar shrubland lichen moss	16947	44.8
##	12	Subpolar or polar grassland lichen moss	13527	35.8
##	13	Subpolar or polar barren lichen moss	1259	3.3
##	14	Wetland	17	0.0
##	16	Barren lands	247	0.7
##	17	Urban	1	0.0
##	18	Water	4724	12.5

```
# binary Land cover
tmp <- data.frame(table(covariates(easternmaskall)$coverf))
names(tmp)[1] <- 'coverf'
tmp$Pct <- round(tmp$Freq/sum(tmp$Freq)*100,1)
print(tmp, row.names = FALSE)

##  coverf  Freq  Pct
##  shrub 20495 54.2
##  open 17301 45.8

# binary Land cover by stratum
tmp <- table(covariates(easternmaskall)$coverf, covariates(easternmaskall)$stratum
f)
pctbycol(tmp)

##
##      1    2    3    4    5    6
##  shrub 59.5 35.1 58.1 52.3 78.8 69.4
##  open  40.5 64.9 41.9 47.7 21.2 30.6
```

Grid-specific masks

Subset for each (eastern) grid (used for plots and summary).

```
pickgrid <- function (grid, buffer = 60000) {
  subset(easternmaskall, distancetotrap(easternmaskall, grid) <= buffer)
}
easternmaskbygrid30 <- lapply(traps(ch2223bygrid), pickgrid, buffer = 30000)
class(easternmaskbygrid30) <- c('mask', 'list')
```

Check strata

```
# original division into strata
table(covariates(stratamask)$stratum)

##
##  1    2    3    4    5    6
## 4198 4198 4197 4197 4197 4197

# after manipulation & transfer to new mega mask
table(covariates(easternmaskall)$stratumf)

##
##  1    2    3    4    5    6
## 4101 4158 4093 4176 4092 4092
```

Summarise percent land cover by stratum and by grid (30-km buffer)

```
strata <- t(table(covariates(easternmaskall)$stratum, covariates(easternmaskall)$c
overw))
gridsw30 <- sapply(lapply(covariates(easternmaskbygrid30), '[[', 'coverw'),
  table, exclude = NULL)[,order(c(1,2,6,3,4,5))]
gridsf30 <- sapply(lapply(covariates(easternmaskbygrid30), '[[', 'coverf'),
  table, exclude = NULL)[,order(c(1,2,6,3,4,5))]

# strata
pctbycol(strata)

##
##      1    2    3    4    5    6
##  shrub 49.5 31.5 50.7 45.9 68.7 60.5
```

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```
## open 33.8 55.9 36.1 42.7 18.6 27.3
## water 16.7 12.6 13.2 11.4 12.7 12.1
```

```
# grid masks
pctbycol(gridsw30)
```

```
##      S1  S2  S3  S4  S5  S6
## shrub 47.5 27.7 53.5 43.5 67.5 64.7
## open  33.8 57.2 32.0 45.9 21.6 23.5
## water 18.7 15.1 14.4 10.7 10.8 11.8
```

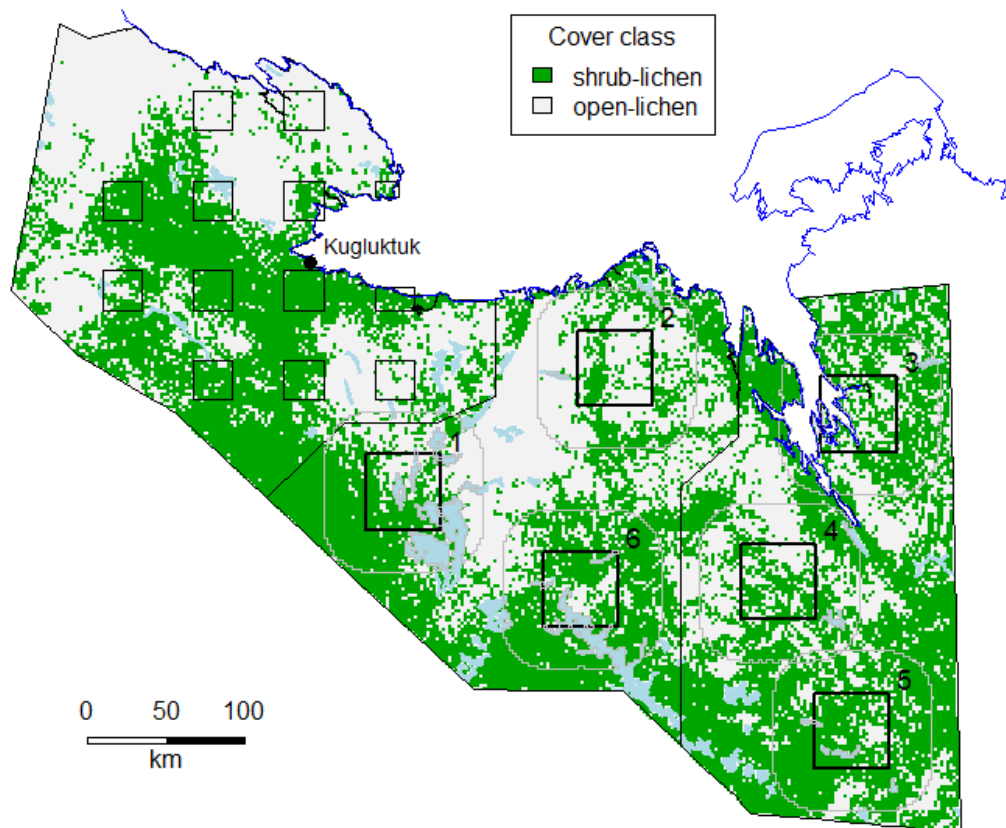
```
pctbycol(gridsf30)
```

```
##      S1 S2  S3  S4  S5  S6
## shrub 59.2 32 61.2 48.9 75.7 73.5
## open  40.8 68 38.8 51.1 24.3 26.5
```

Plot binary landcover

```
if (pngoutput) png(filename = "coverclass.png", width = 750, height = 600)
par(mfrow=c(1,1), mar=c(1,1,1,1))
plot(easternmaskall, cov = 'coverf', legend = FALSE, dots = FALSE)
legend(450000, 769000, legend = c('shrub-lichen', 'open-lichen'), title = 'Cover c
lass',
      fill = terrain.colors(2))
plot(lakes, add = TRUE, col = 'lightblue', border = 'lightblue')
plot(st_geometry(sectors), add = TRUE)
for (i in 1:6) {
  msk <- make.mask(traps(ch2223bygrid[[i]]), buffer = 3000)
  polygon(attr(msk, 'boundingbox'), col= NA, lwd=2)
  tr <- apply(msk, 2, max) + 10000
  text(tr[1], tr[2], c(1,2,6,3,4,5)[i], cex = 1.1)
  plotMaskEdge(easternmaskbygrid30[[i]], add = TRUE, col = 'grey')
}
# add 2021 grids
splitgrids21 <- readRDS('splitgrids21.RDS')
for (i in 1:length(splitgrids21)){
  msk <- make.mask(splitgrids21[[i]], buffer = 2500)
  polygon(attr(msk, 'boundingbox'), col= NA, lwd=1)
}

plot(coast, border = 'blue', add = TRUE)
points(Kugluktuk, cex = 1.3, pch = 16)
text(Kugluktuk + c(40000, 10000), 'Kugluktuk', cex=0.9)
terra::sbar(100000, xy=c(180000, 7225000), type='bar', labels=c(0,50,100), below =
'km',
      adj = c(0.5, -1.2))
```



```
if (pngoutput) dev.off()
```

Fit models

We considered two ways to fit spatial models to the eastern grid data:

1. As multiple sessions, one per grid, and grid-specific masks, and
2. As a single session with a single mask with the covariate 'stratumf' to distinguish grids (equivalent to 'grid' as a session factor).

By grid

The first way ('by grid') turns out to be slower while producing similar results. We focus on the second.

```
grids <- names(ch2223bygrid)
sessioncovariates <- data.frame(year = factor(rep(c(2022,2023), c(3,3))),
                                grid = factor(grids, levels = grids))

baseargs <- list(
  capthist = ch2223bygrid,
  mask = easternmaskall,
  detectfn = 'HEX',
  hcov = "Sex",
  trace = FALSE,
  sessioncov = sessioncovariates,
  details = list(maxdistance = 60000))
fits2223bygrid <- list.secr.fit(
  constant = baseargs,
  model = list(
```

```

    list(D~1,      lambda0~h2, sigma~h2),
    list(D~grid,   lambda0~h2, sigma~h2),
    list(D~coverf, lambda0~h2, sigma~h2)
  )
)
saveRDS(fits2223bygrid, file = 'fits2223bygrid.RDS')

```

Across central and eastern grids

This is the main analysis.

```

# executed
chall <- append.caphist(ch2223)
tmpmask <- subset(easternmaskall,
                  distancetotrap(easternmaskall, traps(chall)) < 60000 &
                  !is.na(covariates(easternmaskall)$stratum))
covariates(tmpmask)$year <- covariates(tmpmask)$stratum %in% c(3,4,5)
baseargs <- list(
  caphist = chall,
  mask = tmpmask,
  detectfn = 'HEX',
  hcov = "Sex",
  trace = FALSE)
fits2223all <- list.secr.fit(
  constant = baseargs,
  model = list(list(D~1,      lambda0~h2, sigma~h2),
               list(D~stratumf, lambda0~h2, sigma~h2),
               list(D~dtc,    lambda0~h2, sigma~h2),
               list(D~coverw,  lambda0~h2, sigma~h2),
               list(D~coverf,  lambda0~h2, sigma~h2),
               list(D~year,    lambda0~h2, sigma~h2)
             )
)
saveRDS(fits2223all, file = 'fits2223all.RDS')

# retrieve fitted models
fits2223bygrid <- readRDS(file = 'fits2223bygrid.RDS')
fits2223all <- readRDS(file = 'fits2223all.RDS')

# no evidence for between-year (central-east) difference in density
LR.test(fits2223all[[6]], fits2223all[[1]])

##
## Likelihood ratio test for two models
##
## data: fits2223all[[6]] vs fits2223all[[1]]
## X-square = 0.1102, df = 1, p-value = 0.74

# timing
sapply(fits2223bygrid, '[', 'proctime')

## fit1.elapsed fit2.elapsed fit3.elapsed
## 534.16 1235.34 796.64

sapply(fits2223all, '[', 'proctime')

## fit1.elapsed fit2.elapsed fit3.elapsed fit4.elapsed fit5.elapsed fit6.elapsed
## 342.31 1045.48 1425.57 1006.32 481.08 438.39

```

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```
# compare fits
terseAIC(fits2223bygrid)

##          model npar  logLik      AIC  dAIC  AICwt
## fit3 D~coverf    7 -978.273 1970.55 0.000 0.7865
## fit2 D~grid     11 -975.633 1973.27 2.719 0.2020
## fit1 D~1        6 -983.490 1978.98 8.435 0.0116

terseAIC(fits2223all)

##          model npar  logLik      AIC  dAIC  AICwt
## fit4 D~coverw    8 -980.579 1977.16 0.000 0.3965
## fit5 D~coverf    7 -981.635 1977.27 0.112 0.3749
## fit2 D~stratumf  11 -978.206 1978.41 1.254 0.2118
## fit1 D~1        6 -986.384 1984.77 7.611 0.0088
## fit3 D~dtc      7 -986.030 1986.06 8.902 0.0046
## fit6 D~year     7 -986.329 1986.66 9.501 0.0034
```

Although the 'coverw' model is competitive by AIC, it generates implausible estimates for cover-specific densities:

```
coef(fits2223all[[4]])

##          beta  SE.beta      lcl      ucl
## D          -9.449932 0.2123455 -9.866121 -9.033742
## D.coverwopen -15.853947      NaN      NaN      NaN
## D.coverwwater  0.516830 0.5618245 -0.584326  1.617986
## lambda0     -0.557153 0.1371628 -0.825987 -0.288318
## lambda0.h2M -1.326842 0.2719984 -1.859949 -0.793735
## sigma        8.351593 0.0642231  8.225718  8.477468
## sigma.h2M    0.399692 0.1511025  0.103536  0.695847
## pmix.h2M     -0.324566 0.2333245 -0.781873  0.132742

newdat <- expand.grid(coverw = factor(c('open', 'shrub', 'water'),
  levels = c('shrub', 'open', 'water')), h2 = factor(c('F', 'M')))
predictbycover <- predict(fits2223all[[4]], newdata = newdat)
predictbycover[1:3]

## $`coverw = open, h2 = F`
##          link  estimate SE.estimate      lcl      ucl
## D          log 1.02486e-11      NaN      NaN      NaN
## lambda0    log 5.72838e-01  0.0789430  0.437803  0.749523
## sigma      log 4.23692e+03 272.3891808 3735.802797 4805.266922
## pmix      logit 5.80437e-01  0.0568215  0.466863  0.686084
##
## $`coverw = shrub, h2 = F`
##          link  estimate SE.estimate      lcl      ucl
## D          log 7.86949e-05 1.69007e-05 5.19037e-05 1.19315e-04
## lambda0    log 5.72838e-01 7.89430e-02 4.37803e-01 7.49523e-01
## sigma      log 4.23692e+03 2.72389e+02 3.73580e+03 4.80527e+03
## pmix      logit 5.80437e-01 5.68215e-02 4.66863e-01 6.86084e-01
##
## $`coverw = water, h2 = F`
##          link  estimate SE.estimate      lcl      ucl
## D          log 1.31948e-04 5.44181e-05 6.06796e-05 2.86922e-04
## lambda0    log 5.72838e-01 7.89430e-02 4.37803e-01 7.49523e-01
## sigma      log 4.23692e+03 2.72389e+02 3.73580e+03 4.80527e+03
## pmix      logit 5.80437e-01 5.68215e-02 4.66863e-01 6.86084e-01
```

There is no harm in using only the 2-class covariate

```
terseAIC(fits2223all[-4])
```

```
##          model npar  logLik    AIC  dAIC  AICwt
## fit5   D~coverf    7 -981.635 1977.27 0.000 0.6211
## fit2  D~stratumf   11 -978.206 1978.41 1.142 0.3509
## fit1         D~1    6 -986.384 1984.77 7.499 0.0146
## fit3         D~dtc   7 -986.030 1986.06 8.790 0.0077
## fit6         D~year  7 -986.329 1986.66 9.389 0.0057
```

Compare estimates from models

```
# constant-density model
```

```
predictnull <- predict(fits2223all[[1]])
```

```
## $`session = 1, h2 = F`
```

```
##          link      estimate SE.estimate      lcl      ucl
## D          log 5.64057e-05 6.31494e-06 4.53234e-05 7.01977e-05
## lambda0    log 5.69150e-01 7.87077e-02 4.34582e-01 7.45388e-01
## sigma      log 4.28935e+03 2.77071e+02 3.77977e+03 4.86763e+03
## pmix       logit 5.76049e-01 5.74379e-02 4.61478e-01 6.82990e-01
##
```

```
## $`session = 1, h2 = M`
```

```
##          link      estimate SE.estimate      lcl      ucl
## D          log 5.64057e-05 6.31494e-06 4.53234e-05 7.01977e-05
## lambda0    log 1.54242e-01 3.70972e-02 9.69054e-02 2.45502e-01
## sigma      log 6.24948e+03 8.90429e+02 4.73340e+03 8.25115e+03
## pmix       logit 4.23951e-01 5.74379e-02 3.17010e-01 5.38522e-01
```

```
# two-cover-class model
```

```
levels(covariates(easternmaskall)$coverf)
```

```
## [1] "shrub" "open"
```

```
newdat <- expand.grid(coverf = factor(c('open','shrub'), levels = c('shrub','open')),
```

```
h2 = factor(c('F','M')))
```

```
predictbycover <- predict(fits2223all[[5]], newdata = newdat)
```

```
predictbycover
```

```
## $`coverf = open, h2 = F`
```

```
##          link      estimate SE.estimate      lcl      ucl
## D          log 1.59435e-05 1.37593e-05 3.69422e-06 6.88087e-05
## lambda0    log 5.70883e-01 7.86731e-02 4.36310e-01 7.46964e-01
## sigma      log 4.23503e+03 2.71557e+02 3.73535e+03 4.80154e+03
## pmix       logit 5.80230e-01 5.71323e-02 4.66045e-01 6.86426e-01
##
```

```
## $`coverf = shrub, h2 = F`
```

```
##          link      estimate SE.estimate      lcl      ucl
## D          log 8.77725e-05 1.33919e-05 6.51978e-05 1.18164e-04
## lambda0    log 5.70883e-01 7.86731e-02 4.36310e-01 7.46964e-01
## sigma      log 4.23503e+03 2.71557e+02 3.73535e+03 4.80154e+03
## pmix       logit 5.80230e-01 5.71323e-02 4.66045e-01 6.86426e-01
##
```

```
## $`coverf = open, h2 = M`
```

```
##          link      estimate SE.estimate      lcl      ucl
## D          log 1.59435e-05 1.37593e-05 3.69422e-06 6.88087e-05
## lambda0    log 1.51515e-01 3.61416e-02 9.55470e-02 2.40267e-01
## sigma      log 6.31424e+03 8.81855e+02 4.80856e+03 8.29139e+03
## pmix       logit 4.19770e-01 5.71323e-02 3.13574e-01 5.33955e-01
##
```

```
## $`coverf = shrub, h2 = M`
```

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```

##          link      estimate SE.estimate          lcl          ucl
## D          log 8.77725e-05 1.33919e-05 6.51978e-05 1.18164e-04
## lambda0    log 1.51515e-01 3.61416e-02 9.55470e-02 2.40267e-01
## sigma      log 6.31424e+03 8.81855e+02 4.80856e+03 8.29139e+03
## pmix       logit 4.19770e-01 5.71323e-02 3.13574e-01 5.33955e-01

# stratum
strata <- levels(covariates(easternmaskall)$stratumf)
newdat <- expand.grid(stratumf = factor(strata, levels = strata),
                      h2 = factor(c('F', 'M')))
predictbystratum <- predict(fits2223all[[2]], newdata = newdat)
predictbystratum

## $`stratumf = 1, h2 = F`
##          link      estimate SE.estimate          lcl          ucl
## D          log 8.76229e-05 1.78151e-05 5.90616e-05 1.29996e-04
## lambda0    log 5.68405e-01 7.86252e-02 4.33982e-01 7.44464e-01
## sigma      log 4.29377e+03 2.77644e+02 3.78317e+03 4.87329e+03
## pmix       logit 5.75789e-01 5.73809e-02 4.61345e-01 6.82643e-01
##
## $`stratumf = 2, h2 = F`
##          link      estimate SE.estimate          lcl          ucl
## D          log 2.40693e-05 8.40161e-06 1.23834e-05 4.67826e-05
## lambda0    log 5.68405e-01 7.86252e-02 4.33982e-01 7.44464e-01
## sigma      log 4.29377e+03 2.77644e+02 3.78317e+03 4.87329e+03
## pmix       logit 5.75789e-01 5.73809e-02 4.61345e-01 6.82643e-01
##
## $`stratumf = 3, h2 = F`
##          link      estimate SE.estimate          lcl          ucl
## D          log 7.41909e-05 1.66698e-05 4.80227e-05 1.14619e-04
## lambda0    log 5.68405e-01 7.86252e-02 4.33982e-01 7.44464e-01
## sigma      log 4.29377e+03 2.77644e+02 3.78317e+03 4.87329e+03
## pmix       logit 5.75789e-01 5.73809e-02 4.61345e-01 6.82643e-01
##
## $`stratumf = 4, h2 = F`
##          link      estimate SE.estimate          lcl          ucl
## D          log 4.28546e-05 1.12179e-05 2.58740e-05 7.09792e-05
## lambda0    log 5.68405e-01 7.86252e-02 4.33982e-01 7.44464e-01
## sigma      log 4.29377e+03 2.77644e+02 3.78317e+03 4.87329e+03
## pmix       logit 5.75789e-01 5.73809e-02 4.61345e-01 6.82643e-01
##
## $`stratumf = 5, h2 = F`
##          link      estimate SE.estimate          lcl          ucl
## D          log 6.06537e-05 1.36541e-05 3.92284e-05 9.37807e-05
## lambda0    log 5.68405e-01 7.86252e-02 4.33982e-01 7.44464e-01
## sigma      log 4.29377e+03 2.77644e+02 3.78317e+03 4.87329e+03
## pmix       logit 5.75789e-01 5.73809e-02 4.61345e-01 6.82643e-01
##
## $`stratumf = 6, h2 = F`
##          link      estimate SE.estimate          lcl          ucl
## D          log 5.84226e-05 1.41146e-05 3.66307e-05 9.31789e-05
## lambda0    log 5.68405e-01 7.86252e-02 4.33982e-01 7.44464e-01
## sigma      log 4.29377e+03 2.77644e+02 3.78317e+03 4.87329e+03
## pmix       logit 5.75789e-01 5.73809e-02 4.61345e-01 6.82643e-01
##
## $`stratumf = 1, h2 = M`
##          link      estimate SE.estimate          lcl          ucl
## D          log 8.76229e-05 1.78151e-05 5.90616e-05 1.29996e-04
## lambda0    log 1.54084e-01 3.69953e-02 9.68822e-02 2.45060e-01

```

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```
## sigma      log 6.25352e+03 8.87775e+02 4.74118e+03 8.24825e+03
## pmix      logit 4.24211e-01 5.73809e-02 3.17357e-01 5.38655e-01
##
## `$stratumf = 2, h2 = M`
##          link      estimate SE.estimate          lcl          ucl
## D          log 2.40693e-05 8.40161e-06 1.23834e-05 4.67826e-05
## lambda0    log 1.54084e-01 3.69953e-02 9.68822e-02 2.45060e-01
## sigma      log 6.25352e+03 8.87775e+02 4.74118e+03 8.24825e+03
## pmix      logit 4.24211e-01 5.73809e-02 3.17357e-01 5.38655e-01
##
## `$stratumf = 3, h2 = M`
##          link      estimate SE.estimate          lcl          ucl
## D          log 7.41909e-05 1.66698e-05 4.80227e-05 1.14619e-04
## lambda0    log 1.54084e-01 3.69953e-02 9.68822e-02 2.45060e-01
## sigma      log 6.25352e+03 8.87775e+02 4.74118e+03 8.24825e+03
## pmix      logit 4.24211e-01 5.73809e-02 3.17357e-01 5.38655e-01
##
## `$stratumf = 4, h2 = M`
##          link      estimate SE.estimate          lcl          ucl
## D          log 4.28546e-05 1.12179e-05 2.58740e-05 7.09792e-05
## lambda0    log 1.54084e-01 3.69953e-02 9.68822e-02 2.45060e-01
## sigma      log 6.25352e+03 8.87775e+02 4.74118e+03 8.24825e+03
## pmix      logit 4.24211e-01 5.73809e-02 3.17357e-01 5.38655e-01
##
## `$stratumf = 5, h2 = M`
##          link      estimate SE.estimate          lcl          ucl
## D          log 6.06537e-05 1.36541e-05 3.92284e-05 9.37807e-05
## lambda0    log 1.54084e-01 3.69953e-02 9.68822e-02 2.45060e-01
## sigma      log 6.25352e+03 8.87775e+02 4.74118e+03 8.24825e+03
## pmix      logit 4.24211e-01 5.73809e-02 3.17357e-01 5.38655e-01
##
## `$stratumf = 6, h2 = M`
##          link      estimate SE.estimate          lcl          ucl
## D          log 5.84226e-05 1.41146e-05 3.66307e-05 9.31789e-05
## lambda0    log 1.54084e-01 3.69953e-02 9.68822e-02 2.45060e-01
## sigma      log 6.25352e+03 8.87775e+02 4.74118e+03 8.24825e+03
## pmix      logit 4.24211e-01 5.73809e-02 3.17357e-01 5.38655e-01
```

The two competitive models (2,5) cannot be compared directly because one estimates a grid-specific density and the other estimates density for each cover class. We base a comparison on the predicted number for each stratum (subregion). A stratum-wide density is predicted from the cover-class model by summing pixel-level estimates (i.e. allowing for the composition of the stratum with respect to cover class).

```
# create stratum-specific masks
# drop western areas that are outside any stratum
eastern <- subset(easternmaskall, !is.na(covariates(easternmaskall)$stratumf))
# one mask per stratum
strata <- split(eastern, covariates(eastern)$stratumf, drop = TRUE)

# predict stratum-specific N
en <- mapply(region.N, region = strata, MoreArgs = list(object = fits2223all[[5]]),
,
            SIMPLIFY = FALSE)
EN <- matrix(unlist(sapply(en, function(x) x[1,1:4])), nrow = 6, byrow = TRUE,
            dimnames = list(1:6, c('estimate', 'SE.estimate', 'lcl', 'ucl')))
```

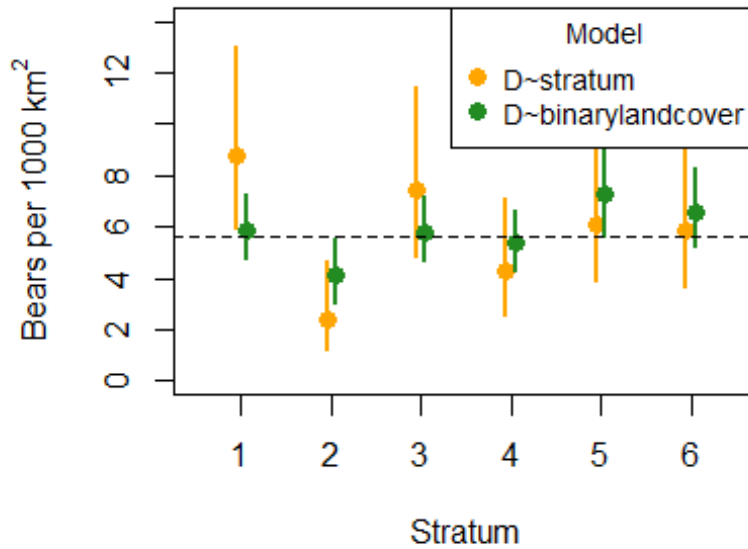
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```
# predict stratum-specific average density from overall model
area <- sapply(strata, maskarea) / 1e5 # 1000 km^2
Dcoverf <- data.frame(sweep(EN, 1, area, '/'))

Dgrid <- sapply(predictbystratum[1:6], '[', 1, -1)
Dgrid <- matrix(unlist(Dgrid) * 1e5, nrow=6, byrow = TRUE,
               dimnames = list(1:6, c('estimate', 'SE.estimate', 'lcl', 'ucl')))
Dgrid <- data.frame(Dgrid)
# display estimates by grid (= stratum)
Dgrid

## estimate SE.estimate lcl ucl
## 1 8.76229 1.781505 5.90616 12.99961
## 2 2.40693 0.840161 1.23834 4.67826
## 3 7.41909 1.666979 4.80227 11.46187
## 4 4.28546 1.121785 2.58740 7.09792
## 5 6.06537 1.365415 3.92284 9.37807
## 6 5.84226 1.411459 3.66307 9.31789

if (pngoutput) png(filename = "easternstratumdensities.png", width = 750, height =
500)
par(mfrow=c(1,1), mar=c(5,5,5,5))
plot(0,0, type='n', xlim=c(0.5,6.5), ylim=c(0,14), xlab = 'Stratum',
     ylab = expression(paste("Bears per 1000 ", km^2)))
x <- (1:6)-0.05
cols <- c('orange', 'forestgreen')
points(x, Dgrid$estimate, pch=16, cex=1.3, col=cols[1])
segments(x, Dgrid$lcl, x, Dgrid$ucl, col = cols[1], lwd=2)
x <- (1:6)+0.05
points(x, Dcoverf$estimate, pch=16, cex=1.3, col=cols[2])
segments(x, Dcoverf$lcl, x, Dcoverf$ucl, col = cols[2], lwd=2)
abline(h = predictnull[[1]][1,2]*1e5, lty = 2)
legend('topright', legend = c('D~stratum', 'D~binarylandcover'), pch = 16, cex = 0
.9, pt.cex = 1.3,
     col = cols, title = 'Model')
```



```
if (pngoutput) dev.off()
```

The dashed line is the density predicted by the constant-density model.

Population density and size by sector

Sector areas

```
# compare area mask vs sector polygons (sq km)
sectorarea <- table(covariates(easternmaskall)$sector) * 4
data.frame(GISarea = sectorlandarea, maskarea = as.numeric(sectorarea))

##   GISarea maskarea
## 1 53394.8   53448
## 2 48090.4   48088
## 3 49720.6   49648
```

These are very similar but differ from those in caption of Fig. 5 of the interim report (54200, 51500 and 50800 km²). This can be explained by the exclusion of lakes for consistency with the bear model.

Landcover summary by sector

```
easternmaskall <- readRDS(file = 'easternmaskall.RDS')
# summary mask areas by sector and 2-class (coverf) or 30class (coverw) Landcover
pctbycol(table(covariates(easternmaskall)$landcover5, covariates(easternmaskall)$sector))

##
##      0      1      2
## 1  0.1  0.0  0.0
## 2  6.4  1.6  0.0
## 11 35.3 44.6 55.3
## 12 40.1 38.2 28.9
## 13  5.2  1.8  2.9
```

```
## 14 0.0 0.1 0.1
## 16 1.6 0.0 0.2
## 17 0.0 0.0 0.0
## 18 11.3 13.7 12.7

# overall
pctbycol(cbind(table(covariates(easternmaskall)$landcover5)))

##      [,1]
## 1  0.1
## 2  2.8
## 11 44.8
## 12 35.8
## 13  3.3
## 14  0.0
## 16  0.7
## 17  0.0
## 18 12.5

# 3-class
pctbycol(table(covariates(easternmaskall)$coverw, covariates(easternmaskall)$sector))

##
##           0      1      2
##  shrub 41.9 46.3 55.3
##  open  46.8 40.1 32.0
##  water 11.3 13.7 12.7

# overall
pctbycol(cbind(table(covariates(easternmaskall)$coverw)))

##      [,1]
## shrub 47.7
## open  39.8
## water 12.5

# 2-class
pctbycol(table(covariates(easternmaskall)$coverf, covariates(easternmaskall)$sector))

##
##           0      1      2
##  shrub 46.2 53.6 63.5
##  open  53.8 46.4 36.5

# overall
pctbycol(cbind(table(covariates(easternmaskall)$coverf)))

##      [,1]
## shrub 54.2
## open  45.8
```

Sector population N from 2022-2023 constant model

```
# areas from sectorLand
Nhat <- sapply(c(48090.4, 49720.6, 48090.4+49720.6), function(A)
  predictnull[[1]][1,c(2,4,5)] * A * 100)
colnames(Nhat) <- c('central', 'eastern', 'total')
t(Nhat)
```

2022 and 2023 western Kitikmeot Region grizzly bear survey

```
##      estimate lcl      ucl
## central 271.257 217.962 337.584
## eastern 280.453 225.351 349.027
## total   551.71  443.313 686.611
```

Sector population N from 2022-2023 landcover model

```
# predict sector-specific N
# with extrapolation of 2022-2023 model to sector 0 (western)
sectormasks <- split(easternmaskall, covariates(easternmaskall)$sector, drop = TRUE)
cemask <- subset(easternmaskall, covariates(easternmaskall)$sector %in% c('1','2'))
sectormasks <- c(sectormasks[2:3], list(cemask))
en <- mapply(region.N, region = sectormasks, MoreArgs = list(object = fits2223all[[5]]),
             SIMPLIFY = FALSE)
EN <- matrix(unlist(sapply(en, function(x) x[1,1:4])), nrow = 3, byrow = TRUE,
            dimnames = list(c('central','eastern','total'),
                           c('estimate', 'SE.estimate', 'lcl', 'ucl')))
EN
##      estimate SE.estimate      lcl      ucl
## central  261.902    29.2309 210.586 325.722
## eastern  305.533    34.7045 244.727 381.446
## total    567.434    63.1843 456.484 705.352

# overall F+M density by sector
sweep(EN, MARGIN=1, STATS = sectorarea, FUN = "/" ) * 1000

##      estimate SE.estimate      lcl      ucl
## central  4.90012    0.546903 3.94002  6.09418
## eastern  6.35361    0.721688 5.08915  7.93225
## total   11.42915    1.272646 9.19440 14.20705
```

Note the sector 0 N-hat is based on the out-of-area (central and eastern) model.

Eastern grid density

Review the grid-specific estimates. Code here was used with earlier model fits (interim.R).

```
AIC(fits2223bygrid[1:3])

##      model      detectfn npar  logLik
## fit3 D~coverf lambda0~h2 sigma~h2 pmix~h2 hazard exponential    7 -978.273
## fit2  D~grid lambda0~h2 sigma~h2 pmix~h2 hazard exponential   11 -975.633
## fit1   D~1 lambda0~h2 sigma~h2 pmix~h2 hazard exponential    6 -983.490
##      AIC      AICc  dAIC  AICwt
## fit3 1970.55 1971.59 0.000 0.7865
## fit2 1973.27 1975.83 2.719 0.2020
## fit1 1978.98 1979.76 8.435 0.0116

t(sapply(derived(fits2223bygrid[[2]]), '[','D',))

##      estimate      SE.estimate      lcl      ucl      CVn      CVa
## S1 0.0000869567 0.0000179586 0.0000582563 0.000129797 0.192616 0.0745043
## S2 0.00002373 0.00000797168 0.0000125015 0.0000450438 0.333447 0.0407911
## S6 0.000058194 0.0000139362 0.0000366327 0.0000924459 0.229616 0.0680179
## S3 0.0000727836 0.0000160997 0.0000474233 0.000111706 0.213362 0.0583626
## S4 0.0000425403 0.0000107948 0.0000260715 0.0000694122 0.250125 0.0427641
```

2022 and 2023 western Kitikmeot Region grizzly bear survey

```
## S5 0.00006082 0.0000135616 0.0000394951 0.0000936589 0.21337 0.0647548
## CVD
## S1 0.206523
## S2 0.335932
## S6 0.239479
## S3 0.2212
## S4 0.253754
## S5 0.222979
```

Sex-specific estimates

Sex-specific eastern estimates 2022-2023

```
baseargs <- list(mask = easternmaskall, detectfn = 'HEX',
                 model = list(D~coverf), trace = FALSE)
sexfit <- list.secr.fit(capthist = chall.sex, constant = baseargs, names = c('F', 'M'))
saveRDS(sexfit2223, file='sexfit2223.RDS')

sexfit2223 <- readRDS('sexfit2223.RDS')
# infer N for each sex/sector
# convert to density
sumone <- function(fit, bysector = TRUE) {
  # drop western sector; sectors are named 0, 1, 2
  if (bysector)
    mask <- split(easternmaskall, covariates(easternmaskall)$sector)[2:3]
  else
    mask <- list(subset(easternmaskall, covariates(easternmaskall)$sector %in%
c('1', '2'))))
  en <- mapply(region.N, region = mask, MoreArgs = list(object = fit),
               SIMPLIFY = FALSE)
  nsectors <- length(mask)
  EN <- matrix(unlist(sapply(en, function(x) x[1,1:4])), nrow = nsectors, byrow
= TRUE,
               dimnames = list(1:nsectors, c('estimate', 'SE.estimate', 'lcl', '
ucl'))))
  if (bysector) row.names(EN) <- c('central', 'eastern')
  if (bysector)
    D <- 1000* sweep(as.data.frame(EN), 1, sectorlandarea[2:3], '/')
  else {
    D <- 1000* data.frame(EN/sum(sectorlandarea[2:3]))
  }
  D$RSE <- D$SE.estimate / D$estimate
  list(EN = EN, D = D)
}

# by sector
lapply(sexfit2223, sumone, bysector = TRUE)

## $F
## $F$EN
## estimate SE.estimate lcl ucl
## central 150.801 19.4437 117.248 193.955
## eastern 171.850 22.7057 132.792 222.397
##
## $F$D
## estimate SE.estimate lcl ucl RSE
## central 3.13577 0.404316 2.43807 4.03314 0.128937
## eastern 3.45632 0.456667 2.67076 4.47294 0.132125
```

2022 and 2023 western Kitikmeot Region grizzly bear survey

```
##
##
## $M
## $M$EN
##      estimate SE.estimate      lcl      ucl
## central  107.813      20.9125 73.9747 157.129
## eastern  131.760      25.5576 90.4058 192.030
##
## $M$D
##      estimate SE.estimate      lcl      ucl      RSE
## central  2.24187      0.434858 1.53824 3.26736 0.193971
## eastern  2.65000      0.514024 1.81828 3.86218 0.193971

sumone(fits2223all[[5]], bysector = TRUE)

## $EN
##      estimate SE.estimate      lcl      ucl
## central  261.902      29.2309 210.586 325.722
## eastern  305.533      34.7045 244.727 381.446
##
## $D
##      estimate SE.estimate      lcl      ucl      RSE
## central  5.44603      0.607832 4.37897 6.77312 0.111610
## eastern  6.14499      0.697991 4.92205 7.67179 0.113587

# sectors combined
lapply(sexfit2223, sumone, bysector = FALSE)

## $F
## $F$EN
##      estimate SE.estimate      lcl      ucl
## 1  322.651      41.5828 250.889 414.938
##
## $F$D
##      estimate SE.estimate      lcl      ucl      RSE
## 1  3.29872      0.425134 2.56504 4.24224 0.128879
##
##
## $M
## $M$EN
##      estimate SE.estimate      lcl      ucl
## 1  239.572      46.4701 164.381 349.159
##
## $M$D
##      estimate SE.estimate      lcl      ucl      RSE
## 1  2.44934      0.475101 1.68059 3.56973 0.193971

sumone(fits2223all[[5]], bysector = FALSE)

## $EN
##      estimate SE.estimate      lcl      ucl
## 1  567.434      63.1843 456.484 705.352
##
## $D
##      estimate SE.estimate      lcl      ucl      RSE
## 1  5.80134      0.645984 4.667 7.21138 0.111351
```

Combined N-hat for 2021–2023 (all sectors)

2022 and 2023 western Kitikmeot Region grizzly bear survey

```
Estimates from 2021 (earlier report Table 4)
      N-hat lcl ucl
Female 219 161 299
Male   141  98  200
Total  359 275 470
```

Previously the CI was inflated for a supposed effect of overdispersion. This was a mistake - see Efford and Fletcher (2024) - and we do not do that anymore.

```
load('fits2021.RData') # 2021 models
# models fitted to 2021 data did not exclude Lakes, so use this area
area.ha <- as.numeric(st_area(sectors)[1]) * 1e-4
fitlist <- list(F = fit2021F, M = fit2021M)
predlist <- list(
  F = predict(fit2021F),
  M = predict(fit2021M),
  FM = predict(fit2021FM)[[1]])
N <- function(pred) pred['D',c(2:5)] * area.ha
western <- do.call(rbind, lapply(predlist, N))
row.names(western) <- c('F', 'M', 'F+M')

area.ha <- sum(sectorlandarea[2:3]) * 100
ceFM <- lapply(sexfit2223, sumone, bysector = FALSE)
centraleastern <- rbind(
  ceFM$F$EN,
  ceFM$M$EN,
  sumone(fits2223all[[5]], bysector = FALSE)$EN)
row.names(centraleastern) <- c('F', 'M', 'F+M')

combine <- function (w, ce) {
  w <- as.data.frame(w)
  ce <- as.data.frame(ce)
  est <- w$estimate + ce$estimate
  se <- sqrt(w$SE.estimate^2 + ce$SE.estimate^2)
  data.frame(estimate = est,
             SE.estimate = se,
             lcl = est - 1.96*se,
             ucl = est + 1.96*se,
             RSE = se/est,
             row.names = c('F', 'M', 'F+M')
  )
}

# western sector 2021
print(western)

##      estimate SE.estimate      lcl      ucl
## F      219.135    28.4591 170.070 282.355
## M      140.330    20.7204 105.231 187.136
## F+M    359.465    35.0932 296.999 435.070

# central and esatern sectors 2022-2023
print(centraleastern)

##      estimate SE.estimate      lcl      ucl
## F      322.651    41.5828 250.889 414.938
## M      239.572    46.4701 164.381 349.159
## F+M    567.434    63.1843 456.484 705.352
```

```
# combined 2021-2023
round(combine(western, centraleastern),3)

##      estimate SE.estimate      lcl      ucl  RSE
## F      541.786      50.389 443.024  640.548 0.093
## M      379.902      50.880 280.177  479.628 0.134
## F+M    926.900      72.276 785.239 1068.560 0.078
```

Probability of detection 2022-2023

Following estimates of detection parameters match those from the hcov model fits2223all[[2]].
Ignore the density

```
lapply(lapply(sexfit2223,predict), '[', -1, )

## $F
##      link      estimate SE.estimate      lcl      ucl
## lambda0 log  0.576566  0.0795841  0.440464  0.754722
## sigma  log 4210.485319 270.9816489 3711.987246 4775.928753
##
## $M
##      link      estimate SE.estimate      lcl      ucl
## lambda0 log  0.151813  0.0360112  0.0959738  0.240139
## sigma  log 6229.316201 854.5709787 4766.6346449 8140.833778
```

Generate sex-specific map of predicted probability detected. Added 2025-02-19.

```
tmpmask <- subset(easternmaskall, easternmaskall$x>301000 & easternmaskall$y<755000)
covariates(tmpmask)$pdotF <- pdot(tmpmask, traps(chall),
  detectfn = 'HEX', detectpar = detectpar(sexfit2223$F), noccasions = 3)
covariates(tmpmask)$pdotM <- pdot(tmpmask, traps(chall),
  detectfn = 'HEX', detectpar = detectpar(sexfit2223$M), noccasions = 3)

extras <- function() {
  # plot(Lakes, add = TRUE, col = 'lightblue', border = 'lightblue')
  plot(coast, border = 'blue', add = TRUE)
  points(Kugluktuk, cex = 1.2, pch = 16)
  text(Kugluktuk + c(40000, 10000), 'Kugluktuk', cex=0.8)
  terra::sbar(100000, xy=c(320000, 7218000), type='bar', labels=c(0,50,100),
    below = 'km', adj = c(0.5, -1.2))
}

if (pngoutput) png(filename = "pdotbysex.png", width = 900, height = 450)

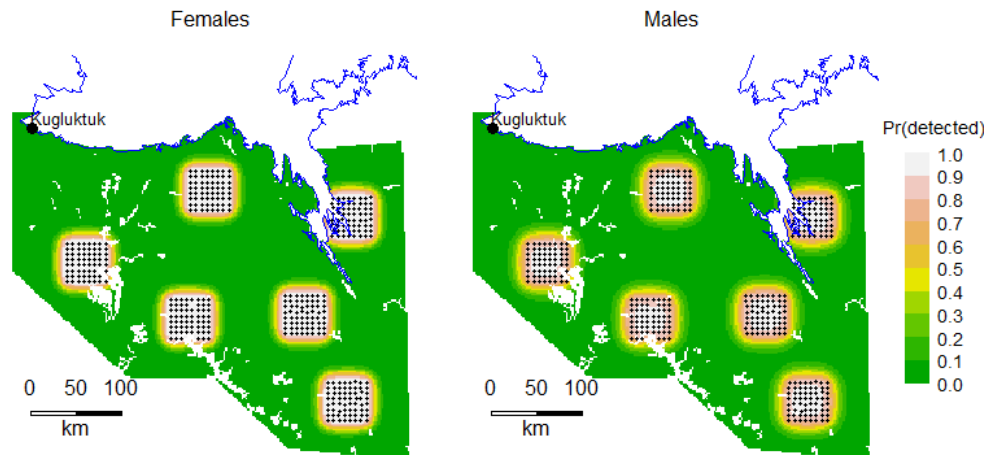
par(mfrow = c(1,2), mar = c(1,1,1,1), oma = c(0,0,2,8))

# females
plot(tmpmask, cov = 'pdotF', legend = FALSE, dots = FALSE)
plot(traps(chall), add = TRUE, detpar = list(cex=0.4, pch=16, fg = 'black'))
mtext(side=3, line = 1, 'Females', xpd = TRUE, cex = 1)
extras()

# males
plot(tmpmask, cov = 'pdotM', legend = FALSE, dots = FALSE)
mtext(side=3, line = 1, 'Males', xpd = TRUE, cex = 1)
plot(traps(chall), add=T, detpar = list(cex=0.4, pch=16, fg = 'black'))
extras()
```

2022 and 2023 western Kitikmeot Region grizzly bear survey

```
strip.legend(c(765000, 7530000), legend=seq(0,1,0.1), legendtype = 'breaks',  
            title = 'Pr(detected)', col = terrain.colors(10), xpd = NA)
```



```
if (pngoutput) dev.off()
```

Caption: Probability of being detected at least once on the Kitikmeot subgrids surveyed in 2022 and 2023. A female whose activity centre lay at the edge of a subgrid had approximately 97% chance of detection at least once, whereas a male in the same location had 84% chance of detection.

References

- Awan, M., M. Efford, and J. Boulanger. 2023. Grizzly bear DNA mark—recapture sampling in the Western Kitikmeot Region of Nunavut, 2021. Department of Environment, Government of Nunavut.
- Awan, M., J. Boulanger, M. G. Efford, and K. G. Poole. 2025. Grizzly bear DNA mark—recapture sampling in the Western Kitikmeot region of Nunavut, 2022–2023. Unpublished report. Department of Environment, Government of Nunavut.
- Efford, M. G., and D. J. Fletcher. 2024. Effect of spatial overdispersion on confidence intervals for population density estimated by spatial capture-recapture. *bioRxiv* DOI: 10.1101/2024.03.12.584742
- Walvoort, D. J. J., D. J. Brus, and de J. J. Gruijter. 2010. An R package for spatial coverage sampling and random sampling from compact geographical strata by k-means. *Computers & Geosciences* 36: 1261-1267. <http://dx.doi.org/10.1016/j.cageo.2010.04.005>