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**DNA capture-recapture
population survey of black and
grizzly bears in the Beaver River
watershed, Yukon**

August 2022



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Government of Yukon
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SR-23-18

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Abstract

We conducted a DNA capture–recapture population survey of black and grizzly bears in the Beaver River watershed using non-invasive hair-snagging techniques. We erected 138 hair snag structures over the 6700 km² study area and revisited each site four times to collect hair. Individual identifications obtained from hair samples were used in spatially explicit capture–recapture analysis to estimate overall abundance of both black and grizzly bears. We also conducted density surface model analysis to explore factors influencing the distribution of both bear species in the study area. The estimated population density for grizzly bears was found to be 5.94 (4.45, 7.92 95% CI) bears / 1000 km²; the estimated population density for black bears was found to be 25.1 (17.1, 36.8 95% CI) bears / 1000 km². The estimated sex ratio was even for both species with the proportion of females estimated to be 49.1 % (36.0, 62.3; 95% CI) for grizzly bears and 50.6 % (39.9, 61.3; 95% CI) for black bears. For both bear species, models with elevation as a predictor were more supported than landcover models. Models predicted highest densities for grizzly bears in areas above 1300 m, with densities then decreasing in upper high altitude barren areas. Black bear densities were highest at low elevation and decreased gradually as elevation increased. A quartz claim covariate was used to assess if disturbance may be influencing grizzly and black bear densities. This covariate was not supported for grizzly bear and had weak support for black bears; however, the actual level of human activity and disturbance associated with claims is unknown so the association with density is difficult to assess. Results suggest that grizzly and black bears do inhabit areas of different elevations, but habitat segregation is not complete as some black bears are still found within moderate elevation areas that grizzly bears inhabit.

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Introduction

This document describes results from a DNA mark-recapture study focused on grizzly bears, but inclusive of black bears, in the Beaver River watershed.

Currently, very little is known about bear densities in the Beaver River Land Use Planning area, an area that has significant mineral potential. The area lies within the Traditional Territory of the First Nation of Na-Cho Nyak Dun, and includes the Beaver River watershed. It offers pristine habitat, has very little disturbance, and very little access. A recent proposal to build a 65-km all season access route (the “Tote Road”) within the area has been proposed by the exploration company ATAC in order to support advanced exploration. This has driven the development of a land use plan for the area. A planning committee composed of First Nation of Na-Cho Nyak Dun and Government of Yukon delegates is currently gathering information about the planning area.

Grizzly bears were identified as a valued ecosystem component for the planning process, which led to the need to gather information about the bear population in the area. A study design was developed in late 2019 (Boulanger 2019) and sampling followed in the summer of 2020. Sample genotyping and data analyses were completed in late 2020 and early 2021.

The aim of this report is to describe the background, summarize the raw data, and present estimates of overall abundance of grizzly and black bears based on spatially explicit capture–recapture models (SECR). In addition, we conduct a density surface model analysis to explore factors influencing the distribution of grizzly and black bears in the study area. This provides a foundation for continuing work to model spatial variation in density of bears.

Study area

The region of interest is centred on the Rau mining claims and the proposed access road (Figure 1). The site is near latitude 64° N, about 96 km northeast of Mayo. The southwestern edge of the study area is 4 km from Keno City, the western edge of the study area is approximately 175 km due east of Dawson City, and the eastern edge is about 50 km southwest of the NWT border.

The study area encompasses portions of three Yukon ecoregions: Mackenzie Mountains ecoregion, Selwyn Mountains ecoregion, and Yukon Plateau-North ecoregion. These ecoregions see mean annual temperatures from -5° C to -8° C, with mean July temperatures ranging from 5° C to 15° C (Yukon Ecoregions Working Group, 2004). The Mackenzie Mountains ecoregion is characterized by broad U-shaped valleys and bare mountain ridges; the Selwyn Mountains ecoregion is characterized by a rugged high elevation mountain range; and the Yukon Plateau-North ecoregion is characterized by rolling highlands. All three ecoregions noted the wettest period in June and July with 40–90 mm rain over this period. Permafrost is found throughout the Mackenzie Mountains ecoregion, but it is

discontinuous in both the Yukon Plateau-North and Selwyn Mountains ecoregions with heavy snow in the latter insulating valleys from widespread permafrost.

The Mackenzie Mountains ecoregion is primarily alpine tundra with valleys of taiga forest and treeline around 1200 m (Yukon Ecoregions Working Group, 2004). The Selwyn Mountains ecoregion is mainly alpine and subalpine with forested valleys and lower slopes. The Yukon Plateau-North ecoregion is covered in northern boreal forest up to treeline, which occurs at 1500 m. Mixed canopy forests are common within this ecoregion due to the high frequency of fires caused by thunderstorms. The region also holds important wetland complexes.

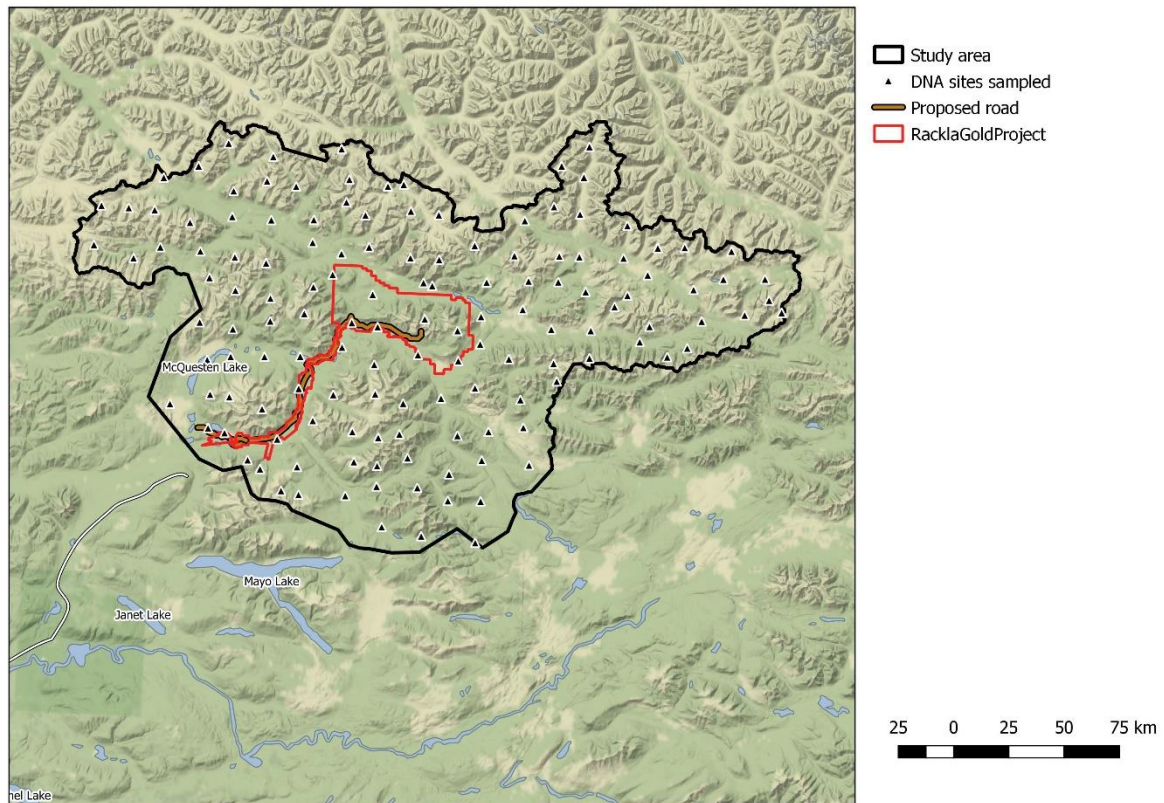


Fig. 1. Beaver River DNA study area with sites sampled. Also shown is the Rau mining claims area with the proposed access road.

Methods

Spatial capture–recapture models

Spatially explicit capture–recapture (SECR) models are a set of methods for extracting unbiased estimates of population parameters, particularly population density, from incomplete data such as the Beaver River dataset. We expect that some bears were present but not detected, and that the sample includes marginal animals not resident in the study area. An SECR model adjusts for these uncertainties.

The model treats each bear population as a set of points distributed in space; each point is the notional centre of a bear’s home range, or its ‘activity centre’. Whether a particular bear leaves a hair sample at a particular hair snag is assumed to have a probability that declines with distance from its activity centre. The probability at zero distance (g_0) is less than 1.0, and the decline has a characteristic shape (e.g., half-normal) and spatial scale (σ , measured in km). The trick of SECR modelling is to choose a suitable shape for this ‘detection function’¹ and to estimate g_0 and σ . Each of the detection parameters g_0 and σ may itself vary systematically over time or in response to other factors. Given these basics it is straightforward to estimate population density (bears per 1000 km²) assuming the population is distributed uniformly in space. There is also the possibility to model spatial distributions that vary with environmental factors, essentially by including in the model a regression of local density on local values of these ‘covariates’.

We use the method of maximum likelihood (ML) to fit the SECR model (Borchers and Efford, 2008; Efford 2021). This uses numerical evaluation of the likelihood, which is computationally intensive. Alternative Bayesian methods are also in widespread use (e.g., Royle et al. 2014; Bischof et al. 2020).

Hair snag stations were placed in each of 138 7-km² grid cells to obtain uniform coverage of a nominal study area of about 6700 km². Hair snag stations were lumber tripods. They were composed of six 5-foot 2x4s, 3 of which were wrapped with barbed wire (upright posts of tripod). Lumber was connected at junctions with cable and clamps. Moss and woody debris were piled in the centre of the station. Liquid lure consisting of fish oil and cured blood was poured over the centre debris at each station and in each session. A handful of moss was collected, and mixed with long distance lure, then enclosed in felt and stapled to the top of each station. Long distance lures were changed each session and included ground beaver castor, K9 triple take, predator long distance call and bear tease (Forsyth Animal Lures Ltd.). Hair snags were set up over 19–25 June 2020 and checked at approximately 2-week intervals (‘sessions’, median 13 days, range 10–18) with the final checks on 11–16 August

¹ We have described the detection function in terms of probability (g_0 refers to the probability of detection at zero distance). There is an equivalent representation as the hazard of detection λ (λ_0 is the hazard of detection at zero distance), and the two are interchangeable ($\lambda(d) = -\log(1-g(d))$ for distance d), although the shapes differ somewhat. For technical reasons our analysis uses the hazard form with parameters (λ_0, σ).

2020. Camera traps were placed at approximately one-quarter of the stations for the third and fourth sessions. This was done to help interpret what was happening when stations were visited, but no samples left, and also to gain insight into other species visiting the sites.

DNA samples were analyzed by Wildlife Genetics International, Nelson, B.C. (WGI) following a defined subsampling strategy. This strategy involved sampling two suspect grizzly bear samples from each barbed post, two suspect black bear samples from each barbed post, 1 sample from each base wood segment, all ground samples, all samples from rub trees and camera trees, and samples from the top of station (on felt or wire) when previous noted targets were not met. Of the 2115 samples submitted on the project, 17 samples did not look like bear hair, 209 samples lacked material suitable for analysis, 435 samples were excluded by subsampling rules, 5 samples were excluded due to mixture of hairs from more than one bear, and 370 samples failed during genetic analysis. Individual identifications were obtained for 1,079 hair samples, approximately half of those submitted. Identification used 8 markers (microsatellites G1A, G10B, G1D, G10J, G10M, MU59 and G10U, plus a ZFX/ZFY sex marker). Error-checking by WGI gave a very high level of confidence in the genetic identifications (Paetkau 2021). Samples were assigned to species on the basis of G10J; assignments were confirmed by ordination of samples on the remaining loci, excluding the sex marker.

Data input and checking

Hair snag locations were projected at Yukon Albers (EPSG code 3578). The black bear and grizzly bear data were analysed separately. Analyses used release 4.4.7 of the R package 'secr' (Efford 2021; R Core Team 2021). Maps were produced in QGIS (QGIS Foundation 2020) and the 'ggmap' (Kahle and Wickham 2013) R package.

Spatial detection model

Our aim in this part of the report is to sift through the possible spatial detection models and use them to estimate the male and female densities of each bear species in 2020. We focus on the spatial detection model and consider only uniform density. Akaike's Information Criterion (AIC) is used for model selection and AIC model weights were also calculated (Burnham and Anderson 2002).

We compared two possible shapes for the detection function (halfnormal HHN and exponential HEX), and considered these possible sources of variation in the detection parameters:

- distinct values in each session ($\sim t$)
- temporal trend over sessions ($\sim T$)
- general learned response to encountering a hair snag (trap avoidance or trap happiness) ($\sim b$)
- localized learned response (for particular hair snag) ($\sim bk$)

The size of home ranges clearly differed between the sexes, so we always fitted sex-specific detection parameters and a sex ratio parameter using a hybrid mixture model ('hcov' in Efford 2021). The effect of sex variation was modelled as additive to the effects above.

Preliminary model comparisons conducted separately on males and females within each species gave erratic results (no clear best model) and wide confidence intervals on model-averaged estimates. We attribute this to noise in the AIC values resulting from small sample sizes and individual differences among bears. Pooling males and females, while allowing for sex differences in key parameters (λ_0 , σ), appeared to overcome the problem.

Other model details

Data were treated as binary at the level of one bear, one hair snag and one occasion (i.e. we used the (binary) 'proximity' detector type in 'secr', and discarded repeat records). The 'fastproximity' option of 'secr' was turned off. We discretized space as a 'habitat mask' with pixels 2 km on a side for black bears and 2.5 km on a side for grizzly bears. For black bears the habitat mask extended 20 km beyond the detectors (3568 pixels) and for grizzly bears it extended 40 km beyond the detectors (4017 pixels). We checked the adequacy of these buffer widths post hoc by verifying that further increase did not significantly alter the derived density estimates. Appendix 1 shows code for the analysis using 'secr' 4.4.7.

Density surface models

SECR models estimate the home range centre of each bear detected on the sampling grid based on the configuration of detectors relative to where the bear was detected. The location of estimated home range centres can then be related to habitat and anthropogenic covariates using density surface modelling (Borchers and Efford 2008, Royle et al. 2014). Density surface models have been used to assess factors related to bear density in Alberta (Boulanger et al. 2018). This analysis defines the distribution of bears relative to the Rau claims based on habitat. The baseline models developed from this analysis can potentially improve the power of subsequent analyses to assess change in density and distribution relative to the mining claims. For this analysis, a mask with 2 km spacing (and 40 km buffer) was used for both grizzly and black bear data sets to facilitate comparison of results.

Landcover, mining claims footprint, disturbance indices, elevation, and mortality history (for grizzly bear model only), were considered as covariates that may explain patterns of density of black bears and grizzly bears on the sampling grid. For this analysis, mask points were populated with point covariate values for elevation and mortality history by Game Management Subzone (based on the raster pixel where the mask point was located).

Landcover classes were derived from the Arctic Boreal Vulnerability Experiment (ABOVE) core domain (Wang et al. 2019). Fifteen landcover classes occurred in the extended study area. Classes of similar habitat types were first pooled (Figure 2) into 8 classes to create a useable set of covariates for the analysis. For landcover, the relative proportion of each landcover class was estimated within 1 km of each mask point. This approach considered the habitat around each mask point rather than only at the point itself. Correlation of habitat types was initially assessed which revealed correlations of woodland and forest habitat types with most other landcover types. Landcover was also considered as a factor variable with classification based on landcover that each mask point fell on.

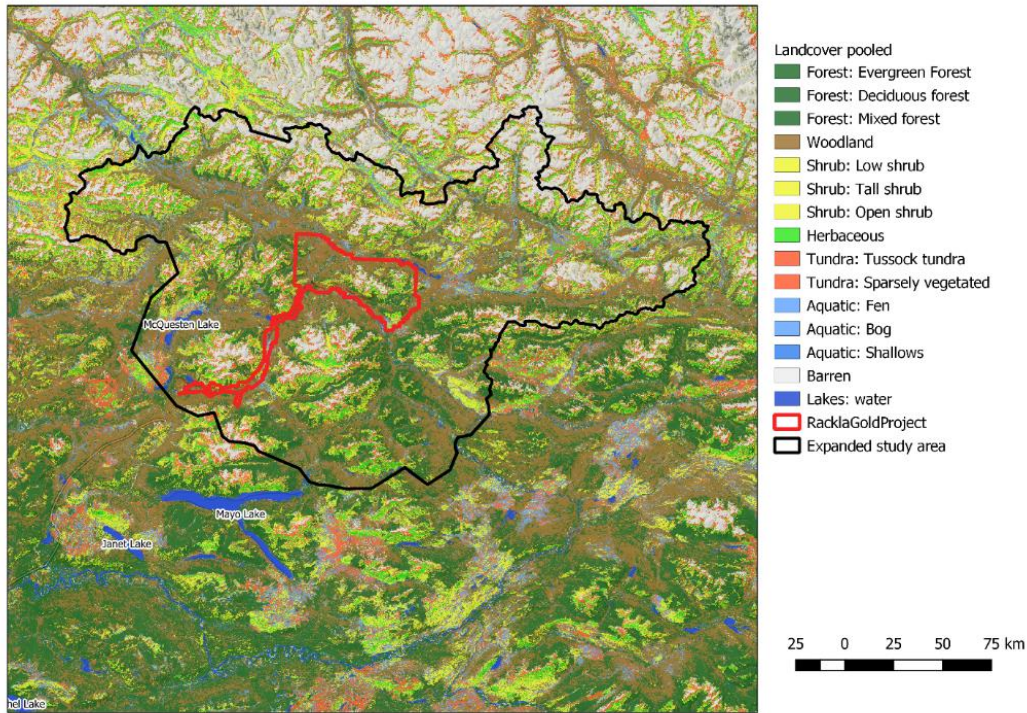


Fig. 2. Landcover classes considered in the analysis.

Landcover classes exist across a gradient of elevations and therefore a simple predictor of density is elevation (Figure 3). Models with elevation as a predictor with elevation thresholds (high/low) and non-linear relationships as modelled by spline-smoother terms were considered with results compared to landcover models. Spline-smoother terms basically allow a non-linear relationship between elevation and density due to factors such as higher proportions of non-habitat in high elevation areas leading to reduced density. The degree of non-linearity in spline models is determined by the degrees of freedom (*df*).

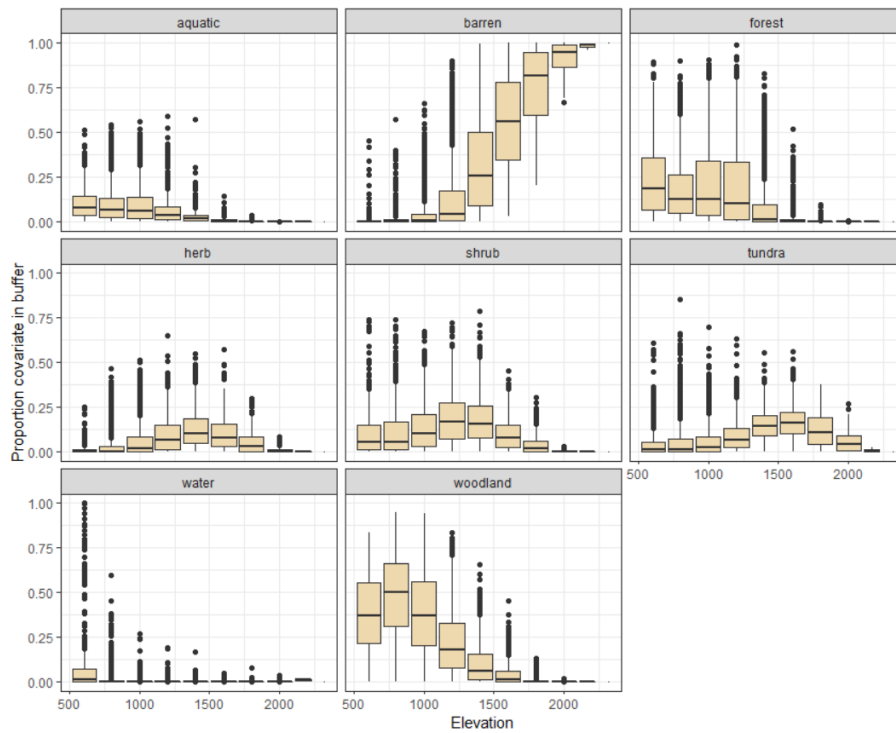


Fig. 3. Distribution of landcover classes by elevation.

Potential disturbance indices for the study area included quartz claims and placer mining leases and claims (Figure 4). The placer leases and claims mainly occurred off the focal study area and were small in scale. Quartz claims extended across much of the lower elevations in the study area and the degree and timing of disturbance associated with claims was unknown. Therefore, quartz claims were cautiously considered as density surface covariates.

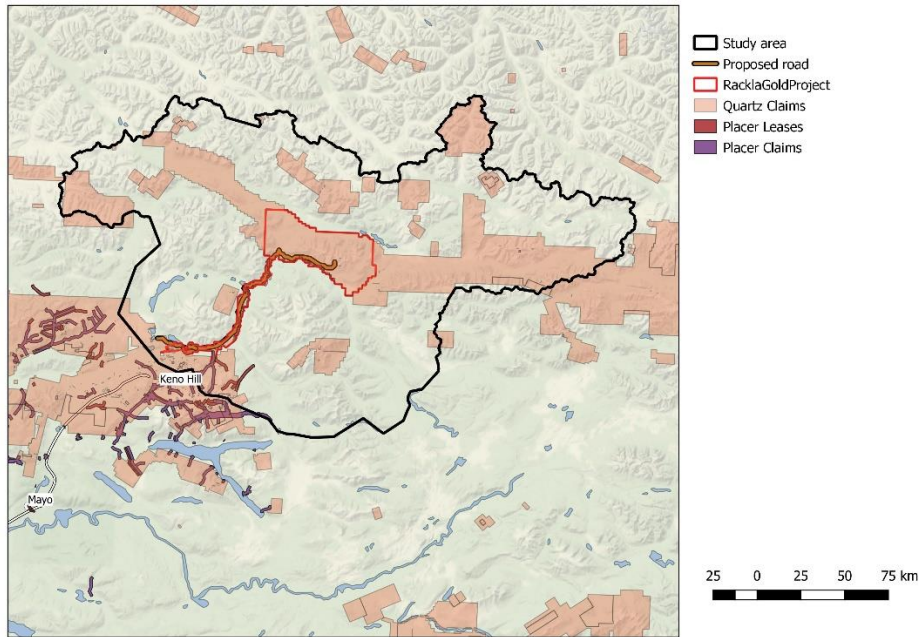


Fig. 4. Quartz and placer mine disturbance indices in the Beaver River study area. The timing and intensity of disturbance associated with quartz mine claims is unknown.

The effect of mortality (known deaths from harvest and other causes) (grizzly bear model only) was also considered as an additive term to the most supported habitat or elevation model. This approach tested if a net effect of mortality could be detected on top of variation due to elevation and habitat types. Mortality history was the average annual grizzly bear mortality that occurred in subregions (Game Management Subzones) from 2011-2021 (Figure 5). Average annual mortalities varied from 0 to 0.73 within the extended study area. We note this surface provided a spatial index of mortality pressure as opposed to an assessment of temporal trends in mortality across the study area.

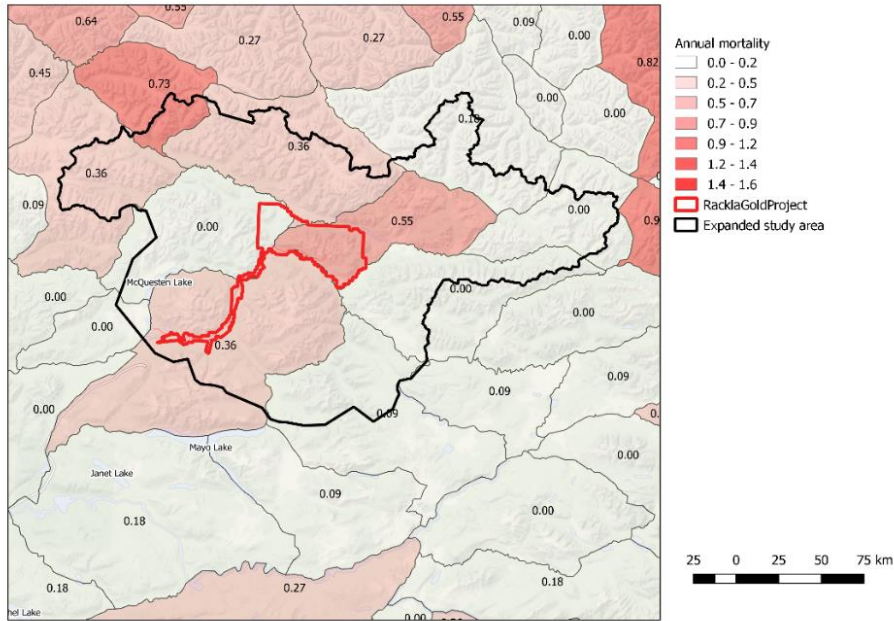


Fig. 5. Number of known human-induced deaths of grizzly bears in each spatial unit within the extended study area (and surrounding area).

Estimates of bears in footprint area

The expected number of bears in the mining claims footprint polygon was estimated using the most supported density surface models for grizzly and black bears with mask points that occurred within the mining claims footprint polygon. This estimate corresponds to the expected number of bears in the footprint area at one time as opposed to the cumulative number of bears that might traverse the mine footprint over the entire duration of sampling.

Of greater interest is the number of bears that may use the footprint polygon area during sampling. To derive this estimate, the area in which bears' home ranges overlap the mining claims footprint by at least 5% was estimated from the detection functions for male and female black and grizzly bears. The general procedure used was to estimate the probability of overlap with mining claims estimated from detection functions for each mask point. The masks for black and grizzly bear males and females were then subset to mask points that had probabilities of overlap of greater than 5%. The resulting masks were then used with density surface models to estimate the number of bears in the footprint and surrounding area. We note that this estimate assumes that the circular detection function is an adequate representation of the utilization distribution of bears during the study. Estimates from this exercise were derived using the openCR R package (Efford 2019).

Results

Data summary and checks

The number of bears detected per session increased over time for each species and sex class (Table 1). The number of new bears detected each session was relatively constant for black bears. For grizzly bears the number of new bears detected by session decreased substantially for females suggesting that sampling detected most of the immediate residents; the pattern was less clear for males. Detection frequencies (the number of bears detected in X sessions) are noted in Table 1; for black bears, 21 of 41 female and 18 of 40 male bears were detected in more than one sampling session. For grizzly bears, 22 of 26 female and 15 of 27 male bears were detected in more than one session.

Table 2. Summary data for black bears and grizzly bears surveyed with hair snags at Beaver River, Yukon in June–August 2020. Frequencies (f) are the numbers of individuals detected in 1, 2, 3 or 4 sessions.

Species/Statistic	Sex/session							
	Females				Males			
	1	2	3	4	1	2	3	4
<u>Black bears</u>								
Number detected (n)	6	17	22	24	12	14	15	22
New bears detected (u)	6	13	13	9	12	10	11	7
Cumulative total (M_{t+1})	6	19	32	41	12	22	33	40
Detection frequencies (f)	20	15	5	1	22	13	5	0
<u>Grizzly bears</u>								
Number detected (n)	12	15	19	19	11	11	12	18
New bears detected (u)	12	10	3	1	11	6	4	6
Cumulative total (M_{t+1})	12	22	25	26	11	17	21	27
Detection frequencies (f)	4	10	7	5	12	7	6	2

A plot of detections and the approximate paths of bears that were detected more than once suggests a relatively uniform distribution of both species throughout the study area (Figure 6). The number of bears detected, and the number of redetections (the total detections minus the number of individual detected) is listed above each figure. For black bears the number of individuals detected was greater than redetections, however, for grizzly bears the number of redetections outnumbered individuals.

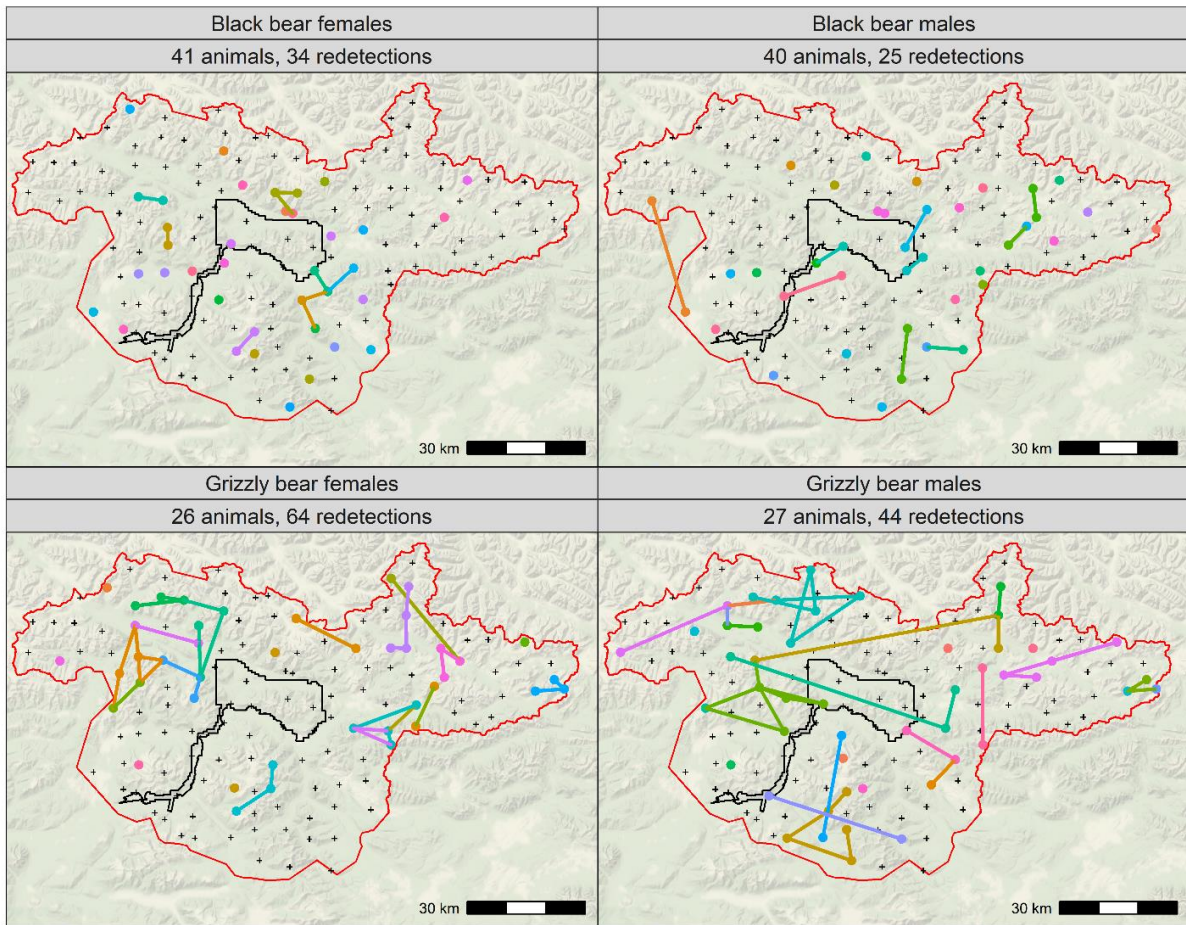


Fig. 6. Detections of black and grizzly bears at 138 hair snag stations (denoted by a + symbol) distributed at approximately 7-km spacing at the Beaver River study site (denoted by a red outline). Individuals are denoted by differently coloured points. The Rau mining claims are denoted by a black polygon. Consecutive detections of individual bears are joined to indicate known movements. The number of individuals detected and the number of redetections (including multiple detections of an individual at different sites within a single session) are listed above each plot.

Male grizzly bear movements traversed a reasonable amount of the study area including possible movements across the mine area. Grizzly bear males moved up to 60 km whereas female movements were restricted to approximately 20 km (Figure 7). In contrast, black bear movements were within the 0–10 and 0–20 km range for females and males respectively.

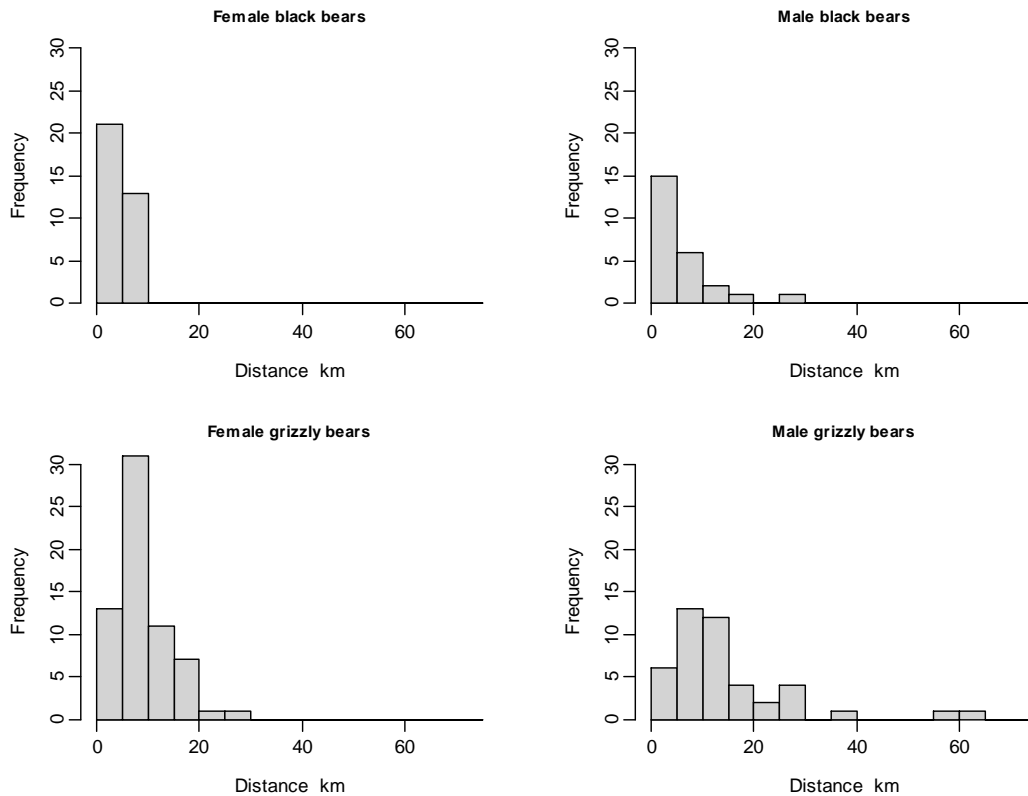


Fig. 7. Histograms of distance between consecutive locations (minimum movements).

Mean detection locations of bears (the mean x and y coordinates of sites where a bear was detected) suggest a higher number of black bears in the vicinity of the Rau claims area (Figure 8). We note that the mean detection location is different than the estimated home range centre in SECR models. SECR model assumes that each bear has a home range centre and the detection probability declines radially from this point, although it is never observed directly. The mean detection point (centroid) is computed from the observed locations and therefore must lie within the perimeter of the detector sites; it only approximates the true activity centre that may lie outside the perimeter (Borchers and Efford 2008).

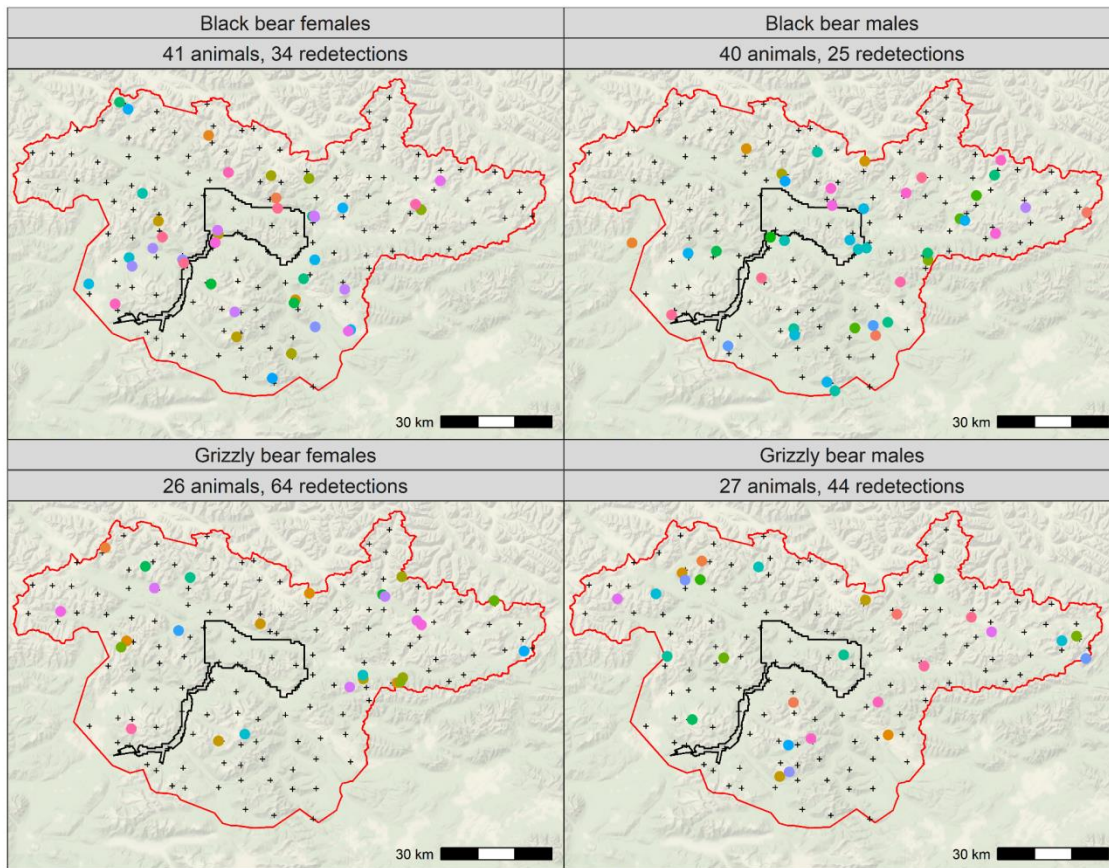


Fig. 8. Mean detection locations of black and grizzly bears at 138 hair snags (denoted by a + symbol) distributed at approximately 7-km spacing at the Beaver River study site (denoted by a red outline). Individuals are denoted by differently coloured points. Points are staggered around sites to reveal multiple individuals detected at a single site. The Rau mining claims are denoted by a black polygon. The number of individuals detected, and the number of redetections are listed above each plot.

Spatial detection model

The exponential shape (HEX) was a uniformly better fit (less negative log likelihood, smaller AIC) than the half-normal (HHN), and models with a site-specific learned response were favoured for both species (Table 2). For both species, a model with detection at home range centre varying by sex with an additive site-specific response to sampling and sex-specific spatial scale ($\lambda_0 \sim bk + \text{sex}$, $\sigma \sim \text{sex}$) was most supported, with no other models tied for support (as indicated by ΔAIC values less than 2). The magnitude of the estimated learned response (bk) was surprisingly large: previous capture at a hair snag increased the baseline detection parameter λ_0 by a factor of about 9 for black bears and 3.5 for grizzly bears (Table 3).

Table 2. Comparison of fitted models for each species. The detection function parameters (λ_0 -detection at home range centre, σ -spatial scale parameter) are given as a function of sex and covariates (bk -trap-specific response, b -bear-specific response, t -session-specific variation, T -linear trend in detection). Model fit is evaluated by: AIC = Akaike Information Criterion, ΔAIC = the difference

in AIC between the model and the most supported model, and AICwt = proportional AIC model weight. The number of model parameters (K) and the log-likelihood (LL) are also shown.

Model	Detection function	AIC	Δ AIC	AICwt	K	LL
<u>Black bear</u>						
$\lambda_0 \sim bk+sex, \sigma \sim sex$	HEX	984.7	0	0.64	7	-485.35
	HHN	986.12	1.42	0.32	7	-486.06
$\lambda_0 \sim b+sex, \sigma \sim sex$	HEX	990.1	5.4	0.04	7	-488.05
	HHN	1008.86	24.16	0	7	-497.43
$\lambda_0 \sim T+sex, \sigma \sim T+sex$	HEX	1004.64	19.93	0	8	-494.32
	HHN	1023.07	38.37	0	8	-503.54
$\lambda_0 \sim t+sex, \sigma \sim t+sex$	HEX	1011.18	26.48	0	12	-493.59
	HHN	1028.53	43.83	0	12	-502.27
$\lambda_0 \sim sex, \sigma \sim sex$	HEX	1021.53	36.82	0	4	-506.76
	HHN	1055.31	70.6	0	4	-523.65
<u>Grizzly bear</u>						
$\lambda_0 \sim bk+sex, \sigma \sim sex$	HEX	1284.14	0	1	7	-635.07
	HHN	1295.52	11.38	0	7	-640.76
$\lambda_0 \sim b+sex, \sigma \sim sex$	HEX	1299.01	14.87	0	7	-642.5
	HHN	1326.04	41.9	0	7	-656.02
$\lambda_0 \sim T+sex, \sigma \sim T+sex$	HEX	1295.63	11.49	0	8	-639.81
	HHN	1323.75	39.61	0	8	-653.87
$\lambda_0 \sim t+sex, \sigma \sim t+sex$	HEX	1299.17	15.03	0	12	-637.58
	HHN	1325.91	41.77	0	12	-650.95
$\lambda_0 \sim sex, \sigma \sim sex$	HEX	1327.22	43.09	0	4	-659.61
	HHN	1391.94	107.81	0	4	-691.97

Table 3. Baseline detection parameter λ_0 estimated from preferred model (HEX, $\lambda_0 \sim bk+sex, \sigma \sim sex$) (95% confidence intervals).

Sex/detection	Black bears	Grizzly bears
Female, first detection	0.288 (0.123, 0.673)	0.495 (0.291, 0.841)
Male, first detection	0.125 (0.057, 0.273)	0.141 (0.085, 0.232)
Female, repeat detection	2.524 (1.436, 4.439)	1.711 (1.091, 2.684)
Male, repeat detection	1.094 (0.608, 1.969)	0.486 (0.275, 0.859)

Spatial scale parameter estimates (Table 4) and detection function plots (Figure 9) illustrate that grizzly bears operate over a relatively larger spatial scale.

Table 4. Spatial scale parameter (km) estimated from preferred model (HEX, $\lambda_0 \sim \text{bk} + \text{sex}$, $\sigma \sim \text{sex}$) (95% confidence intervals).

Sex	Black bears	Grizzly bears
Female	2.04 (1.48, 2.81)	3.63 (2.92, 4.50)
Male	3.19 (2.27, 4.50)	6.88 (5.27, 8.98)

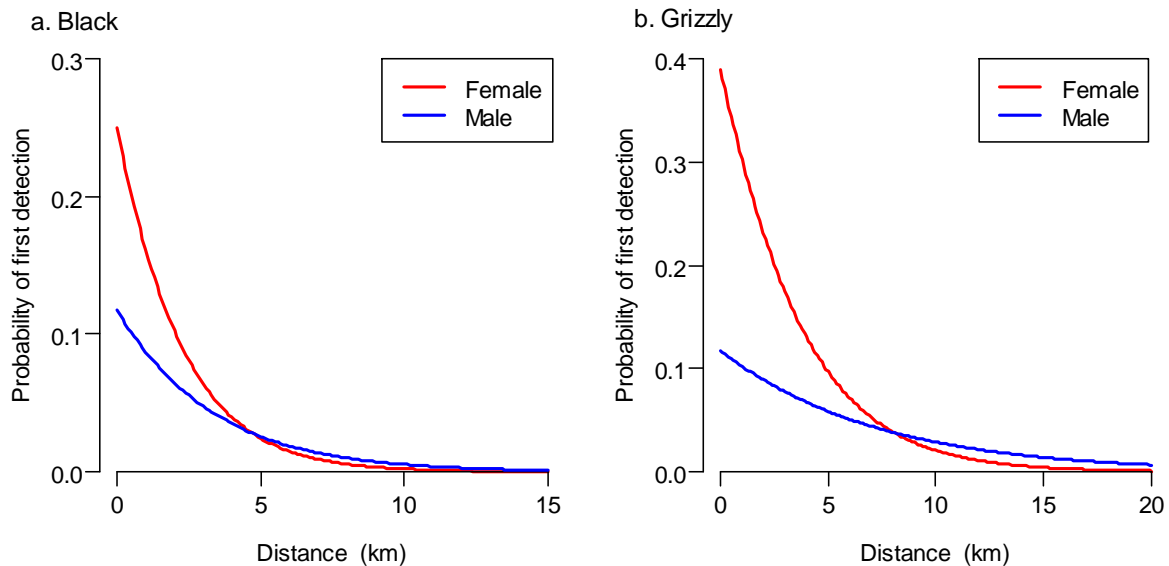


Fig. 9. Fitted detection functions for each sex and species. The probability on the y-axis is the probability a bear will be detected at a hair snag where it has not previously been detected. The x-axis represents the distance from the activity centre.

Population density and sex

More black bears were detected than grizzly bears, and the grizzly bears were substantially more mobile (Table 4 and Figures 6 and 8). As a result, the estimated density of black bears was about four times that of grizzly bears (Table 5). The sex ratios for both species were almost exactly 50:50 (Table 5).

The precision of the density estimates was measured by the relative standard error (RSE, also known as 'CV'). Despite the low density of grizzly bears, the precision of the density estimate (Table 5) matched the target value of 15% (Boulanger 2019). The expected number of bears with activity centres in the study area (area of study \times density) was 41 for grizzly bears and 168 for black bears. These estimates approximate the number of bears on the study area at any one time rather than the cumulative number of bears traversing the study area during sampling. For this reason, the estimate for grizzly bears is lower than the count of bears detected.

Table 5. Estimated population density and sex ratio of black and grizzly bears at Beaver River, Yukon, June–August 2020 (95% confidence intervals).

	Black bears		Grizzly bears	
	Estimate	RSE %	Estimate	RSE %
Population density / 1000 km ²	25.1 (17.1, 36.8)	19.8	5.94 (4.45, 7.92)	14.6
Number centred in study area	168 (114, 247)	–	41 (31,54)	–
Sex ratio (proportion female) %	50.6 (39.9, 61.3)	–	49.1 (36.0, 62.3)	–

Increasing the buffer width had no appreciable effect on the density estimates (Appendix 2).

Density surface models

Model fitting

For grizzly bears, models with elevation as a predictor were more supported than landcover models (Table 6). A model with a non-linear relationship between log-density and elevation was most supported. Landcover models based on two classes, tundra proportion, and woodland proportion were less supported than elevation models but more supported than constant models. Composite landcover models displayed less support than single-proportion land cover models and are omitted from Table 6.

Annual mortality was added to the most supported elevation model and this model was more supported than elevation alone models. Quartz claims were not supported as a predictor when added to the elevation landcover model or as a stand-alone predictor.

Table 6. Density surface model selection for grizzly bears. Model fit is evaluated by: AICc = Sample size corrected Akaike Information Criterion, Δ AICc = the difference in AICc between the model and the

most supported model, and w_i = proportional AICc model weight. The number of model parameters (K) and the log-likelihood (LL) are also shown.

Density	AICc	Δ AICc	w_i	K	LL
Elevation (log-smooth 3 df) + AnnMortality	1273.43	0.00	0.79	10	1268.2
Elevation (log-smooth 3 df)	1277.10	3.67	0.13	9	1272.9
Elevation (log-smooth 3 df) + Quartz claim	1279.87	6.44	0.03	10	1274.6
Elevation (step function at 1000m)	1280.35	6.92	0.02	8	1277.1
Elevation (log-linear)	1282.14	8.70	0.01	8	1278.9
Landcover (Forest/aquatic vs shrub/tundra)	1282.34	8.91	0.01	8	1279.1
Elevation (log-smooth 5 df)	1283.30	9.87	0.01	11	1276.9
Tundra proportion	1285.27	11.84	0.00	8	1282.0
Woodland proportion	1285.91	12.48	0.00	8	1282.6
Mining Claims Footprint	1287.37	13.94	0.00	8	1284.1
Constant	1287.70	14.27	0.00	7	1285.2
Aquatic proportion	1287.97	14.54	0.00	8	1284.7
AnnMortality	1288.29	14.86	0.00	8	1285.0
Barren proportion	1289.67	16.24	0.00	8	1286.4
Quartz claim	1289.94	16.51	0.00	8	1286.7
Shrub proportion	1290.21	16.78	0.00	8	1286.9
Forest proportion	1290.45	17.02	0.00	8	1287.2

For black bears, models with elevation as the main predictor were most supported compared to landcover models. A model with a log-linear relationship between density and elevation was most supported. A model with a non-linear elevation relationship and a model with an additive effect of quartz claims and elevation was tied for support. Confidence limits of the Quartz claim terms ($\beta_{\text{outsideclaim}}=0.64$, SE= 0.48, CI= -0.30-1.58) suggested a weak gradient with higher black bear densities outside of claim areas. The most supported landcover model (shrub) showed substantially lower support than the elevational model. Densities for the mining claims footprint area were not statistically different than the adjoining study area. We present further comparisons of grizzly bears in the mine claims and surrounding area later in the report.

Table 7. Density surface model selection for black bears. Model fit is evaluated by: AICc = Sample size corrected Akaike Information Criterion, Δ AICc = the difference in AICc between the model and the

most supported model, and w_i = proportional AICc model weight. The number of model parameters (K) and the log-likelihood (LL) are also shown.

Density	AICc	Δ AICc	w_i	K	LL
Elevation (log-linear)	971.65	0.00	0.31	8	-476.8
Elevation (log-smooth 3 df)	971.98	0.33	0.27	9	-475.7
Elevation (log-linear) + Quartz claim	972.04	0.38	0.26	9	-475.7
Elevation : Step function at 1000m	973.63	1.98	0.12	8	-477.8
Elevation (log-smooth 5df)	975.91	4.26	0.04	11	-475.0
Shrub proportion	979.12	7.47	0.01	8	-480.6
Woodland proportion	982.43	10.78	0.00	8	-482.2
Barren proportion	983.45	11.80	0.00	8	-482.7
Landcover (Forest/aquatic vs shrub/tundra)	984.13	12.48	0.00	8	-483.1
Tundra proportion	985.40	13.75	0.00	8	-483.7
constant	986.28	14.63	0.00	7	-485.4
Forest proportion	987.32	15.67	0.00	8	-484.7
MineFootprint	987.58	15.93	0.00	8	-484.8
Quartzclaim	987.78	16.13	0.00	8	-484.9
Aquatic proportion	988.34	16.69	0.00	8	-485.2

A prediction plot of density based on elevation for the elevation models predicted highest densities for grizzly bears in areas above 1300 m with densities then decreasing in upper high altitude barren areas. In contrast, black bears densities were highest in low elevation and decreased gradually as elevation increased (Figure 10). We note that these relationships pertain to the time period of sampling (mid-June to mid-August) and will not capture early or late season habitat utilization. For example, potential early season (den emergence to mid-June) utilization of snow-free lower elevation areas by grizzly bears will not be captured in the estimated relationships.

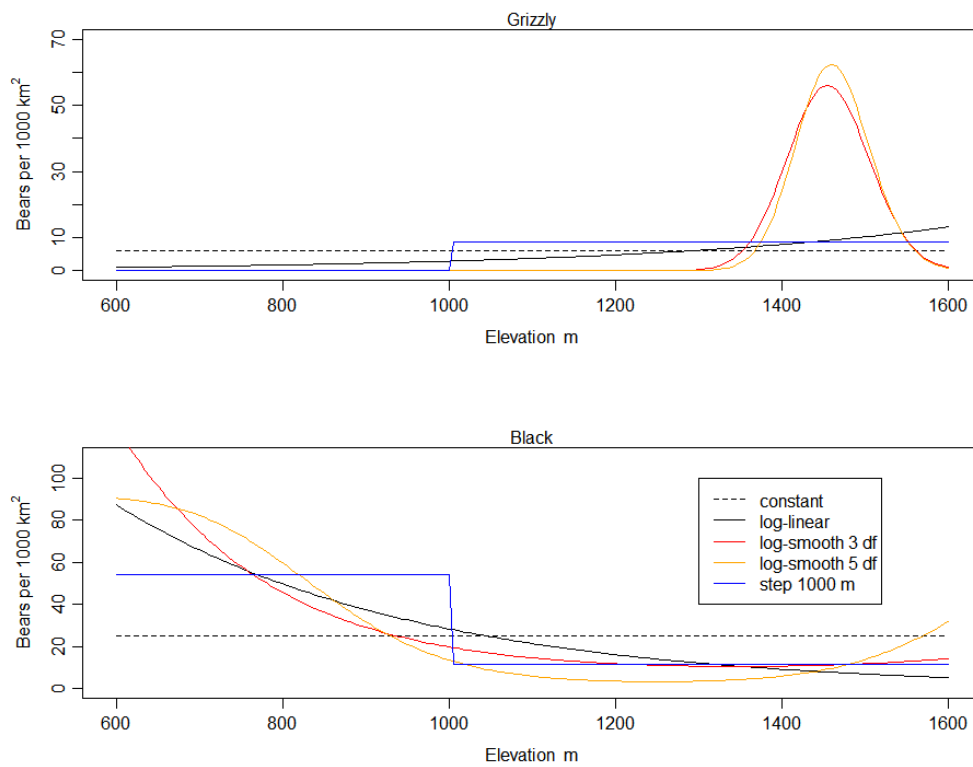


Fig. 30. Predicted relationships between density and elevation for grizzly and black bears.

A plot of density surfaces also predicts grizzly bears in moderate elevation areas with low densities in valley bottoms. In contrast, black bears have highest densities in lower areas but also higher densities than grizzly bears in moderate areas (Figure 11).

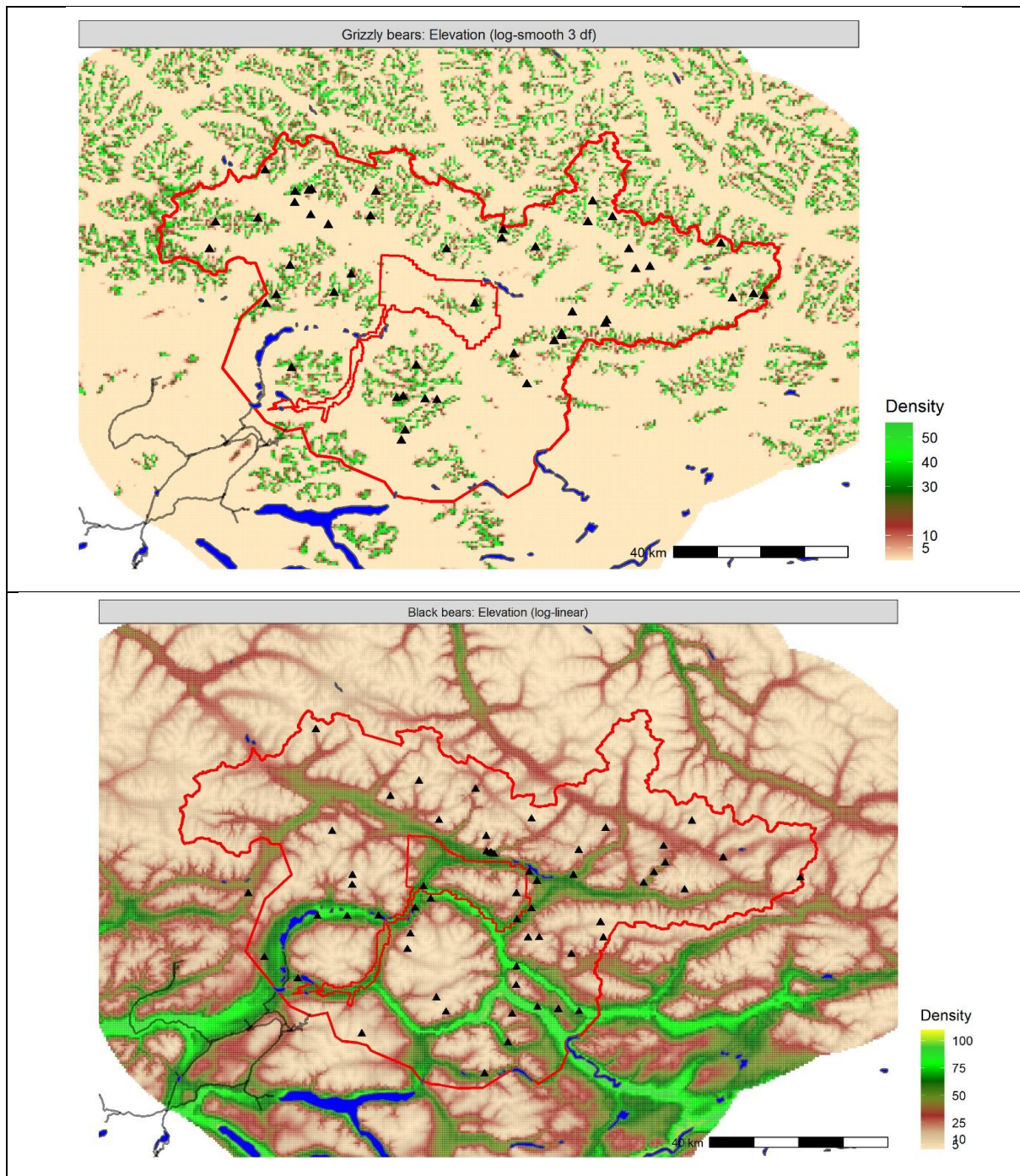


Fig. 41. Predicted density from the most supported elevation density surface models for grizzly and black bears. Also shown are mean detection locations (black triangles) and the mining claims footprint and extended study area boundaries (in red). Note that density is shown on different scales for grizzly and black bears. Predictions are shown for the habitat mask (that extends approximately 40 km from the sampled area).

Another way to demonstrate the density surface model results is by simulating a potential distribution of bear activity centres from each of the supported density surface models

(Figure 12). For these simulations, the number of generated activity centres was set equal to the expected number of bears in the mine footprint. The results of these simulations demonstrate the difference in density of grizzly and black bears and the general tendency for grizzly bear activity centres to occur in moderate elevation areas. In contrast, black bears are found in lower areas but also in moderate elevation areas (as also shown in Figure 9).

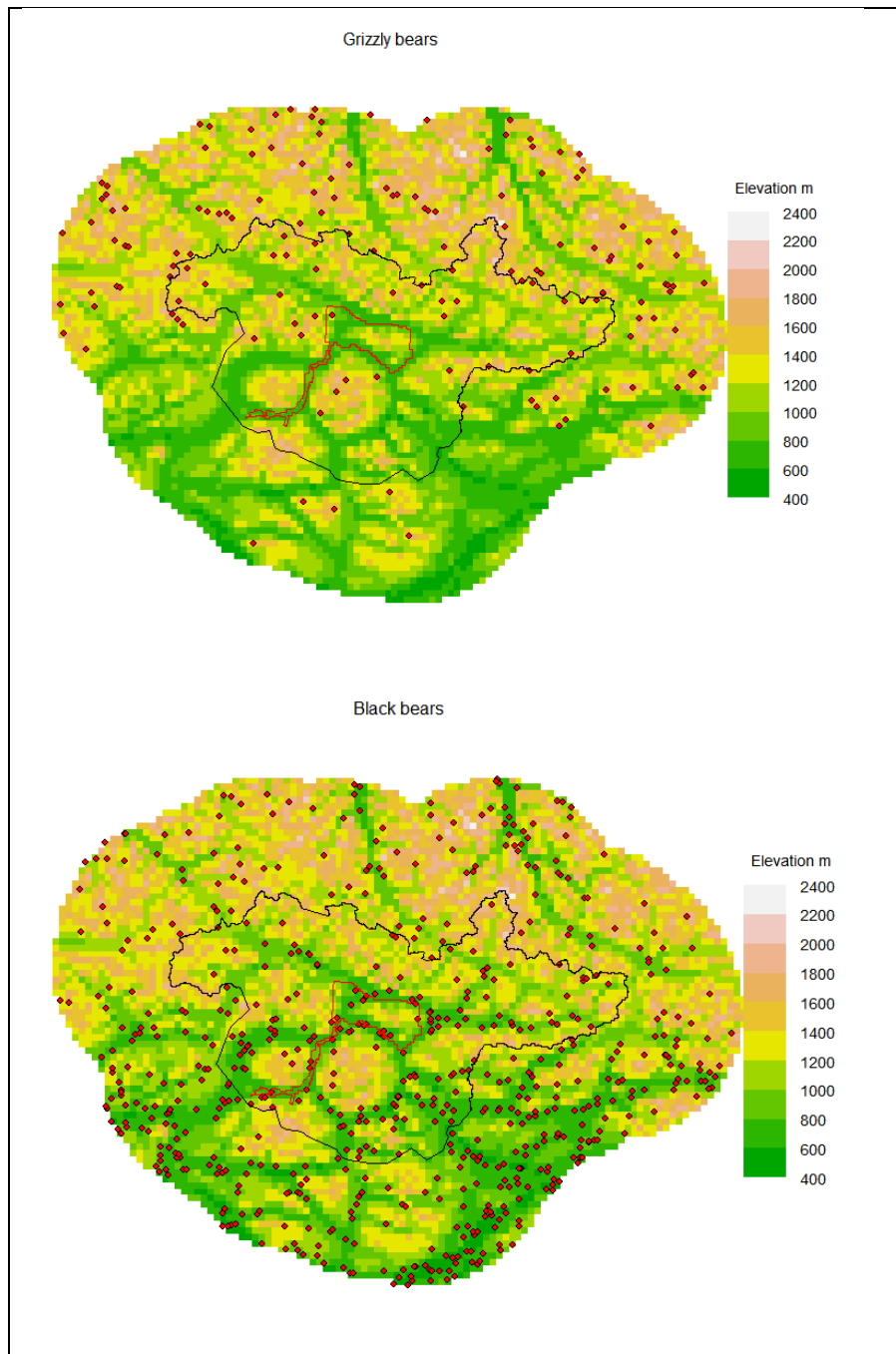


Fig. 52. Simulation of activity centres from the grizzly bear (elevation (log-smooth, 3df)) and black bears (log-linear elevation) density surface models across the entire habitat mask. The red dots are simulated activity centres.

The additive effect of mortality on density of grizzly bears

The most supported grizzly bear model contained a term for annual mortality. The β term for annual mortality was -2.4 (SE=0.91, CI=-4.7 to 0.58) suggesting a negative association with density. We suggest this result be interpreted cautiously given that the subregions are relatively broad with low sample sizes of historic mortalities. A plot of predicted density by mortality region shows reduction of density in areas that had higher historic mortality levels (Figure 13).

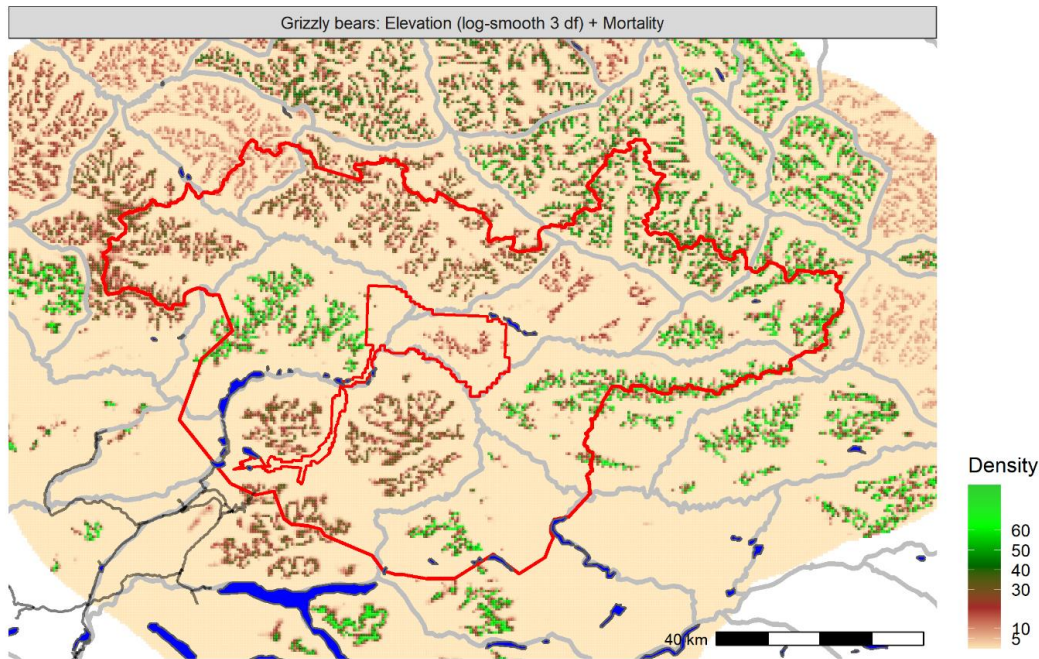


Fig. 63. Predictions for elevation + mortality model for grizzly bears in comparison to predictions in Figure 11. The subzones that defined mortality regions (Figure 5) are outlined in grey.

Estimates of bears in footprint area

The expected number of bears in the mining claims footprint polygon was estimated using the elevation density surface models. This resulted in estimates of 0.9 grizzly bears (SE=0.27, CI=0.5-1.6) and 13.6 black bears (SE=2.9, CI=8.9-20.5).

Estimates of bears who encountered the mine area during sampling, as indexed by detection function overlap of at least 5%, were 9 grizzly bears (4F, 5M) and 45 (22F, 23M) black bears. The area of overlap used for estimates is shown in Figure 14. Black bears, whose detection functions indicate smaller home ranges, have a smaller buffer area around the footprint but with higher levels of overlap within the footprint area when compared to grizzly bears. However, black bear density is higher, especially in lower elevation areas where the mining claims footprint occurs. Therefore, more black bears are in the encounter area of the mining claims footprint.

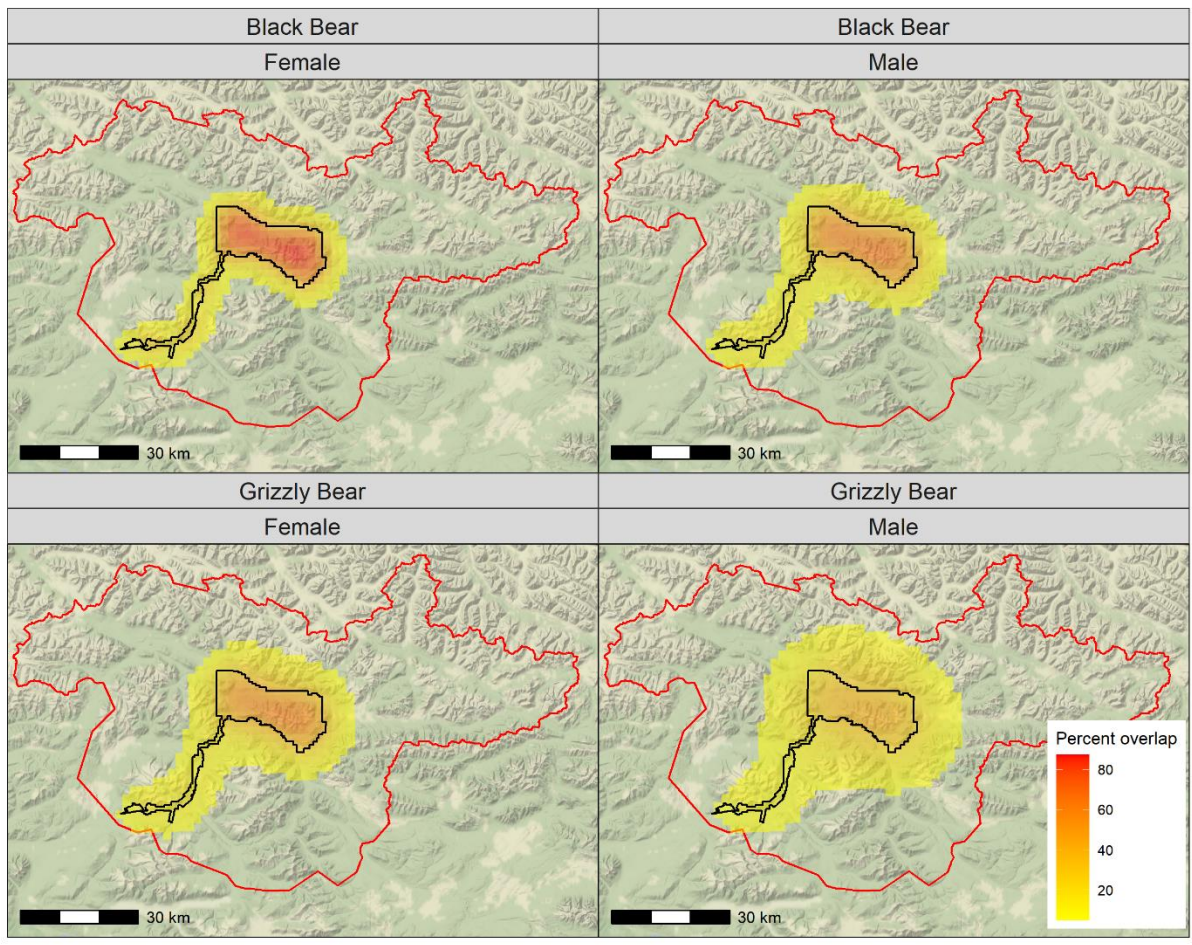


Fig. 74. The area around the mining claims footprint where the home ranges, as determined by detection functions, of black and grizzly bears overlap by greater than 5%. The percentage overlap is shown as a ramped colour scale. This area was used to estimate the number of bears that have a greater than 5% probability of encountering the mining claims footprint during the time of sampling using elevational density surface models.

Discussion

Population density and sex

Overall, the Beaver River study was successful in that estimates with target levels of precision (RSE=15%) were obtained for grizzly bears. Estimates of precision were lower for black bears which was likely due to lack of redetections caused by the large spacing of sites relative to black bear home range size. In general, the optimal design should balance the numbers of unique individuals detected and redetections of all bears across all sessions (Efford and Boulanger 2019). In the case of black bears, the limiting quantity is the number of redetections (Figure 2). In contrast, the number of redetections for grizzly bears is larger than individuals detected suggesting the number of individuals in the study area is the limiting factor in terms of precision. The high number of redetections was partially due to the trap-specific response which increased detection rates after initial site encounter.

The current analysis employed hair snagging with a wooden tripod structure, as widely used in northern regions that are void of trees (Boulanger and Branigan 2020; Efford et al. 2018). During the first and second check sessions we noted signs that bears had visited sites but not left any hair. We have no way of knowing whether the bears that visited and did not leave hair samples were detected in other sessions or in other stations during the same session. Boulanger et al. (2004) estimated in an encounter rate analysis that 63% of bears that encountered traps were snagged, however their traps were constructed of a barbed wire fence which is somewhat different than the tripod structure. Future work could benefit from a better understanding of encounter rate for tripod hair snag structures. We note that because detection probability is estimated as part of the SECR model it is not assumed that all bears that encounter sites will leave hair and a subsequent genotype. Therefore, lower site efficiency will not cause a bias in estimates, but precision is reduced when site efficiency is lower.

Conducting black bear studies concurrent with grizzly bear work is cost effective and efficient. Other studies (Stetz et al. 2014, Boulanger et al. 2008) have been able to increase the precision of population estimates by employing secondary sampling methods (e.g. sample collection from rub trees), which could be considered in future studies with black bears in mind.

The estimated grizzly bear density in the Beaver River watershed of 5.9 bears / 1000 km² is of the lowest observed in areas south of the latitudinal treeline. It is much lower than those observed in interior British Columbia and Alberta populations which were in the range of 19–49 bears / 1000 km² in mountainous areas and 10–17 bears / 1000 km² in lower elevation boreal plateau and boreal plains habitats (Mowat et al. 2005; Stenhouse et al. 2021). The Beaver River watershed grizzly bear density is also lower than those estimated for the Yukon Coastal Plains (~10–12 bears / 1000 km²) (Yukon Fish and Wildlife Branch 2017), the Southern Lakes region of Yukon (10 bears per 1000 km²) (Yukon Fish and Wildlife Branch 2016), and the Mackenzie Delta area of the Northwest Territories (9.73 bears per 1000 km²) (Boulanger and Branigan 2020). It is, however, higher than the grizzly

bear density estimate in the Kivalliq area of Nunavut (3.5 bears / 1000 km²) (Efford et al. 2018).

Our estimate of grizzly bear density is much lower than previously predicted by expert opinion (Smith and Osmond-Jones 1990). Expert-based estimates currently used for management were derived by evaluating habitat components and included expert opinions and interviews with outfitters/guides. Within the area that overlaps the Beaver River watershed, expert opinion grizzly bear densities were estimated to be 12.8 and 14.3 bears / 1000 km² in what were then the Mayo Lake-Ross River and Wernecke Mountains ecoregions respectively (now roughly corresponding to the currently mapped Yukon Plateau North and Mackenzie Mountains ecoregions; Smith et al. 2004).

A regression modeling exercise by Mowat et al. (2013) also predicted grizzly bear densities from habitat variables and human-caused mortality. Predicted grizzly bear densities in an area that overlapped the Beaver River watershed were much higher than we observed, and ranged from 28.8 – 31.4 bears / 1000 km². These differences highlight the increased need for robust science-based population work to continue across the Yukon landscape.

The current study is one of few that examines grizzly and black bear densities concurrently near the northern limit of the latter species' distribution. Black bear densities in the Beaver River watershed are about 25 bears / 1000 km², roughly four times those of grizzly bears. Black bear populations in interior Alaska have been estimated to range upward from 88.5 black bears / 1000 km², and be 3 times denser than those of brown bears in the surrounding areas (Susitna River Basin, Miller et al. 1997). There has been little work done regarding black bear densities in British Columbia, however, in the interior Parsnip plateau area grizzly bear densities were estimated to be ~16.6 bears / 1000 km² and black bear densities 257 bears / 1000 km², whereas in the Parsnip mountains grizzly bear densities were higher at 49 bears / 1000 km² and black bear densities lower at 100 bears / 1000 km (Mowat et al. 2005). Stetz et al. (2014) estimated black bear density to be 114 bears / 1000 km² in Glacier National Park, approximately twice the estimated density of grizzly bears in the area. It is recognized that the pattern of black bear density complements that of grizzly bears, with black bears more abundant where grizzly bears are in low densities or absent (Miller et al. 1997, Mowat et al. 2014). In addition, black bears in mountains are typically detected in the valley bottoms and rarely detected near the treeline (Mowat et al. 2005).

Our analyses did not directly try to model the relationship between grizzly and black bears. However, results suggest they do inhabit areas of different elevation. Habitat segregation is not complete: some black bears are still found within moderate elevation areas that grizzly bears inhabit. Other studies of grizzly and black bear range overlap suggest that both habitat selection and behavioural avoidance are likely causes of segregation (Stetz et al. 2019).

There is compelling evidence to support the hypothesis that when black bears exist at high densities on the landscape and there is substantial diet overlap, black bears can negatively affect grizzly bears through exploitation competition (Mattson et al. 2005; Stetz et al. 2019). Black bears also have a shorter inter-birth interval, and use much smaller ranges than adult female grizzly bears, collectively these characteristics result in an overall higher unit

productivity (Mattson et al. 2005). For low-density grizzly bear populations, exploitation competition could depress reproductive rates (Mattson et al. 2005).

The nearly even sex ratio for both species is not remarkable, as sex ratios can vary. DNA mark-recapture population studies in Alberta Bear Management Areas (BMAs) resulted in female grizzly bear densities that were higher than those of males in four BMAs, and lower than those of males in two BMAs (Appendix S1, Boulanger et al. 2018; Stenhouse et al. 2021). Genetic mark-recapture work in Banff National Park suggested higher densities of male grizzly bears than females in both years examined (Sawaya et al. 2012). Stetz et al. 2014 also found black bears in Glacier National Park Montana to have a functionally even sex ratio at 56% female. More locally, previous population work conducted in the Southern Lakes and North Slope regions of Yukon revealed a sex ratio slightly favoring females (61% and 54–55% female respectively) (Yukon Fish and Wildlife Branch 2016; 2017).

Density surface models

Density surface models revealed elevational gradients in density of both black and grizzly bears (Figures 9–11). These models will provide a refined baseline for future sampling efforts to assess any shift in the distribution of bears caused by mine or new access development. For example, these models document that grizzly bear density is already low in valley areas and therefore any reduction is likely to occur in mid-elevation zones. In contrast, black bears are common in lower areas and may be more susceptible to the direct effects of mine and road development. These results are further supported by estimates of black bears likely to encounter the mine area (45) compared to grizzly bears (9). The spatial area of influence by the mining claims footprint also differs for grizzly and black bears based on their scale of movement (Figure 13).

Lower support of landcover as a predictor of bear density is not surprising given that (i) elevation strongly predicts the distribution of landcover in this landscape, and (ii) landcover varied on a scale finer than the size of bear home ranges, especially grizzly home ranges. If the objective of the density surface model is to describe distribution, then elevation could be an adequate descriptor. It might be possible to further improve landcover models, but the relatively low number of grizzly bears detected would likely limit the development of more complex models.

A quartz claim covariate was used to assess if current disturbance might be influencing grizzly and black bear densities. This covariate was not supported for grizzly bears with weak support for black bears. We suggest that this covariate should be interpreted cautiously for a variety of reasons. First, it is hard to ascertain the actual level of activity and disturbance associated with claims and therefore an association with density is difficult to assess. Second, claims mainly occurred in lower elevation and therefore there was potential confounding with elevational gradients in bear density. Finally, the density surface models are mainly oriented towards the detection of variation in population density (the distribution of home range centers), and behavioural changes due to helicopter traffic or smaller scale disturbance that affect the distribution of activity within home ranges are unlikely to be detected. We suggest that future monitoring efforts should track activity levels within claim areas to allow more precise inference regarding disturbance.

The support of annual mortality as a predictor of density could be investigated further if more detailed information on mortalities, such as specific locations, were available. Regardless, the support of this covariate demonstrates the need to track mortalities including obtaining genotypes of mortalities. Other studies of grizzly bears (Boulanger and Stenhouse 2014, Neilsen et al 2004, Boulanger et al. 2018) have demonstrated that mortality, as reflected by road density or mortality models, is one of the stronger predictors of grizzly bear distribution.

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Appendices

Appendix 1. Example of R code for fitting SECR models

```
# define function to fit a suite of different detection models
fittwo <- function (species = 'Black', mask = 'bkmask', ...) {
  models <- list(
    null = list(),
    t = list(lambda0~t+h2, sigma~t+h2),
    T = list(lambda0~T+h2, sigma~T+h2),
    b = list(lambda0~b+h2, sigma~h2),
    bk = list(lambda0~bk+h2, sigma~h2)
  )
  mod <- expand.grid(dfn = c('HHN','HEX'), modeli = 1:length(models),
    stringsAsFactors = FALSE)
  fits <- list()
  for (m in 1:nrow(mod)) {
    cat('Fitting model ', paste0(mod$dfn[m], names(models)[mod$modeli[m]]), ' ',
      format(Sys.time(), "%H:%M:%S %d %b %Y"), '\n')
    fits[[m]] <- secr.fit(
      capthist = BRCH[[species]],
      hcov = 'Sex',
      detectfn = mod$dfn[m], # choose detection function HHN, HEX
      model = models[[mod$modeli[m]]], # choose model
      mask = mask,
      details = list(fastproximity = FALSE),
      ...)
  }
  out <- secrlist(fits) # form 'secrlist' object
  names(out) <- paste0(mod$dfn, names(models)[mod$modeli])
  out
}
#-----
library(secr) # load package
setNumThreads(7) # number of cores for parallel processing
BRCH <- readRDS (file = 'BRCH.RDS') # read previously prepared data object
bkmask <- make.mask(traps(BRCH[[1]]), buffer = 20000, type='trapbuffer',
  spacing = 2000)
brmask <- make.mask(traps(BRCH[[1]]), buffer = 40000, type='trapbuffer',
  spacing = 2500)
# fit suite of models for each species
fitbk <- fittwo('Black', bkmask)
fitbr <- fittwo('Grizzly', bkmask)
AIC(fitbk, criterion = 'AIC', sort = FALSE) # compare fitted models
predict(fitbk) # etc.
#-----
```

Appendix 2. Check on buffer width

The selected model was re-fitted with wider buffers as a check. The estimated population density of each species did not change:

Black bear

Buffer	Density estimate / 1000 km ²
20 km	25.1 (17.1, 36.8)
25 km	25.0 (17.0, 36.6)
30 km	25.1 (17.1, 36.8)

Grizzly bear

Buffer	Density estimate / 1000 km ²
40 km	5.94 (4.45, 7.92)
50 km	5.93 (4.44, 7.92)
60 km	5.93 (4.44, 7.92)