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INUVIK-TUKTOYAKTUK HIGHWAY 2013 and 2014 GRIZZLY BEAR DNA INVENTORY: ESTIMATES AND DENSITY SURFACE MODELING

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ABSTRACT

This report summarizes field collection and analyses for a grizzly bear (*Ursus arctos*) DNA mark-recapture study conducted as part of the Wildlife Effects Monitoring Program (WEMP) for the Inuvik to Tuktoyaktuk Highway development project. The main objective of the first two years of the study was to collect baseline population abundance and density estimates for grizzly bears in the area surrounding the proposed highway. A grid of 93 and 101 DNA collection tripods spaced in 10x10 km cells were placed in the Mackenzie Delta, west and east of the proposed highway in 2013 and 2014 respectively. Tripods were sampled for four sessions from mid-June to mid-August 2013 and 2014. Seventy-five grizzly bears (46 females, 29 males) and 77 (45 females and 32 males grizzly bears) were detected over the four sampling sessions in 2013 and 2014 respectively. Overall, 57 females were detected in 2013 and 2014 with 34 being detected in both years. For males, 46 individuals were detected with 14 being detected in both years. Detections were highest in the northwest corner of the grid and decreased towards the southeast corner. Spatially explicit mark-recapture methods that modeled the layout of DNA collection tripods and excluded ocean areas of non-habitat were used to estimate density. Mean grizzly bear density was estimated to be 9.73 bears per 1,000 km^2 (CI=6.7-18.4) for 2013 and 2014 and the average number of bears that used the grid was 93 (CI=70-124). Spatially explicit methods estimated that bears whose home range centers were within 20-25 km of the proposed highway were most likely to be detected in the vicinity of the highway. Density of grizzly bears relative to the proposed road area was estimated using density surface models. Density was related to deciduous cover for both male and female bears. Estimated density was lower in areas around the road with an overall increasing density gradient in the southwest to northwest direction on the sampling grid. Open model analyses revealed relatively stable populations of male and female bears over the 2013/2014 time period. Females had higher apparent survival rates with lower rates of addition of new bears whereas males had lower apparent survival and higher rates of addition. It is recommended that the grid is resampled in 2017 or 2018 which will also coincide with completion of the road in the summer of 2017.

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INTRODUCTION

Grizzly bears (*Ursus arctos*) are a high-profile species of local, national and international interest. Grizzly bears are an important furbearer species in the Inuvialuit Settlement Region (ISR) and have been managed under a quota since the late 1980s - early 90s. Inuvialuit have exclusive rights to hunt grizzly bears in the ISR and allow the transfer of that right to guided hunters. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed the status of grizzly bears in Canada as Special Concern (COSEWIC 2011); similarly the Northwest Territories (NWT) Species at Risk Committee (SARC) also assessed grizzly bears as Special Concern in the NWT. The inclusion of grizzly bears in the Wildlife Effects Monitoring Program (WEMP) for the construction of the Inuvik-Tuktoyaktuk Highway is based on this status, their low tolerance to human disturbance, and concern over how the proposed highway may result in changes in distribution and increased mortality of the species.

Industrial development presents several threats to bear populations including the potential for increased destruction of 'problem' bears, potential for collisions with vehicles, and the alteration and fragmentation of habitat. The highway may increase ease of access and therefore possibly cause increased mortality from hunting. However, hunting is managed under a quota system and all human caused mortalities are counted under the quota. Any increases in mortalities due to bear-people conflicts or collisions will cause a decrease in tags available to harvesters.

Developments within the Arctic may present a relatively high risk to grizzly bear populations due to the natural low density of bears in these areas at the northern fringe of their range, the relative scarcity of high quality habitat (and corresponding large area requirements), and the increased vulnerability of bears in open tundra habitats (Ross 2002). During and after construction, grizzly bears may use areas along the highway less than expected as a result of noise from construction activity, camps, and vehicle traffic. Alternatively, grizzly bears may be attracted to camps, cabins, or construction activity if waste and odours are not properly managed; these individuals may be removed from the local population as problem wildlife. After the highway is opened, additional mortalities may occur if grizzly bears that are attracted to ungulate kill sites near roads are themselves hunted or trapped (ungulate kill sites would occur if future harvesting of caribou or other species occurs along the highway or because of animals killed by vehicles). Direct grizzly bear mortality associated with vehicle collisions is expected to be a rare event.

As part of the WEMP, grizzly bear abundance monitoring in the Inuvik-Tuktoyaktuk Highway area was initiated in 2013 during the preconstruction phase of the highway. The study design employed hair snagging for DNA analysis within the Regional Study Areas (RSA). There are many challenges to monitoring the effect of the road on grizzly bears given the large extent of their movements relative to the road area, and the likely large but unknown scale of impacts. The planned approach for monitoring grizzly bears is to estimate bear abundance prior to road construction, during road construction, and during regular use once constructed. Open mark-recapture models will be used here to analyze the bear hair snag DNA data over time. This will allow demographics estimates and will help infer mechanisms for population change in the study area. The study area will be large enough to allow a "control" area and an "impact" area. Spatially explicit mark-recapture methods will also be used to estimate changes in bear density relative to the road area over the course of monitoring.

The objectives of the 2013/2014 grizzly bear DNA inventory were to:

- Assess whether sample sizes of bears, study area extent, and other study design features were adequate to monitor grizzly bear abundance relative to road construction.
- Estimate grizzly bear abundance and distribution during the pre-construction period within the Inuvik to Tuktoyaktuk Highway area.
- Build baseline habitat-based models of grizzly bear distribution relative to the road to be used to infer changes in bear distribution and density relative to the road once construction occurs.
- Conduct baseline demographic analysis of the 2013 and 2014 data to estimate apparent survival and rates of addition for male and female bears on the DNA sampling grid.

In this report grizzly bear population and density estimates from sampling conducted in 2013 and 2014 are described with an emphasis on determining the adequacy of the sampling design. The primary focus of this analysis is estimation of grizzly bear population size, density, and modeling of variation of density on the sampling grid.

The intent is for this to be a two-year program to establish baseline distribution, abundance and density estimates for grizzly bears in the study area.

METHODS

Field Methods

The field design for the grizzly bear DNA inventory was based on studies conducted elsewhere in the Arctic: Government of Nunavut study near Kugluktuk (Dumond et al. 2014); Newmont project near Hope Bay (C. Kent, Rescan, unpublished data); NWT diamond mines study near Lac de Gras (B. Milakovic, Rescan, unpublished data); and Izok project (K. Poole, Aurora Wildlife Research, unpublished data), which were developed from research initiated in British Columbia (Woods et al. 1999, Boulanger et al. 2002, Proctor et al. 2010).

The Inuvik-Tuktoyaktuk Highway grizzly bear DNA inventory was conducted by helicopter from 17 June to 20 August 2013. The initial study area consisted of 100 grizzly bear hair-snagging tripods set out in 10x10 km grids within a 10,000 km^2 study area, which buffered the proposed highway alignment by 30-40 km, and included Richards Island and the northern portion of the Mackenzie Delta; this western area is to serve as a spatial "control" where it is assumed that bear demographics will not be affected by the road. In 2013, part of the north-western section of the study area was too wet for tripod deployment, thus 15 cells within islands were removed and other cells were added to better buffer the highway and to reduce edge effect in 93 10x10 km cells within a resulting 9,300 km^2 study area (Figure 1). In 2014, the study was conducted from 16 June to 13 August with eight additional cells added to the south and north in the vicinity of Inuvik and Tuktoyaktuk (Figure 1).

The 10x10 km cell size was based upon the results of previous barren-ground grizzly bears studies which achieved adequate detection rates for barren-ground grizzly bear populations (Boulanger 2013, Dumond et al. 2014). In addition, the 10x10 km cell size is smaller than the smallest annual home range of a female with cubs ($\bar{x}$ =294 km^2) as determined from an earlier grizzly bear study in the project area (Edwards 2009).

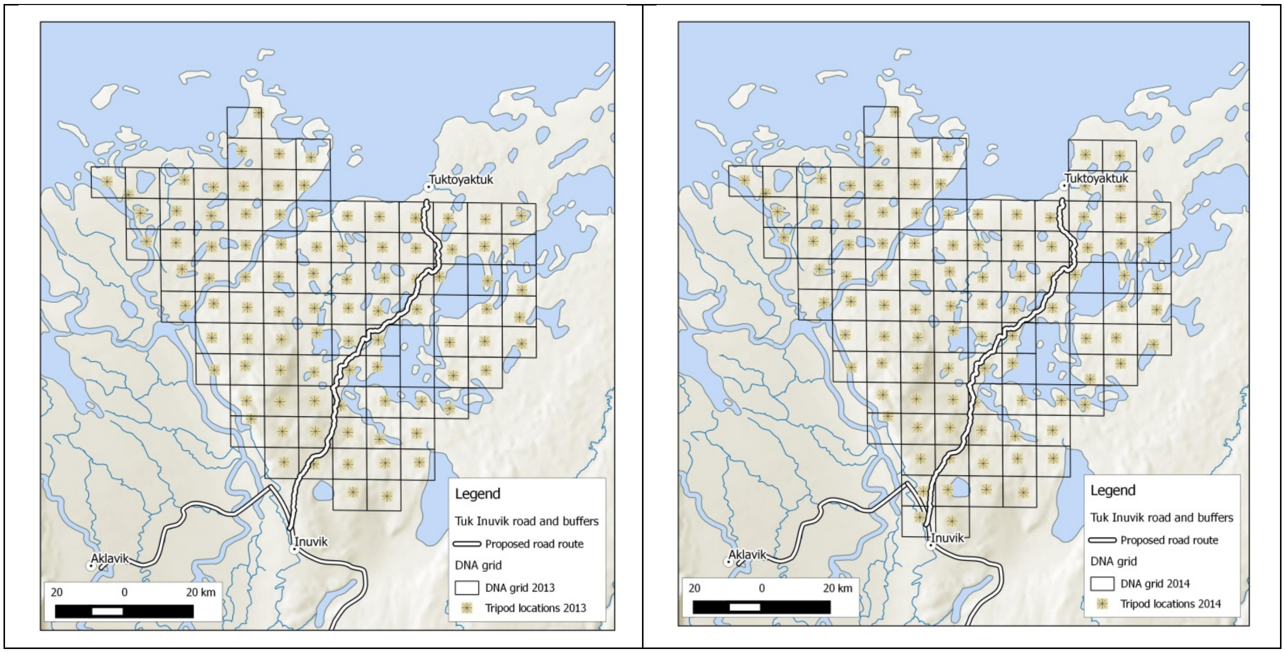

Figure 1. Inuvik-Tuktoyaktuk Highway grizzly bear DNA Sampling Grid, June to August in 2013 and 2014.

Tripods were deployed for four sessions of approximately 14 days each. Tripod design was based on recent work at Izok Lake (Aurora Wildlife Research and EDI Environmental Dynamics Inc., unpublished data) and consisted of six 2"x4" pieces of lumber 5'3" in length and secured at the corners with aircraft cable. Each upright 2"x4" leg was wrapped with double-stranded 15 1/2 gauge four-point high-tensile barbed wire to trap grizzly bear hair (Photo 1). Tripod materials were prepared prior to deployment (drilling holes, wrapping barbed wire, cutting aircraft cable, etc.) and assembled in the field by teams of two using a single A-Star B2 helicopter for transportation. Tripods were deployed near or within 1-2 km of each grid cell centre in the best apparent grizzly bear habitat available (sparsely vegetated or shrubby areas adjacent to water (Edwards 2009)). Large water bodies or avoidance of cabins occasionally resulted in placement slightly further from the cell centre. Tripod bases were not anchored because large rocks are extremely uncommon on the landscape.

Photo 1. Grizzly bear hair snagging tripod.

Lures were spread or poured atop the tripod on a piece of felt underlain by moss for absorption, and on a pile of moss and other vegetation in the centre of the tripod. Sites were revisited four times at approximately 14-day intervals to collect hair and re-bait with different combinations of blood, fish oil, and trapping lures. At the end of each session, hair samples were removed with forceps, placed in coin envelopes, and labeled with tripod number, session number, leg number, and cluster and barb number (an alpha-numeric combination) to facilitate subsampling at the lab. A propane torch was used to remove any remaining hair. Hair samples were dried each night and stored cool and dry.

All samples were sent to Wildlife Genetics International (WGI; Nelson, BC, Canada) for microsatellite genotyping. Individuals were identified using seven genetic markers, including six microsatellites and a gender marker. In 2014, an additional marker was added due to low observed heterozygosity. WGI analyzed one sample per tripod leg, except when there were multiple clusters on a given leg, in which case up to two samples were analyzed. In addition, up to two samples were analyzed from the ground per collection device, for a total of up to eight analyzed samples per cell/check combination. A quality threshold of a minimum of two guard hair roots or 20 underfur hairs were used. The genotyping procedures are described further in published studies from WGI (Paetkau 2003, Paetkau 2004, Paetkau et al. 2004).

Spatially Explicit Mark Recapture Analysis to Estimate Grizzly Bear Density and Population Size

Spatially explicit capture-recapture (SECR) methods (Efford 2004, Efford et al. 2004, Efford et al. 2009, Efford 2011), also known as spatially explicit mark-recapture methods, were used to estimate grizzly bear density. Spatially explicit methods estimate the spatial scale movement for bears that are detected repeatedly to estimate the area that individual bears covered during sampling. Unlike closed models, that pooled data from multiple tripods within each session for each bear, the SECR method used multiple detections of bears at unique tripods within a session to model bear movements and detection probabilities. Using this information, the detection probabilities of grizzly bears at their home range center (g_0), spatial scale of grizzly bear movements (σ) around the home range center, and bear density were estimated. An assumption of this method is that grizzly bear home range can be approximated by a circular symmetrical distribution of use (Efford 2004). The actual shape and configuration of the sampling grid was used in the process of estimating home range, scale of movements and density, therefore accounting for the effect of study-area size and configuration on the degree of closure violation and subsequent density estimates. For the study area a habitat mask, that accounted for areas unusable to grizzly bears such as the ocean and large lakes within and in the immediate area of the sampling grid, was used to ensure the study area size included only useable habitat.

As an initial step in the modeling process the effective sampling area (termed the habitat mask) of the grid was estimated. The effective sampling area in the context of spatially explicit modeling is the grid and surrounding area where a bear could be detected. Using an iterative process this was estimated to be the grid and a buffer area of 30 km surrounding the grid. Significant water bodies such as the ocean and large lakes were also modeled as non-habitat and density was set to 0 in these areas as indicated by no mask centroids over these areas (Figure 2). This mask area was used for both the male and female analyses.

Analyses were conducted separately for each sex but with years treated as sessions. This approach was optimal given that male and female bears have different scale of movement and detection SECR parameters (Boulanger et al. 2014). By treating the years as sessions, it was possible to test for differences in densities between years as well as test for differences in distribution in the context of density surface modeling. As an initial step "activity centers" of bears were estimated using baseline SECR models (Royle et al. 2013, Royle et al. 2014, Kendall et al. 2015). This approach provides an initial assessment of likely locations of home range centers of bears, however, it is also influenced by trap placement and edge areas of the grid (Efford 2014a). Therefore density surface models were used to further model and explore factors associated with observed bear density on the sampling grid (Boulanger et al. 2018).

Variation in Grizzly Bear Density

The primary objective of baseline spatially explicit analyses was to assess variation in density on the sampling grid relative to the road. The longer-term objective is to use the methods and baseline estimates to evaluate potential changes in the distribution of grizzly bears relative to the road once the road is operational.

Two approaches were used to establish baseline densities of bears and provide a method to assess potential impacts of the road once it was operational (Table 1). The first approach stratified the DNA grid area by distances where road encounter was most likely based on estimated movements from analysis of the 2013 data set (Boulanger et al. 2014) to estimate broad scale effects of the road. The second approach attempted to describe natural variation on the sampling grid based on landcover covariates. Once this model was developed, the distance of each SECR centroid from the road was entered as an additional covariate. This approach could potentially allow a direct estimate of "zone of influence" of the road (Boulanger et al. 2012, Boulanger et al. 2016) rather than an assumed distance used in the strata-based approach.

Table 1. Summary of approaches used to assess impacts of road on grizzly bear density.

Objective	Approach	Details
Broad scale effects of road	Stratified estimate of bears within vicinity of road.	Estimates of bears within 20 km (females) and 25 km (males) of road.
Estimated scale of impact of road	Density surface model to describe natural variation in density. Estimated "zone of influence" of road where density is affected by road.	Most supported density surface model with distance from road as a covariate. Support of density surface models with distance from road term evaluated.

Stratified Estimates of Areas near Road

The DNA grid area was stratified based on likely areas of movement and detection for male and female bears relative to the route of the road. For this approach, SECR centroids that were within the 20 or 25 km distance of the road were classified as male or female strata with centroids beyond the buffers being categorized as "control" strata. The 20 and 25 km distances were based upon estimates of movement during sampling from SECR analysis of the 2013 data set. Using this approach allowed specific estimates for the road buffer areas in comparison to areas outside the buffer (Stenhouse et al. 2015). When the road is active this approach will allow comparison of trends in density in the road buffer areas in comparison to control areas using a before and after controlled impact (BACI) type design (Underwood 1997).

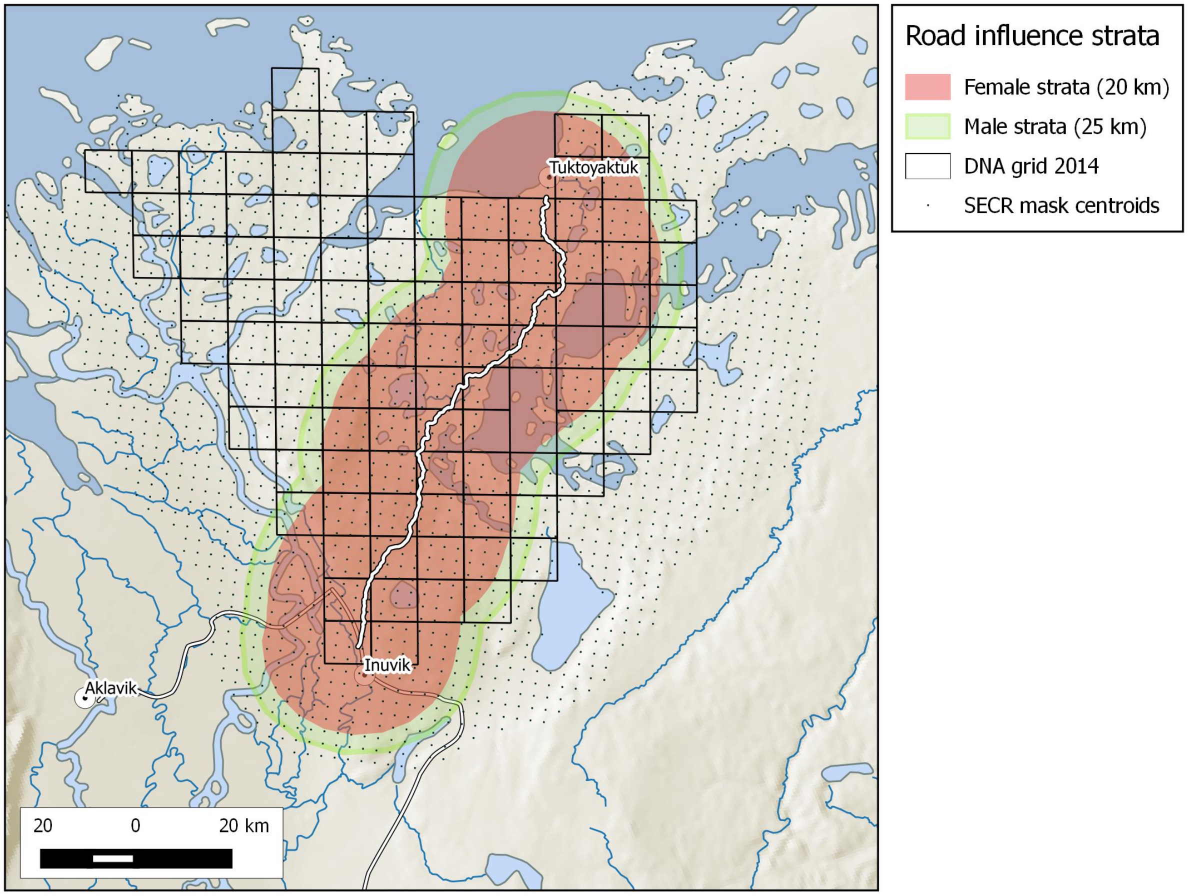

Figure 2. Proposed Inuvik-Tuktoyaktuk Highway with SECR based buffers of 20 km (females) and 25 km (males) which define the potential area of greatest influence of the road on grizzly bears during sampling. In addition, centroids of the habitat mask used by the SECR model are shown.

Structural Relationships between Habitat Covariates using Density Surface Modeling

Spatially explicit mark-recapture models were used to model variation in grizzly bear density on the study grid area and to estimate population size and density for areas that were in the proximity of the Inuvik-Tuktoyaktuk road. This approach also provided a baseline model of density in the study area and will allow estimation of the zone of influence of the road on grizzly bear density once the road is in place through the use of distance from road as a covariate in the density surface model.

Spatially explicit mark-recapture methods estimate density for a systematic grid of points/centroids that are overlaid on the study area (termed the habitat mask; Figure 2). For non-spatial models it is assumed that bear density is equal for each mask point. Density surface models estimated bear density at each mask centroid based upon habitat covariates summarized around the mask point. The fit of each of the density surface models was then compared to models that assumed similar density for each mask point. This approach is similar to resource selection function (RSF) models that are fit to detection frequencies at DNA collection sites with the strong advantage that the response surface is a systematic grid of points rather than trap locations (Efford and Dawson 2012, Efford and Fewster 2013, Royle et al. 2013, Royle et al. 2014, Boulanger et al. 2018).

Remote sensing data and previous RSF analyses based upon collared grizzly bears were used (Edwards 2009) to formulate density surface models. The covariates used for density surface modeling included RSF scores, which categorized each 28.5 m^2 patch of vegetation, from Edwards (2009) as well as habitat covariates used to formulate the RSF models (Table 2). The coverage of the RSF and landcover surfaces included all tripod sites but excluded some of the areas in the southwest of the sampling grid (Figure 3); scores for these areas were based upon scores of the closest mask centroid. Coverage of the RSF model extended to where the hair collection sites occurred and therefore the overall effect of missing RSF scores for peripheral areas probably was not substantial. Dwarf shrub and water were the most dominant landcover forms in the study area comprising over 50% of centroid buffer areas (Table 2, Figure 3).

Table 2. Habitat covariates used for density surface modeling based upon Edwards (2009). The mean, min, and max percentage area in the 1 km buffer area around each centroid is also given.

Habitat covariate	Dominant land cover features	Mean	Minimum	Maximum
Forest				
Coniferous				
Closed spruce	Closed mixed needleleaf	0.1	0.0	11.1
Open spruce	Open spruce	0.2	0.0	9.7
Deciduous				
Closed Deciduous	Closed birch	0.9	0.0	41.7
Open Deciduous	Open birch	2.2	0.0	36.0
Shrub				
Dwarf shrub	Dwarf shrub	28.3	0.0	88.6
Low shrub lowland	Low shrub willow alder	5.2	0.0	42.7
Tall shrub	Closed tall shrub	6.0	0.0	66.5
Low shrub upland	Low shrub-tussock tundra	6.0	0.0	42.7
Barren/sparse				
Sparse vegetation	Sparse	4.6	0.0	99.3
Herbaceous				
Herbaceous	Mesic dry meadow	6.1	0.0	84.3
Wet herbaceous	Wet graminoid	6.5	0.0	55.0
Water				
Water	Clear water	24.7	0.0	100.0

Habitat covariates were extracted within a 1 km buffer around each centroid. The proportion of area of each covariate was measured. Habitat covariates within a 500 m buffer of each tripod location were also extracted to determine if habitat also influenced detection rates at tripod sites.

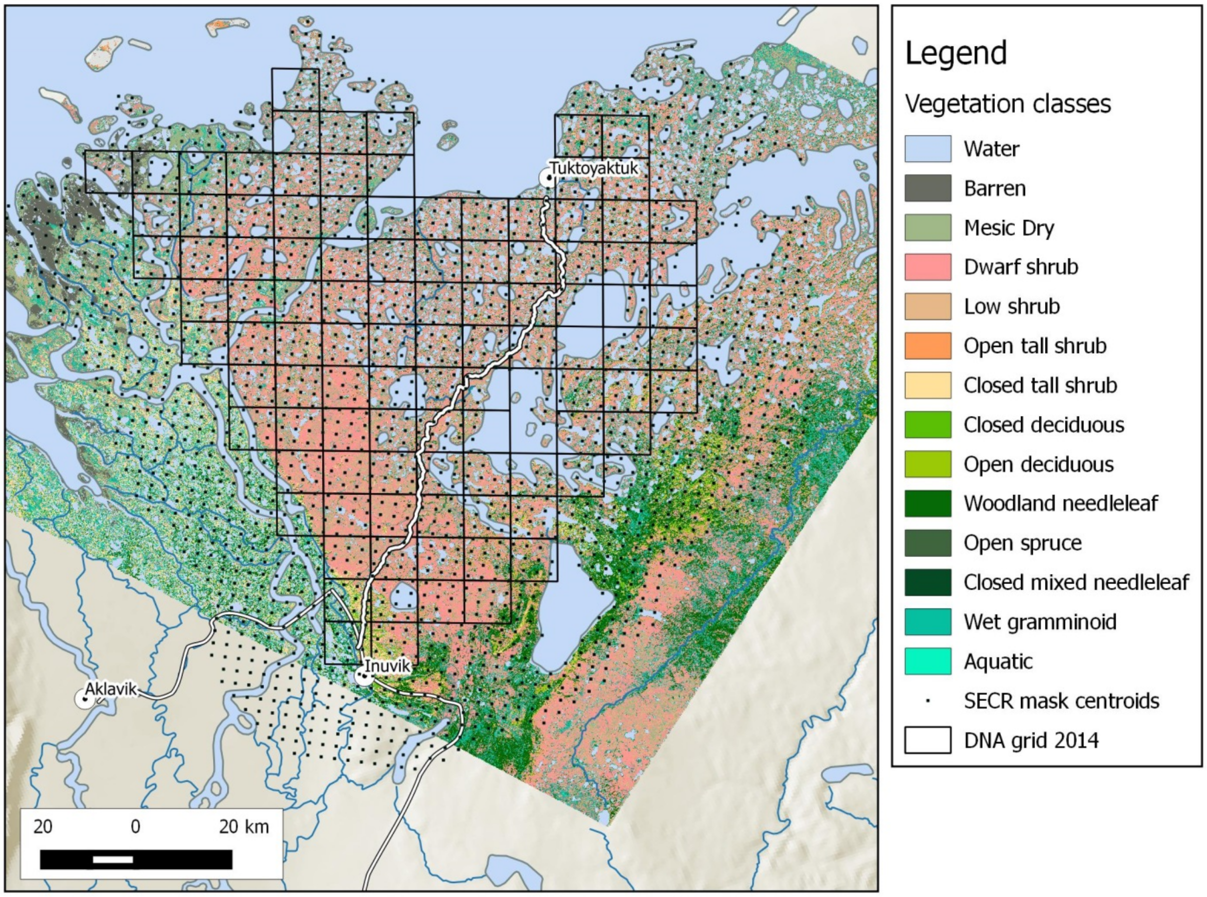

Figure 3. Habitat mask centroids, DNA tripod sites, and landcover covariates used in the density surface model exercise.

It is likely that the proportion of habitat classes across centroids were structurally related given the similarity of land cover and likely associations among different vegetative types. Of most interest in modeling was determination of the most parsimonious combinations of covariates to describe grizzly bear density and therefore it was useful to assess this structure. Principal components analysis was used to discern structural relationship between habitat covariates to allow further interpretation of density surface modeling results (Tabachnick and Fidell 1996, McGarigal et al. 2000). The results of this analysis are given in Appendix 2.

Density surface models were built separately for male and female grizzly bears given likely differences in habitat selection and previous RSF modeling (Edwards 2009). The most supported SECR model from the initial SECR analysis was used as a base model for the density surface analysis. Habitat covariates were added individually to compare support to the base model using information theoretic model selection methods (Burnham and Anderson 1998). The relative fit of models was evaluated using the sample size adjusted Akaike Information Criterion (AIC_c). The model with the lowest AIC_c score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AIC_c values between the most supported model and other models (ΔAIC_c) was also used to evaluate the fit of models when their AICc scores were close. In general, any model with a ΔAIC_c score of less than two was worthy of consideration.

Regional Estimates of Population Size Relative to the Proposed Road

The realized or average number of grizzly bears that could potentially encounter the road at any one time was estimated (by spatially explicit mark-recapture models) (Efford and Fewster 2013). Estimates from models that assumed constant density throughout the study area were compared to density surface models that accounted for habitat specific variation in density for the entire grid and the road strata.

Analyses were conducted primarily in R (R_Development_Core_Team 2009) program SECR (Efford 2014b) with data screening conducted in the Windows-based program DENSITY (Efford et al. 2004). Program SECR uses a maximum likelihood approach to estimate model parameters (Borchers and Efford 2008, Efford et al. 2009). Full likelihood models were used for model fitting. Results were plotted using the *ggplot2* package (Wickham 2009) in R.

Open Model Demographic Analyses

The Robust design (Pollock and Otto 1983) Pradel model (Pradel 1996) in program MARK (White and Burnham 1999) was used to estimate demographic parameters from the 2013 and 2014 data. Detection probability (p*) was estimated for each year using the Huggins closed population size model (Huggins 1991) and the change in population size (λ) as well as apparent survival (ϕ) and rates of additions between years (*f*) was estimated using the Pradel model. Apparent survival (ϕ) is the probability that a bear that was on the grid in one sampling year would still be on the grid in the next sampling year. It encompasses both deaths and emigration from the sampling grid. Rate of addition (*f*) is the number of bears on the grids in the current year per bear on the grid in previous year. It encompasses both births and immigration of grizzly bears from outside the grid area during the time period between. Apparent survival and rates of addition are added together to estimate change in population size (λ) for the interval between each sampling occasion. Population rate of change is equivalent to the population size for a given sampling period divided by the population size in the previous sampling period ($\lambda=N_{t+1}/N_t$). Given this, estimates of λ will be one with a stable population, less than one if the population is declining and greater than one if the population is increasing.

Sex was entered as a group in this analysis to allow sex-specific estimates of demography. Models were built that considered sex-specific, grid-specific and year-specific capture probabilities and demographic parameters. As with SECR models, the fit of models was evaluated using information theoretic (AIC) methods.

RESULTS

Summary of Sessions

The number of samples collected was higher in 2013 compared to 2014. However, the proportion of tripods with hair was similar in 2013 and 2014 (Table 3).

Table 3. Summary of sampling success for 2013 and 2014. The number of tripods employed in 2013 and 2014 was 93 and 101 respectively.

Year Session	Sampling interval (days)	Samples collected	Tripods with hair
2013			
1	14.4	231	18 (19%)
2	13.6	271	26 (28%)
3	14.1	282	29 (31%)
4	18.4	478	35 (38%)
Pooled	15.1	1262	60 (65%)
2014			
1	12.8	140	21 (19%)
2	14	309	30 (30%)
3	15	287	33 (33%)
4	13	253	33 (33%)
Pooled	13.7	989	57 (56%)

Summary of DNA Data

Genotyping success, as estimated by the percentage of viable hair samples that yielded successful genotypes, was 70% and 61% for 2013 and 2014 respectively. Differences in success were due to sample quality (higher frequencies of under fur samples and ground samples in 2014 than 2013) as well as probable weather factors as has been shown in other northern grizzly bear studies (Dumond et al. 2015). An additional genetic marker was added in 2014 to ensure accurate individual identification in partially due to low variability and high consanguinity in region of Richards Island.

Overall, 75 (46 females, 29 males) and 77 (45 females and 32 males grizzly bears) were detected over the four sampling sessions in 2013 and 2014 respectively (Table 4). The number of unmarked (bears not previously detected and genotyped) bears in each session decreased for both males and females in both years, however, new bears were detected in the fourth session suggesting that not all bears were detected on the grid during sampling. Detection frequency, which is the number of sessions that each bear was detected, demonstrated that sampling was efficient with 41 bears detected once and 34 bears detected more than once for 2013, and 38 bears detected once and 39 detected more than once for 2014. The number of bears detected increased after session one and stayed relatively even for females across sessions. In contrast, detections were relatively similar for each session for males in both 2013 and 2014. One female black bear was detected in the far south cell of the grid in the proximity of Inuvik.

Table 4. Summary statistics of the number of grizzly bears detected during the Inuvik-Tuktoyaktuk Highway grizzly bear project in 2013 and 2014. All samples from an individual bear were pooled within each session for this summary for 'Bears detected,' 'Unmarked bears,' and 'Cumulative bears.' Detection frequencies refers to number of individual bears captured during one to four (all) sessions that year.

	2013 Sessions				2014 Sessions			
Statistic	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Females								
Individual bears detected	11	20	22	21	13	22	20	17
Unmarked bears	11	15	12	8	13	19	6	7
Cumulative bears	11	26	38	46	13	32	38	45
Detection frequencies	25	15	5	1	20	23	2	0
Males								
Bears detected	12	13	13	11	10	15	13	12
Unmarked bears	12	8	7	2	10	11	4	7
Cumulative bears	12	20	27	29	10	21	25	32
Detection frequencies	16	7	5	1	18	10	4	0
Males + Females								
Bears detected	23	33	35	32	23	37	33	29
Unmarked bears	23	23	19	10	23	30	10	14
Cumulative bears	23	46	65	75	23	53	63	77
Detection frequencies	41	22	10	2	38	33	6	0

Summary of Distribution of Bears on the Sampling Grid

A plot of mean detection locations shows that the northern part of the grid had the most detections with fewer detections in the southeast portion of the grid (Figure 5) for both 2013 and 2014. Overall, 57 females were detected in 2013 and 2014 with 34 being detected in both years. For males, 46 individuals were detected with 14 being detected in both years. Overall there were 103 individual bears over the two years. For bears detected both years the mean distance between mean detection locations on the sampling grid was relatively small (Females, mean distance=8.3 km, std. dev.=7.1, min=0.01, max=30.5, n=34 Males: mean distance=14.1 km, std. dev.=11.6, min=0.1, max=37.6, n=14). The demography of the population is explored further using open population models in later sections of this report.

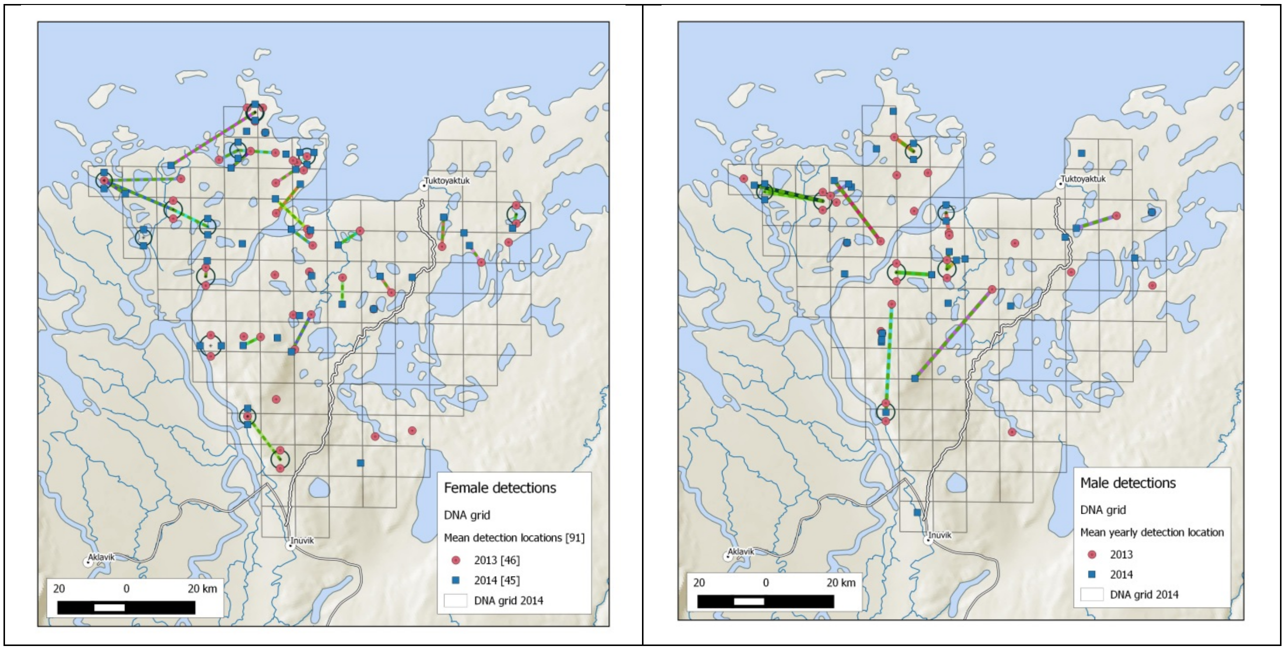

Figure 3. Mean detection of male and female bears during the 2013 and 2014 Inuvik-Tuktoyaktuk Highway grizzly bear DNA project. Mean detection locations of bears that were detected in both years are connected by lines. Multiple detections at single tripod sites are indicated by a concentric circle around the tripod site location.

Spatially Explicit Mark-recapture Analysis

Male and female analyses were conducted separately given likely differences in movement, detection rates, and distribution on the DNA grid. Data from 2013 and 2014 was modeled together using year as a "session" in the SECR analysis. Female and male analyses are now described separately.

Female SECR Analyses

Description of Spatial Data

Detection locations, movements, and estimated activity centers revealed a high amount of use of the northern portion of the DNA grid in both 2013 and 2014 (Figure 5). In both years, activity centers and movements also suggested areas of activity that extend west to east in a diagonal pattern. The activity centers indicated a slightly higher activity and density surface in 2013, however, the activity center approach will be sensitive to trap layout and mean density levels and therefore should be interpreted cautiously. There were two cases where bears were detected on both sides of the proposed highway route in 2013 and 2014.

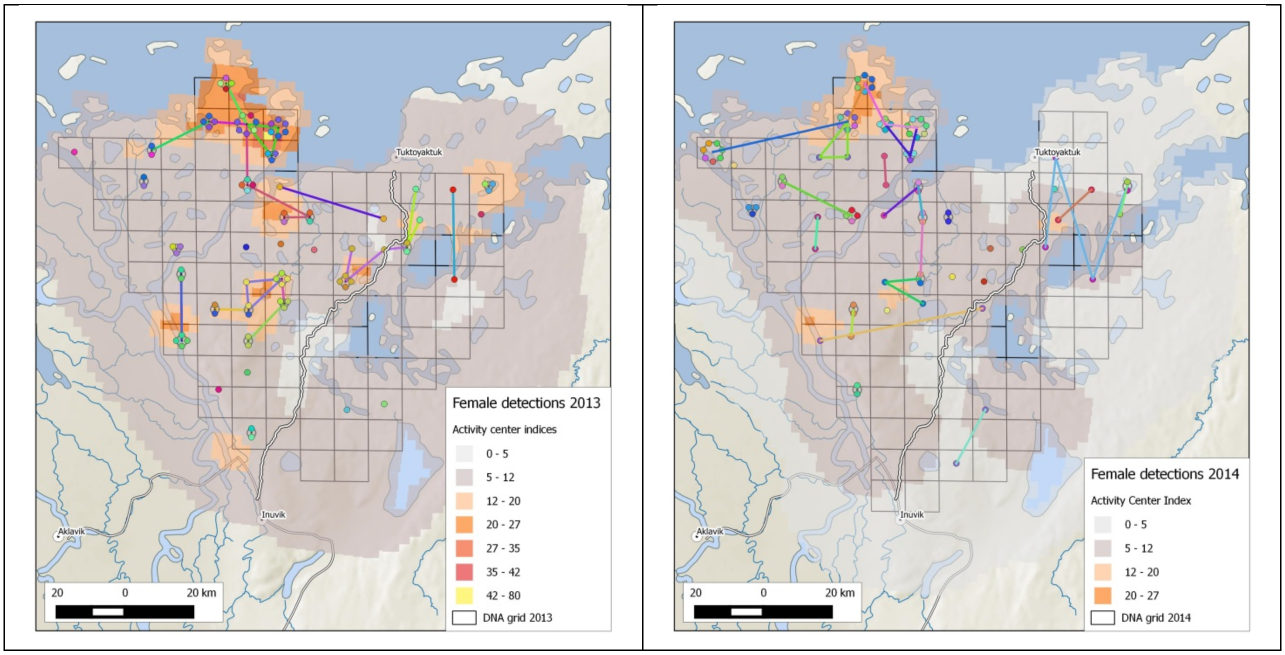

Figure 4. Movements of individual female grizzly bears and activity centers from SECR for 2013 (left) and 2014 (right). Multiple detections at hair snag sites were offset in a circle to facilitate interpretation.

Base SECR Analysis

Spatially explicit model selection focused on variation in detection probability at home range center (g_0) and movement (sigma, σ). Models that considered behavioural change in g_0 were most supported (Table 5, Models 1-4). Models that considered change in detection probability of individual bears based on previous detection (in any session) (Models 1 and 2: denoted by 'b') were more supported than models that assumed change in detection probabilities based on detection in the previous session (denoted by 'B'; Models 2 and 6).

Other models that were considered were year-specific variation in density, detection, and scale of movement as well as site-based covariates for detection and scale of movement. None of these models were supported compared to the model that assumed equal densities of females in 2013 and 2014 as well as detection and scale of movement (Model 1). Year-specific variation in density was considered further in the context of density surface modeling and estimates of abundance and density for 2013 and 2014.

Table 5. Female spatially explicit model selection for 2013 and 2014 with models indicated by assumptions made about density, detection at home range center g_0 and scale of movement (σ). Sex =sex-specific estimates, B =the change in detection rate if the bear was detected in previous session, b = change in detection if the bear was detected previously (in any session), T =linear trend, t =session-specific parameters, constant =single value for parameter, t_1 =specific estimate for session 1, and h_2 =2-mixture model for heterogeneity of detection rates. Sample size adjusted Akaike Information Criterion (AIC_c), the difference in AIC_c from the most supported model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and log-likelihood are given.

No	Density	Detection (g_0)	Scale (σ)	AIC_c	ΔAIC_c	w_i	K	LL
1	Constant	b	constant	1293.20	0.00	0.18	4	-642.4
2	Constant	B	constant	1293.76	0.56	0.14	4	-642.8
3	Constant	year+b	constant	1294.90	1.70	0.08	5	-642.1
4	Constant	year+year*b	constant	1295.62	2.42	0.05	6	-641.3
5	Year	b	constant	1295.03	1.83	0.07	5	-642.2
6	Year	B	constant	1295.78	2.58	0.05	5	-642.5
7	Constant	year+B	constant	1295.81	2.61	0.05	5	-642.6
8	Constant	constant	elevation	1295.90	2.70	0.05	4	-643.7
9	Constant	year*T	constant	1296.14	2.94	0.04	6	-641.6
10	Constant	year*t	constant	1296.58	3.39	0.03	10	-636.9
11	Constant	constant	constant	1296.93	3.73	0.03	3	-645.3
12	Constant	constant	b	1297.09	3.89	0.03	4	-644.3
13	Year	year+b	constant	1297.14	3.94	0.03	6	-642.1
14	Constant	elevation	constant	1297.26	4.06	0.02	4	-644.4
15	Constant	RSF	RSF	1297.28	4.08	0.02	5	-643.3
16	Constant	RSF	elevation	1297.31	4.11	0.02	5	-643.3
17	Constant	elevation	elevation	1297.80	4.60	0.02	5	-643.5
18	Constant	RSF	constant	1297.85	4.65	0.02	4	-644.7
19	Year	year+B	constant	1297.98	4.78	0.02	6	-642.5
20	Constant	year	constant	1298.78	5.58	0.01	4	-645.2
21	Constant	constant	RSF	1298.86	5.67	0.01	4	-645.2
22	Constant	constant	year	1299.00	5.81	0.01	4	-645.3
23	Constant	elevation	RSF	1299.34	6.14	0.01	5	-644.3
24	Constant	year	year	1299.51	6.31	0.01	5	-644.4
25	Year	constant	year	1300.32	7.13	0.01	5	-644.8
26	Year	year	constant	1300.81	7.61	0.00	5	-645.1
27	Year	year	year	1301.43	8.24	0.00	6	-644.2

Plots of the detection function from Model 1 in Table 4 revealed an increase in detection at home range center (g_0) after initial detection (Figure 6).

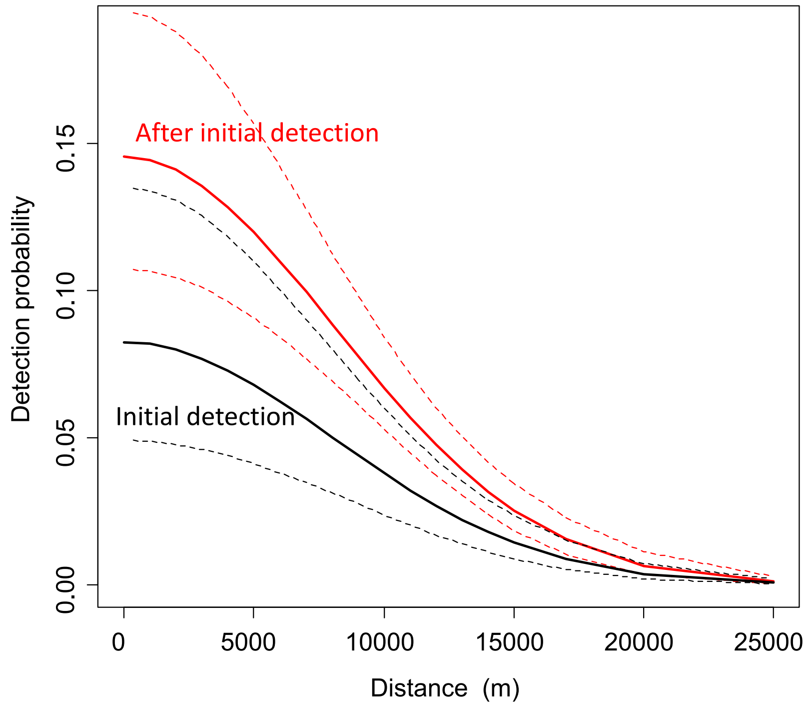

Figure 5. Spatially explicit detection function from Model 1 (bears with different initial detection and redetection rates), Table 4. The black line is the initial detection function and the red line is the detection function after initial detection. Confidence limits are given as hashed lines.

Variation in Density on the Sampling Grid

Initial analyses of a female grizzly bear density surface model considered the best baseline model for detection probabilities and it was sigma based on the most supported models from the baseline analysis in Table 5. As with the 2013 analysis (Boulanger et al. 2014), deciduous cover was most supported as a covariate for density variation (Table 6). The general relationship was similar in 2013 and 2014 as indicated by lower support from a model with year-specific relationships (Model 3). Models with more than one density surface covariate (i.e. Model 3), strata (Model 13: as defined by a buffer area of 20 kilometers around the road), or distance from road (Model 5) were also not supported.

Table 6. Female spatially explicit density surface modeling model selection results. A base model (g_0 (b), sigma (.)) was used for all analyses except when noted. An exponential relationship between covariates and density was assumed except where noted. The base model (with no density covariates) is shaded in grey. Sample size adjusted AIC_c, the difference in AIC_c between the most supported model for each model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and deviance are given.

No	Density	AIC_c	ΔAIC_c	w_i	K	LL
1	Deciduous	1253.3	0.00	0.29	5	-621.3
2	Conifer + Deciduous + Shrub	1254.8	1.41	0.14	7	-619.7
3	Deciduous * year	1255.1	1.74	0.12	6	-621.0
4	Deciduous + year	1255.4	2.05	0.10	6	-621.2
5	Deciduous+log(dRoad)	1255.5	2.18	0.10	6	-621.3
6	Conifer + Deciduous+Shrub	1255.5	2.18	0.10	6	-621.3
7	Conifer+Deciduous+Shrub+Herbaceous	1257.0	3.70	0.05	8	-619.6
8	Deciduous+Water	1255.4	2.08	0.10	6	-621.2
9	Forest+Shrub+Herbaceous+Aquatic+Water	1263.6	10.26	0.00	9	-621.7
10	Log (distance to Road)	1278.3	24.96	0.00	5	-633.8
11	Shrub	1281.6	28.25	0.00	5	-635.4
12	Open tall shrub	1281.7	28.36	0.00	5	-635.5
13	Strata	1281.8	28.49	0.00	5	-635.6
14	Elevation	1283.8	30.42	0.00	5	-636.5
15	RSF	1284.6	31.28	0.00	5	-637.0
16	Dwarf_shrub	1284.6	31.28	0.00	5	-637.0
17	Closed tall shrub	1284.7	31.41	0.00	5	-637.0
18	Constant	1293.2	39.86	0.00	4	-642.4

A plot of predicted density as a function of deciduous cover indicates an abrupt threshold at percent deciduous cover of five or above with low densities in mask centroids above this score. The actual distribution of percent deciduous cover also indicates that few centroids have scores above 10% (Figure 7).

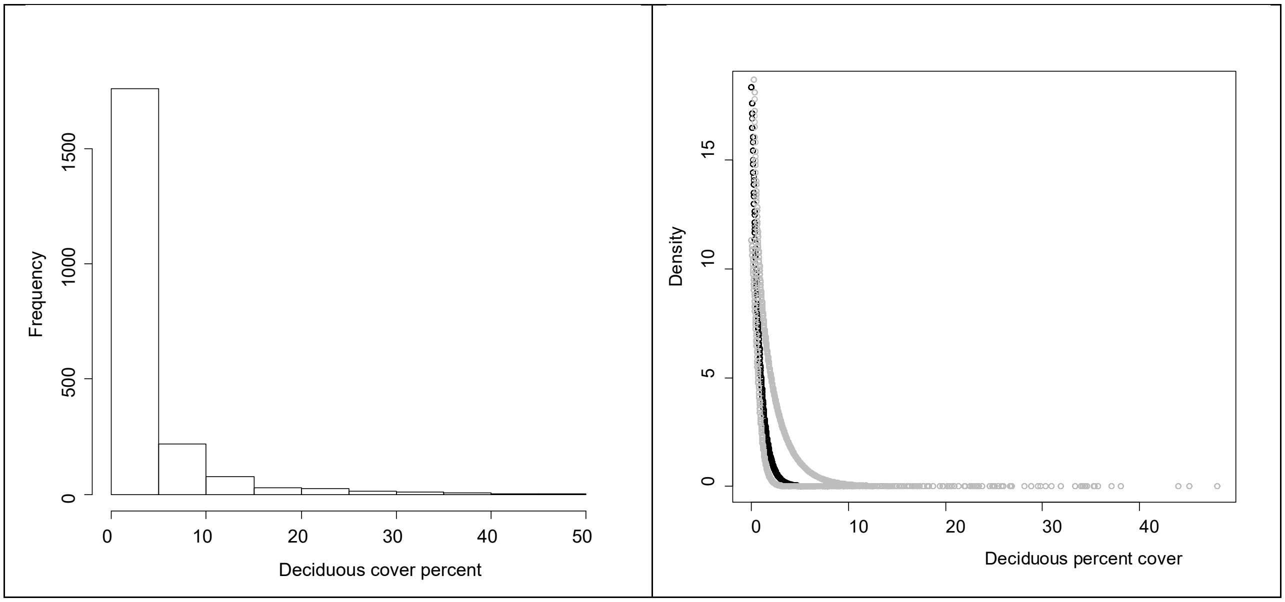

Figure 6. Distribution of percent deciduous in mask centroid buffer (left) and predicted density for female grizzly bears as a function of percent deciduous from Model 1 in Table 5.

A plot of predicted density on the DNA grid indicates higher densities for the northern part of the sampling grid with intermittent areas of higher density in the central area of the grid. The correspondence with predicted home range centers is variable as is the correspondence with movements and activity centers (Figure 8). This comparison suggests that deciduous may indicate general range of bears on the study grid but does not predict hotspot areas in the central area of the grid which may be based on ephemeral resources not related to landcover.

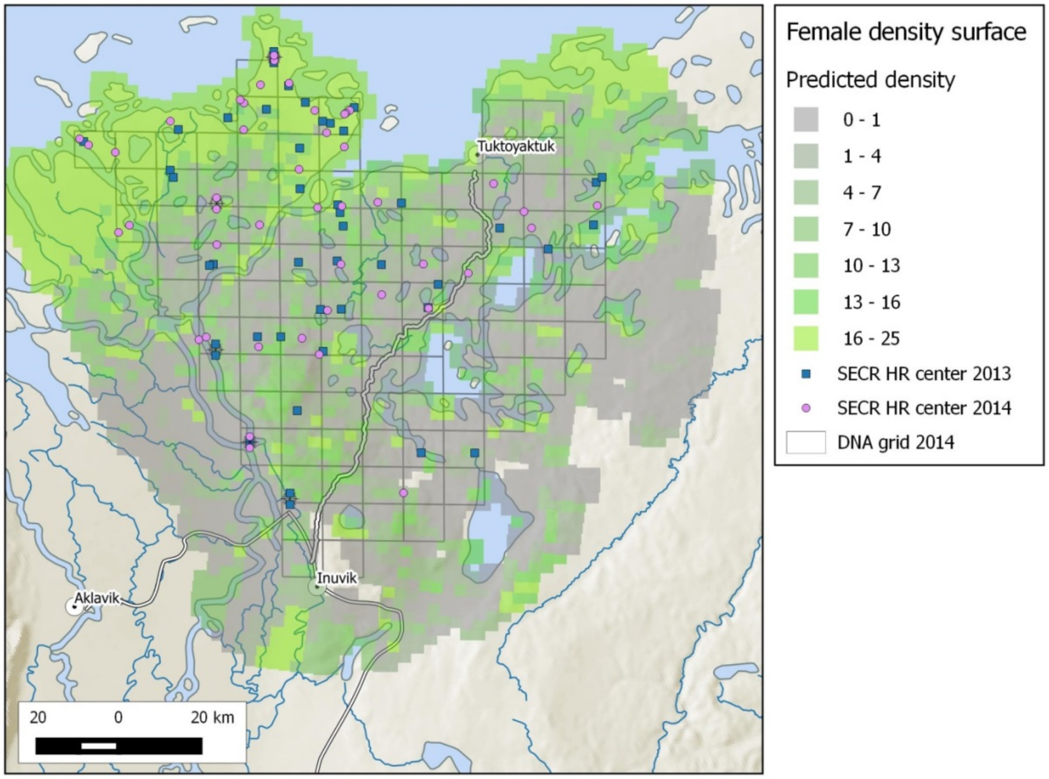

Figure 7. Predicted female grizzly bear density of mask centroids based upon deciduous (closed birch) Model 1 (Table 6). Also shown are SECR estimated home range centers for 2013 and 2014. The density surface model basically attempts to predict the location of these centers using land cover and other covariates.

Male SECR Analysis

Description of Spatial Data

Detection locations and movements of male bears were relatively similar to females with clusters of detections and activity along the coastline and in the upper central area of the DNA grid with few detections to the south of the route of the road (Figure 9). In 2014, two "hotspot" areas were indicated in the central portion of the DNA grid as indicated by activity centers and multiple detections at tripod sites in this area. As mentioned earlier, the activity center index will be sensitive to trap layout and therefore the actual distribution indicated by activity centers should be interpreted cautiously.

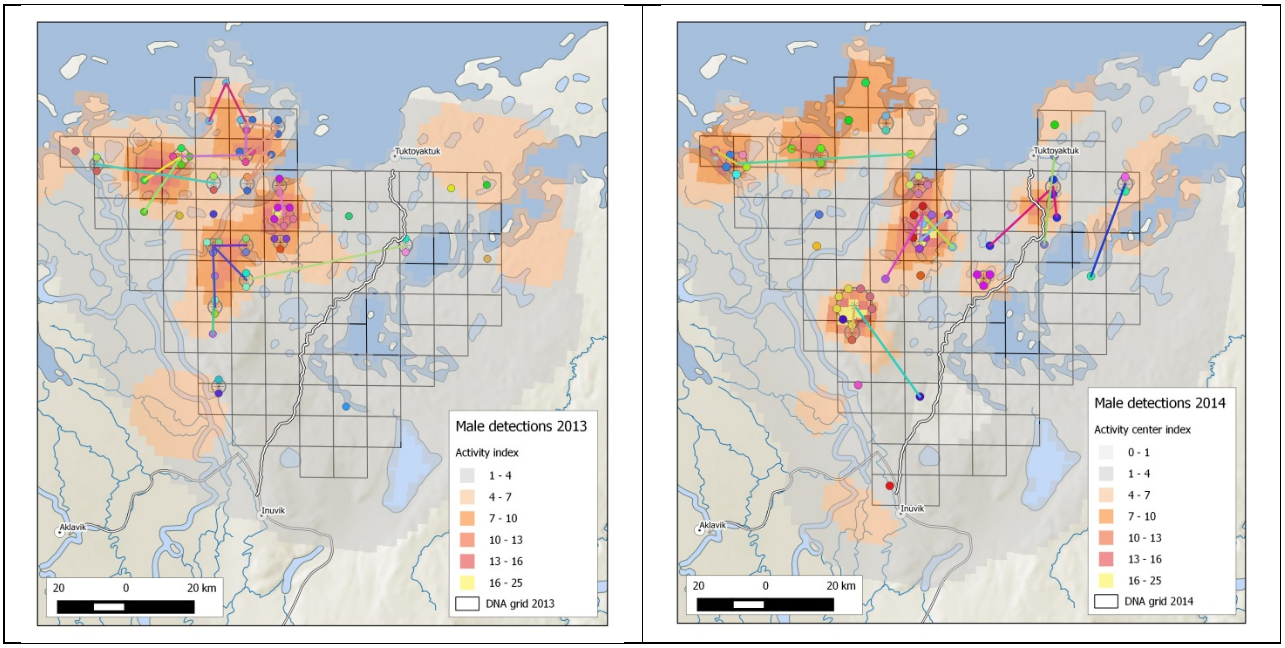

Figure 8. Movements of individual male grizzly bears and activity centers from SECR for 2013 (left) and 2014 (right). Multiple detections at hair snag sites were offset in a circle to facilitate interpretation.

Base SECR Analysis

Models that considered year-specific, session-specific, and variation based on site covariates were considered in the male SECR analysis. A model with detection at home range center varying with the elevation of the tripod site and scale of movement varying by RSF score was most supported (Model 1, Table 7). This model, which assumed equal densities for 2013 and 2014 was more supported than a model that estimated year-specific densities (Model 2). A model with behavioural response, which was supported in the 2013 analysis (Model 6) was more supported than a model with constant detection probabilities (Model 8) but less supported than the site covariate Model 1.

Table 7. Male spatially explicit model selection with models indicated by assumptions made about density, detection at home range center (g_0) and scale of movement (σ). Sex = sex-specific estimates, B = the change in detection rate if the bear was detected in previous session, b = change in detection if the bear was detected previously (in any session), T = linear trend, t = session-specific parameters, constant = single value for parameter, t_1 = specific estimate for session 1, and h_2 = 2-mixture model for heterogeneity of detection rates. Sample size adjusted AIC_c, the difference in AIC_c from the most supported model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and log-likelihood are given.

No	Density	Detection (g_0)	Scale (σ)	AIC_c	ΔAIC_c	w_i	K	LL
1	constant	elevation	RSF	949.75	0.00	0.66	5	-469.3
2	year	elevation	RSF	952.18	2.43	0.20	6	-469.3
3	constant	constant	RSF	954.85	5.10	0.05	4	-473.1
4	constant	elevation	constant	955.28	5.53	0.04	4	-473.3
5	constant	constant	elevation	957.14	7.39	0.02	4	-474.2
6	constant	B	constant	958.20	8.46	0.01	4	-474.7
7	constant	RSF	constant	960.13	10.38	0.00	4	-475.7
8	constant	constant	constant	960.26	10.52	0.00	3	-476.9
9	year	B	constant	960.57	10.83	0.00	5	-474.7
10	constant	year+B	constant	960.58	10.83	0.00	5	-474.7
11	constant	b	constant	962.34	12.59	0.00	4	-476.8
12	constant	constant	B	962.34	12.59	0.00	4	-476.8
13	constant	constant	b	962.37	12.62	0.00	4	-476.8
14	constant	constant	year	962.52	12.77	0.00	4	-476.9
15	constant	year	constant	962.56	12.81	0.00	4	-476.9
16	year	year+B	constant	963.04	13.29	0.00	6	-474.7
17	year	b	constant	964.70	14.96	0.00	5	-476.8
18	constant	year+b	constant	964.71	14.96	0.00	5	-476.8
19	constant	year	year	964.78	15.04	0.00	5	-476.8
20	year	constant	year	964.84	15.09	0.00	5	-476.9
21	year	year	constant	964.93	15.18	0.00	5	-476.9
22	year	year+b	constant	967.17	17.42	0.00	6	-476.8
23	year	year	year	967.23	17.48	0.00	6	-476.8
24	constant	year*T	constant	967.34	17.60	0.00	6	-476.9
25	constant	year*t	constant	977.08	27.33	0.00	10	-476.3

A plot of detection probabilities and scale of movement revealed that detection probabilities at home range center were higher at lower elevation sites and scale of movements were less in areas of higher RSF scores (Figure 10).

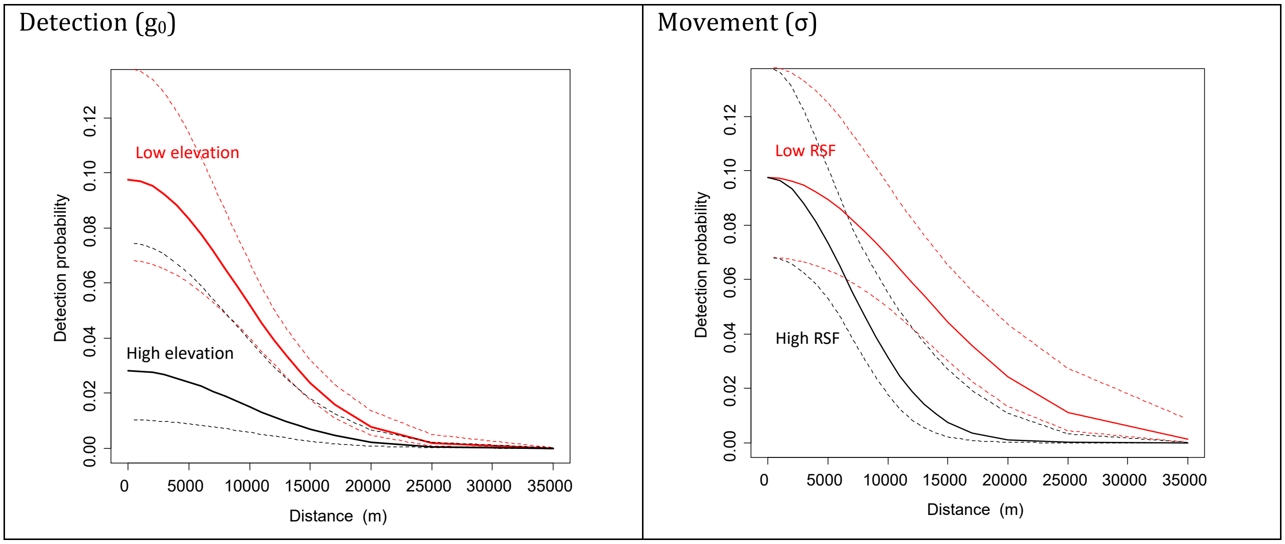

Figure 9. The effect of elevation of detection at home range center (g_0: left graph) and the effect of RSF on scale of movement (σ) from model 1 (g_0 (Elevation), σ (RSF)) in Table 6. RSF was held constant at mean values for the detection plot and elevation was held constant at mean levels for the movement plot.

Variation in Density on Sampling Grid

As with females, deciduous land cover was the most supported predictor of density (Model 1, Table 8). There was no indication of year-specific variation in deciduous cover and density as indicated by lower support of Model 7. Other covariates such as RSF (Model 21), strata (Model 14) or distance to road (Model 16) were also less supported.

Table 8. Male spatially explicit density surface modeling model selection results. A base model (g_0 (B), sigma (.)) was used for all analyses except when noted. An exponential relationship between covariates and density was assumed except where noted. The base model (with no density covariates) is shaded in grey. Sample size adjusted AIC_c, the difference in AIC_c between the most supported model for each model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and log-likelihood (LL) are given.

No	Covariates	AIC_c	ΔAIC_c	w_i	K	LL
1	Deciduous	936.5	0.0	0.36	6	-461.5
2	Conifer+deciduous	939.1	2.5	0.10	7	-461.5
3	Forest	939.4	2.8	0.09	6	-462.9
4	Conifer+Deciduous+Shrub	939.6	3.1	0.08	8	-460.4
5	Deciduous+year	939.1	2.5	0.10	7	-461.5
6	Deciduous+distance to road	939.1	2.6	0.10	7	-461.5
7	Deciduous*year	940.9	4.4	0.04	8	-461.1
8	Forest + Shrub	941.4	4.9	0.03	7	-462.6
9	Conifer+ Deciduous + Low shub	941.7	5.2	0.03	8	-461.5
10	Conifer + Deciduous + Shrub + Herbaceous	942.1	5.6	0.02	9	-460.3
11	Open spruce	942.9	6.4	0.01	6	-464.7
12	Forest + Shrub + Herbaceous + Aquatic	943.4	6.9	0.01	9	-461.0
13	Forest + Shrub + Herbaceous	944.0	7.5	0.01	8	-462.6
14	Strata	944.0	7.5	0.01	6	-465.2
15	Forest+Shrub+Herbaceous+Aquatic+Water	944.6	8.1	0.01	10	-460.1
16	log(distance from road)	945.1	8.6	0.00	6	-465.8
17	Closed tall shrub	945.4	8.8	0.00	6	-465.9
18	Barren	949.6	13.1	0.00	6	-468.0
19	Constant	949.7	13.2	0.00	5	-469.3
20	Low_shrub	951.9	15.4	0.00	6	-469.2
21	RSF	952.1	15.5	0.00	6	-469.2

Plots of male density versus deciduous habitat revealed a similar relationship with females but the precision of predictions was poor as evidence by large confidence limits on predictions (Figure 11). As with females, only centroids with lower (<7%) deciduous cover had significant densities predicted.

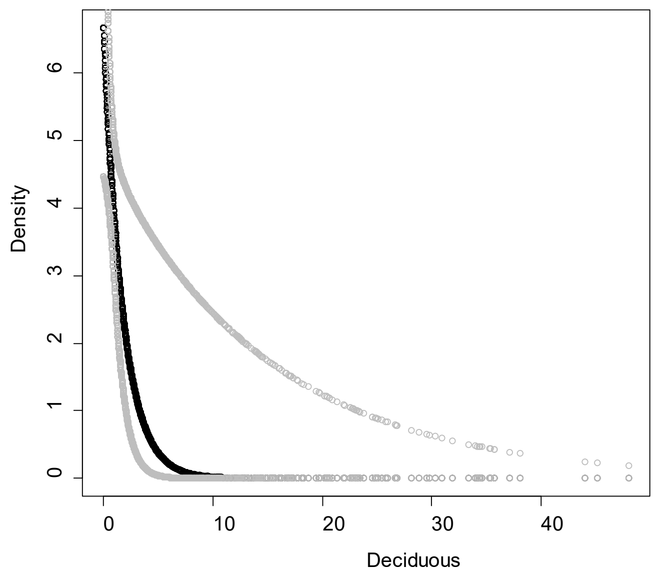

Figure 10. Predicted density of male grizzly bears as a function of deciduous habitat from Model 1 and deciduous and wet herbaceous habitat (Model 2, Table 9). Density is expressed in bears per 1,000 km^2.

Predictions from the deciduous habitat model (Model 1) were plotted and compared with SECR estimated home range center locations from 2013 and 2014 (Figure 12). As with females, higher densities were predicted in the northern part of the grid which also corresponded in general to the home range centers (Figure 12). Hot spot area indicated in Figure 9 had moderate densities predicted but not higher densities suggesting that as with females these areas may correspond to ephemeral food resources not well described by landcover.

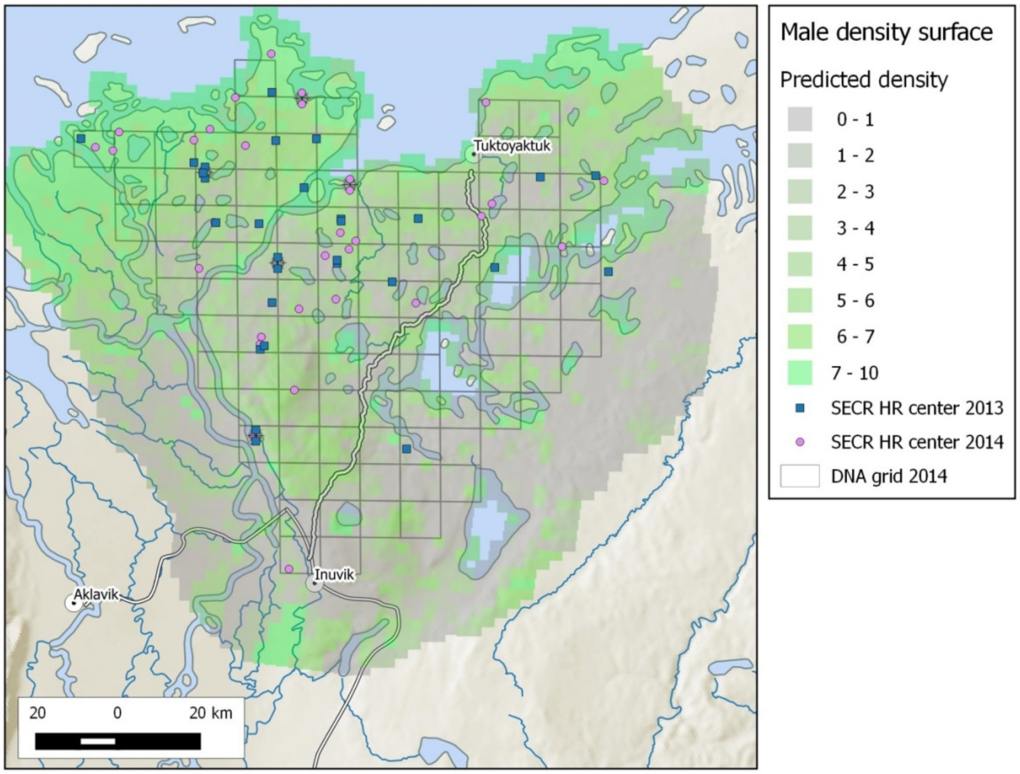

Figure 11. Predicted density at mask centroids for male grizzly bears based on deciduous (closed birch) habitat (Model 1, Table 8). The density surface model basically attempts to predict the location of these centers using land cover and other covariates.

Estimates of Abundance and Density

The DNA Grid Area

Estimates of average number of bears on the 2014 sampling grid were compiled from the most supported detection and density surface models for male and female bears. In all cases, models that assumed equal density for 2013 and 2014 were most supported suggesting that the number of bears on the grid was similar in 2013 and 2014. For comparison purposes, estimates from models that assumed similar densities for 2013 and 2014 were produced (Table 9).

Yearly estimates from a constant density (year model) and density surface (deciduous) models were reasonably similar for both years of the analysis. Comparison of estimates for 2013 and 2014 revealed a slight reduction of the number of females on the grid and virtually no change in males. The average of both years was 58.8 females and 34.2 males on the grid for an overall estimate of 93 bears on the sampling grid (CI=70-124) on average for 2013 and 2014. Precision of estimates was reasonable in all cases with CV's of less than 20%.

Table 9. Estimates of average number of bears on the sampling grid and density (bears per 1,000 km^2) for females, males, and females + males as a function of the year of study and underlying density model. The most supported detection models were used for males and females. The area of the 2014 survey grid perimeter minus the area of large lakes (9,558 km^2) was used for density calculations.

Sex	Density		Average N on grid					Density			
Year	Model	n	$\hat{N}$	SE	Conf. Limit		CV	$\hat{D}$	SE	Conf. limit	
Females											
2013	Year	46	62.0	11.2	43.6	88.0	18.1%	6.48	1.17	4.56	9.21
2013	Deciduous+year	46	62.3	12.0	42.8	90.7	19.3%	6.52	1.26	4.48	9.49
2014	Year	45	55.8	10.0	39.4	79.0	17.9%	5.84	1.05	4.12	8.27
2014	Deciduous+year	45	57.4	11.1	39.5	83.6	19.3%	6.01	1.16	4.13	8.74
	Constant(Ave)		58.8	9.5	42.9	80.6	16.2%	6.16	1.00	4.49	8.44
Males											
2013	Year	29	34.8	5.5	25.5	47.4	15.9%	3.64	0.58	2.67	4.95
2013	Deciduous+year	29	32.6	5.0	24.2	44.0	15.3%	3.41	0.52	2.53	4.60
2014	Year	32	33.7	4.9	25.4	44.8	14.6%	3.53	0.51	2.65	4.68
2014	Deciduous+year	32	32.6	4.6	24.7	42.9	14.1%	3.41	0.48	2.59	4.49
	Constant(Ave)		34.2	4.0	27.1	43.0	11.8%	3.57	0.42	2.84	4.50
Females+Males											
2013	Year	75	96.7	12.5	69.1	135.4	12.9%	10.12	1.31	7.23	14.16
2013	Deciduous+year	75	94.9	13.0	67.0	134.7	13.7%	9.93	1.36	7.01	14.09
2014	Year	77	89.5	11.1	64.7	123.8	12.4%	9.36	1.17	6.77	12.95
2014	Deciduous+year	77	90.0	12.0	64.2	126.4	13.3%	9.42	1.26	6.72	13.23
	Constant(Ave)		93.0	10.3	70.1	123.7	11.1%	9.73	1.08	7.33	12.94

Regional Estimates of Population Size for Road and Control Strata

Regional population size estimates were generated for areas within 20 and 25 km of the proposed road which was the buffer distance estimated for females and males respectively. These estimates correspond to the average number of bears that would be within 20-25 km of the road at any one time. The 20-25 km buffer would ensure that the bears included in the estimate would have home ranges that would encompass the road, based on female and male grizzly bear scales of movement. Regional estimates were also generated for areas on the DNA grid outside the road buffers. These could be considered a control area where bear density would be less likely to be influenced by the road. We note that average population size and density was estimated only for areas within the 2014 DNA grid (Figure 2) and not areas beyond the grid boundary such as areas south of Inuvik. This is a conservative approach that ensures that areas where bears are estimated are in the vicinity of tripod sampling sites.

The difference in yearly estimates of average number of bears in control or road area depended on the underlying SECR model. We use a notation for the SECR models where the spatial model is described first followed by a '|' separator and then the temporal models is described (i.e. Spatial model | temporal model). The spatial model describes how spatial variation was modeled including models that assumed no spatial variation which was termed as "constant'. The temporal variation models mainly pertain to whether year-specific densities were assumed. A model that assumed constant density but yearly variation in abundance (Constant | Year model in Figure 13) suggested roughly equal numbers in road and control areas. However, estimates from this model are likely biased due to density gradients on the sampling grid. The density surface models (Deciduous | Constant and Deciduous| Year) suggested lower abundances on road buffer areas for females and roughly equal abundances for males. The strata models, (Strata | Constant and Strata | Year) which directly estimate observed abundance suggested lower numbers of bears in road buffer areas for all years of the study. The estimates for females from density surface and strata models were similar whereas the strata model estimated lower numbers of males bears in road buffer areas. Of all models, the strata model is the most direct estimate of abundance; however, precision of these models is lower than the density surface models (discussed later). Comparison of 2013 and 2014 estimates for yearly variation models (Constant | Year, Deciduous | Year, and Strata |Year) suggest that abundances were relatively similar for 2013 and 2014.

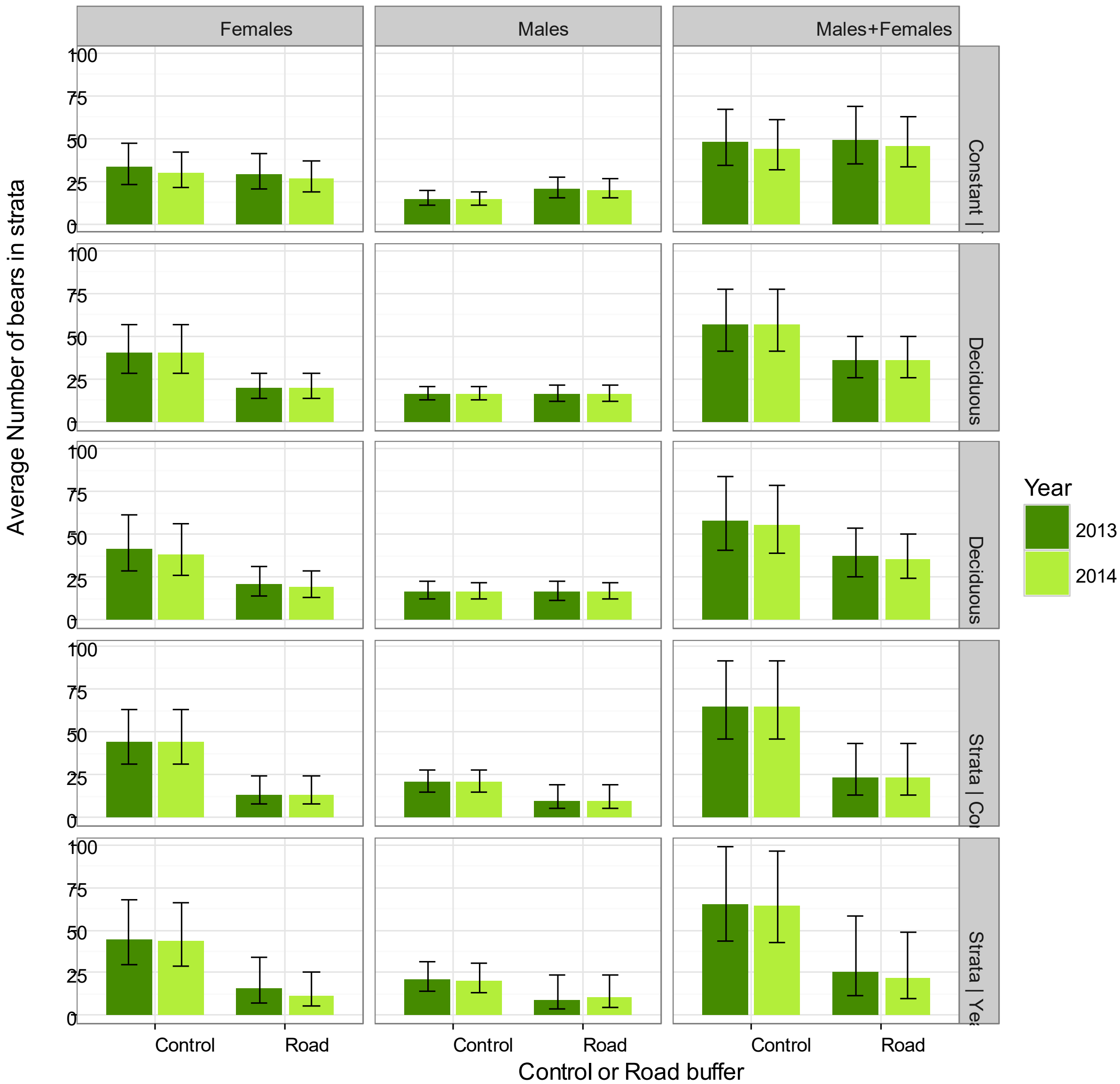

Figure 12. Estimates of average bears within 20 km (females: left graphs) and 25 km (males: middle graphs) of the highway route compared to areas other areas of the grid (control) under different spatial and temporal trend models. Each row represents the results from a different underlying SECR model denoted as Spatial trend model | Temporal trend model.

The average number of bears will be affected by size differences of the road buffer and control areas and therefore a more direct comparison can be gained by comparison of density of bears in each area (Figure 14). In this case, however, comparison in densities yields quite similar results as average number of bears due to relative equivalency in size of road buffer (Female 20 km=4,474.2 km^2, Male 25 km=5,518 km^2) and control areas (Females 5,083.8km^2, Males 4,039.2 km^2). Density is probably still the best metric for comparison since it accounts for these small size differences. As with the average N graph, road buffer areas display lower densities especially with the strata models that directly estimate density in the road buffer areas. Estimates from the deciduous density surface models are reasonably close to the strata models, especially for females, suggesting that deciduous landcover is partially describing variation in density on the sampling grid.

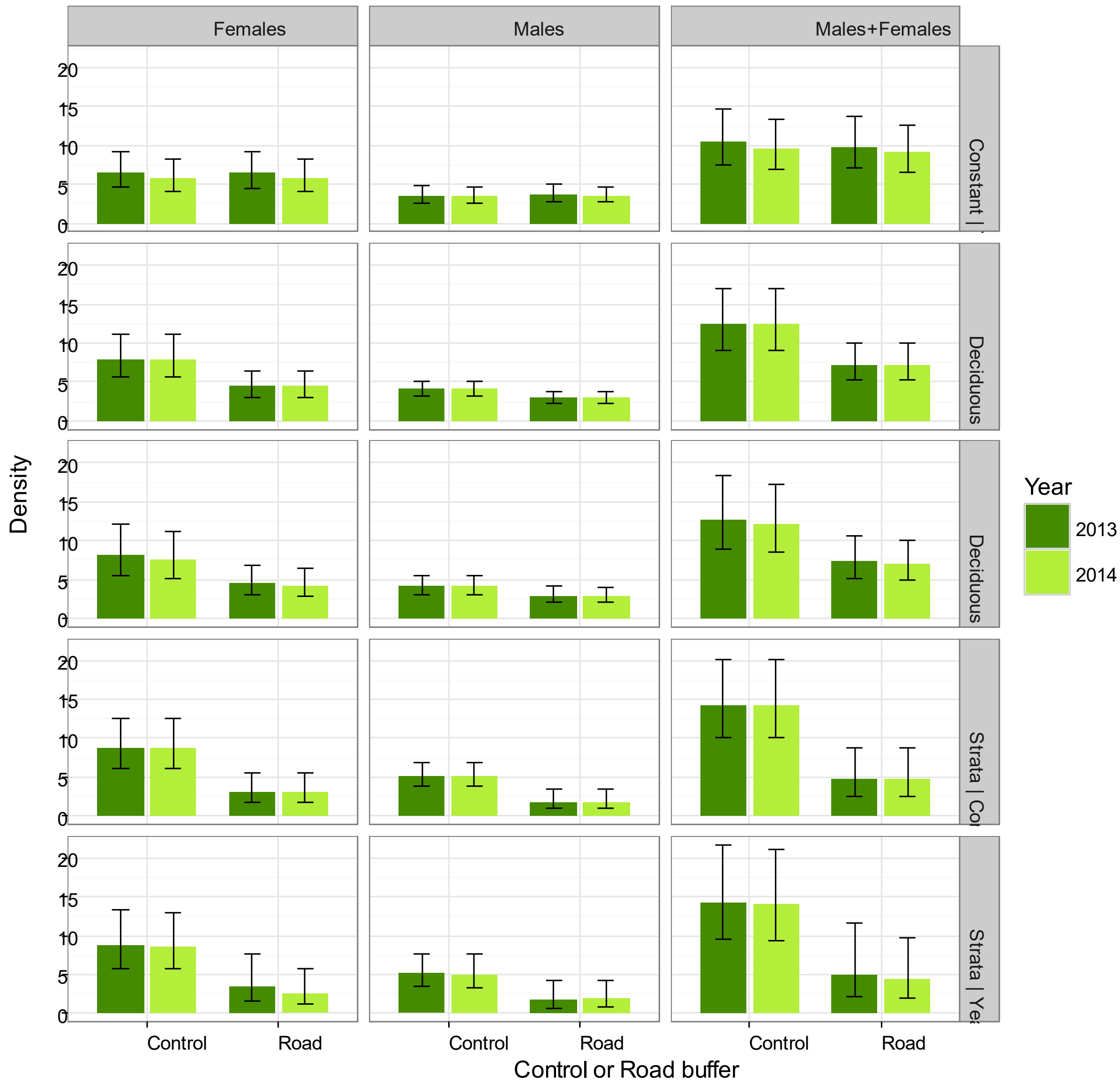

Figure 13. Estimates of density (bears per 1,000 km^2) within 20 km (females: left graphs) and 25 km (males: middle graphs) of the highway route compared to areas other areas of the grid (control) under different spatial and temporal trend models. Each row represents the results from a different underlying SECR model denoted as Spatial trend model | Temporal trend model.

Precision of estimates as indexed by coefficient of variation suggested reasonable precision (CV's <20%) for all estimates except the road estimates from the strata models for male or female bears (Figure 14). If sexes are pooled to estimate average density, then precision of the Strata | Constant model is close to the threshold CV of 20% level.

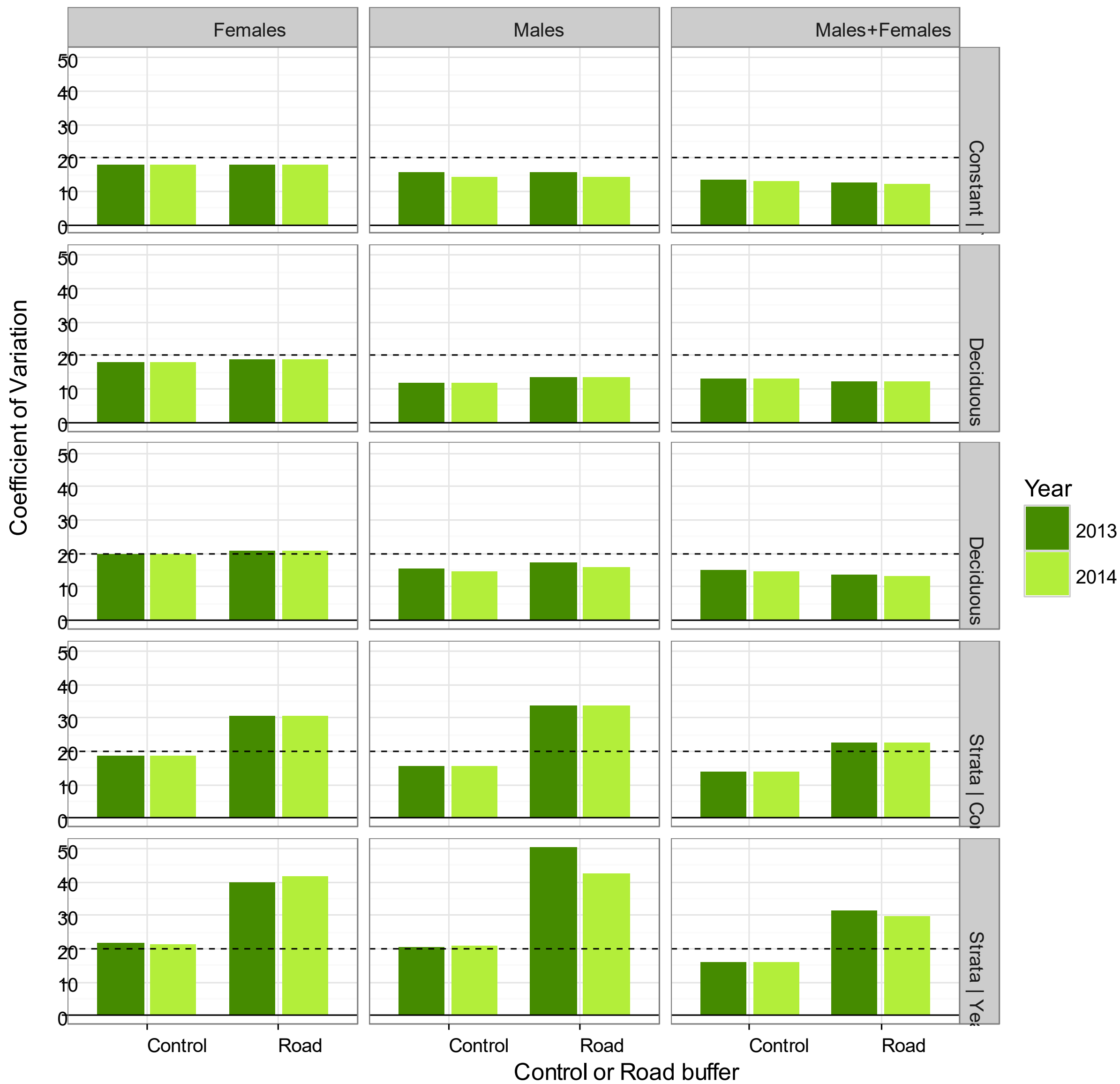

Figure 14. Estimates of coefficient of variation of estimates within 20 km (females: left graphs) and 25 km (males: middle graphs) of the highway route compared to areas other areas of the grid (control) under different spatial and temporal trend models. Each row represents the results from a different underlying SECR model denoted as Spatial trend model | Temporal trend model. The threshold coefficient of variation of 20% that indicates reasonable estimate precision is indicated by a dashed line on the y-axis.

Open Model Demographic Analyses

Initial evaluation of detections and redetections in 2013 and 2014 revealed that relatively similar numbers of bears were detected in 2013 and 2014 (Table 10). However, for females a higher percentage of bears were redetected (34 of 46 bears≈74%) in 2014 compared to males (14 of 29 bears≈48%). In addition, there was a larger percentage of new males detected in 2014 (18 of 32 bears≈56%) compared to females (11 of 45 bears≈24%). These differences suggest the influence of sex-specific demographics despite the fact that similar numbers of bears were detected each year. The Pradel analysis uses a model-based framework to compare these differences and determine how much they may be attributed to differences in detections compared to demographic differences between years and sexes.

Table 10. Summary of detections, redetections, and new bears for the 2013 and 2014 surveys.

Statistic	Females	Males	Females + Males
Bears detected in 2013	46	29	75
Bears detected in 2014	45	32	77
Bears from 2013 redetected in 2014	34	14	48
New bears in 2014	11	18	29

Base detection models were built partially using the results of the SECR analysis that suggested a behavioural response as modeled using a unique recapture term in the Huggins model. Of models considered, a model with sex-specific apparent survival (φ) and rates of addition(f), and year-specific detection rates with a constant redetection probability, was most supported (Model 1, Table 11). This model was marginally more supported than models that assumed no behavioural response (Model 2) or sex-specific detection rates (Model 3). Reduced versions of Model 1 that assumed similar demography between sexes were not supported.

Table 11. Pradel model (2013-2014) model selection results. The parameters of the Pradel model are apparent survival (φ), rates of addition (f), detection probability (p) and redetection probability (c). Covariates are given with each parameter with a (.) indicating that the parameter was constant. Sample size adjusted AIC_c, the difference in AIC_c between the most supported model for each model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and deviance are given.

No	Model	AIC_c	ΔAIC_c	w_i	K	Deviance
1	Φ (sex) f(sex) p(year) c(.)	988.23	0.00	0.25	7	253.7
2	Φ (sex) f(sex) p(year)	988.69	0.46	0.20	6	256.3
3	Φ (sex) f(sex) p(sex)	988.89	0.66	0.18	6	256.5
4	Φ (sex) f(sex) p(year) c(year)	989.99	1.77	0.10	8	253.3
5	Φ (sex) f(.) p(sex)	991.19	2.96	0.06	5	260.9
6	Φ (.) f(sex) p(year)	991.63	3.40	0.04	5	261.3
7	Φ (.) f(.) p(.)	992.33	4.10	0.03	3	266.2
8	Φ (.) f(.) p(sex)	992.43	4.21	0.03	4	264.2
9	Φ (sex) f(.) p(year) c(.)	992.60	4.37	0.03	6	260.2
10	Φ (sex) f(sex) p(sex*year)	992.68	4.46	0.03	8	256.0
11	Φ (.) f(sex)) p(sex)	992.70	4.48	0.03	5	262.4
12	Φ (sex) f(.) p(year)	992.83	4.60	0.02	5	262.5
13	Φ (.) f(.) p(sex + year)	994.38	6.15	0.01	5	264.1
14	Φ (sex) f(sex) p(year*sex*t)	1007.75	19.52	0.00	20	244.0

Model averaged parameter estimates revealed relatively high apparent survival for females and relatively high rates of addition for males. Inclusion of apparent survival and rates of addition suggested stable population sizes for females and an increasing population of males. However, the level of precision of trend estimates was low and therefore this estimate should be interpreted cautiously (Table 12).

Table 12. Pradel model averaged demographic parameter estimates for the models in Table 11.

Parameter	Estimate	SE	LCI	UCI
Females				
Apparent survival (ϕ)	0.95	0.10	0.24	1.00
rates of addition (*f*)	0.05	0.11	0.00	0.80
Population rate of change (λ = ϕ + *f*)	1.00	0.11	0.78	1.23
Males				
Apparent survival (ϕ)	0.69	0.15	0.36	0.90
rates of addition (*f*)	0.43	0.22	0.11	0.82
Population rate of change (λ = ϕ + *f*)	1.12	0.23	0.66	1.57

The estimates from Table 12 can also be viewed graphically which demonstrates that females maintained their population size with higher apparent survival whereas males had lower apparent survival but higher rates of addition (Figure 16).

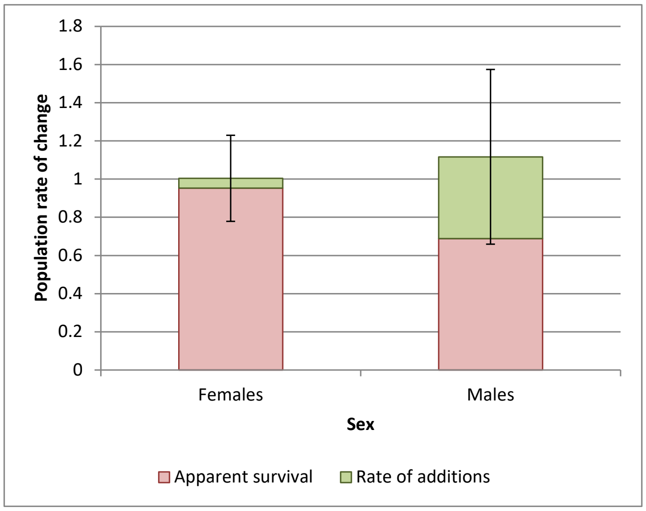

Figure 15. Model averaged estimates of apparent survival, rates of addition and λ as listed in Table 12.

DISCUSSION

The main objectives of this study were to estimate baseline population size and density of grizzly bears in the Inuvik-Tuktoyaktuk Highway and surrounding area, and assess whether sample sizes of bears, study area extent, and other study design features were adequate to monitor grizzly bear populations relative to road construction and operation. This analysis identified a reasonably large population of bears and results suggested that sampling was adequate to provide an estimate of baseline population size and distribution.

Addition of the 2014 data improved the overall precision of estimates as well as providing a baseline measurement of bear fidelity to the study area. The density estimates of grizzly bears for 2013 based on the multi-year model of 10.12 (CV=12.9%, CI=7.23-14.2) was lower and more precise than the estimate of 11.1 (CV=19.1%, CI=6.66-18.43%), however, the confidence limit of estimates overlap. The decrease in the estimate was due to random sample variation as well as the use of a non-behavioural response model for males. In review, the behavioural response models increased estimates and decreased estimate precision. Estimates of bears in 2014 were slightly lower (i.e. 97 vs 90 bears) than 2013, however, this difference was minimal and within the range of sampling variation. In addition, model selection for both males and females suggested that densities were statistically equal for 2013 and 2014 on the sampling grid.

The density surface modeling in this report represents the first attempt at describing the association of remote sensing-based habitat variables with grizzly bear density in the Arctic. The resulting models are reasonably simplistic in that only one or two habitat features are associated with density. This is presumably due to sample size limitations as well as the relatively large scale of habitat selection of grizzly bears detected by DNA sampling. One important point to note is that associations with habitat variables such as deciduous (closed birch) habitat most likely represent gradients of habitat selection rather than selection for the single factor. For example, principal component analysis results suggest that deciduous (closed birch) habitat is negatively related with sparse vegetation and non-vegetated areas, so negative association with this habitat type also could infer positive selection for the sparse/non-vegetated habitat types (Appendix 2). It is also possible that ephemeral food sources not indicated by habitat covariates such as caribou, Arctic char, whitefish, or marine resources may influence grizzly bear distribution as suggested by previous studies (Edwards et al. 2010). Stable isotope analysis of hair samples might provide a way to assess whether bears are relying more on marine resources as was the case in Edwards et al. 2010. Current caribou locations suggest few, if any caribou, are on the sampling grid during the time of the survey. There is, however, a reindeer herd that spends the summer on Richards Island during the time of the survey.

Finally, current distribution could be influenced by historic mortality events as well as the location of cabins in the survey area.

The success rate of genotyping was relatively low in this study compared to southern grizzly bear studies. The probable reason for this is exposure of samples to environmental factors given that the tripods are relatively exposed to weather factors compared to studies that occur below the treeline (Dumond et al. 2015). We note that lower rates of genotyping success will not bias estimates given that it probably occurs equally across all samples collected. The main potential effect is reduced estimate precision due to reduction of detection probabilities. Recapture frequencies were relatively high for this study suggesting that the overall effect of reduced genotyping success was not substantial.

The presence of a behavioural response with detection rates increasing after subsequent capture was somewhat unique to this study. For the female only density surface analysis, a model with detection probability change after initial capture, independent of whether it was the previous session, was most supported (denoted by b). Other studies, such as the Kitikmeot study, only used two sessions which precluded testing for behavioural response (Dumond et al. 2014). The main effect of behavioural response is negative bias in estimates which can be offset by use of behavioural response models which are less precise but presumably more accurate. With the 2013 and 2014 data it was possible to obtain precise estimates even with the behavioural response for females.

The association of scale of movement of males with habitat quality as indexed by RSF scores (Figure 10) follows previous studies (Edwards 2009, Edwards et al. 2009) which suggested that bears home range sizes are based upon the availability of resources which vary spatially and temporally. Interestingly, bears did display a reasonable level of fidelity to home range areas based upon detection of individuals on the sampling grid in 2013 and 2014 (Figure 4). The lack of correspondence between RSF habitat quality and density may be due to the differences in scale of selection indicated by RSF scores compared to broader scale selection based on detection of bears across the two-month sampling time frame.

Further Refinement of the Monitoring Design

The spatial information from the SECR analysis is useful for a variety of purposes to monitor grizzly bear populations (Table 13). First, it defines "impact" and "control" areas based upon the road buffer widths. In this context, it becomes clear that the northwest portion of the grid could be considered a control area, while the road and surrounding 20-25 km buffer zone (Figure 2) would serve as the impact area. The regional population size estimates (Table 9, Figures 13, 14) present a baseline estimate of bears that can be used for future estimates of trend and population size of bears relative to the road. For example, trend in density can be compared for the road buffer versus control area to assess if the road is influencing the trend of bear densities. A recent study in Alberta used SECR density surface models to explore dominant factors influencing grizzly bear distribution across the entire range of occupied habitat (Boulanger et al. 2018). It was found that both habitat and mortality factors influenced broad scale distribution of bears which was partially dependent on past mortality history and current conservation practices. The analysis also identified potential "sink" areas of higher habitat value but also higher mortality risk. This general approach could be used to assess the relative impact of the road once it is operational.

Table 13. Summary of metrics used to monitor bear populations on the DNA sampling grid.

Metric	Method	Assessment of impact
Density	SECR estimates of road vs control areas for male and female bears	Trend in density over time for each stratum as estimated using density surface models or stratified estimates (Figure 14)
Distribution and density	Zone on influence of road as estimated by SECR density surface model for male and female bears	A term with distance from road is introduced into density surface model. The relative support of this term will determine impact of road and assess the scale of impact. A prediction can be generated for the gradient in density change relative to the road
Apparent survival	Pradel open model estimates apparent survival for male and female bears on grid and covariates.	The estimate of apparent survival will assess the fidelity and survival of bears on the sampling grid. These can be compared to estimates from sub regions near the road. In addition, the proportion of home range of each bear relative to the road strata can be used as a covariate to determine if the road impacts apparent survival.
Rates of addition	Pradel open model estimates rates of addition for male and female bears on grid and covariates.	The estimate of rates of addition can help assess if there is a greater influx of new bears on the grid over time as well as the relative influence of additions versus survival on overall trend (Figure 16). In addition, the proportion of home range of each bear relative to the road strata can be used as a covariate to determine if the road impacts rates of addition. If the road has an impact, then it is hypothesized that rates of addition will be lower for bears near the road.

Difference in road and control areas can be further tested in terms of bear demography using the open population models (Boulanger et al. 2004). For this analysis individual covariates can be entered for bears based on proportion of activity centers in the road and control areas as estimated by the SECR model. If there is an impact of the road apparent survival should be affected by the proportion of activity centres in the road area. In addition, reduced rates of addition in the road area might indicate directional movement from this area. The analyses in this report (Figure 16) provide baseline apparent survival rates that can be compared to rates in the proximity of the road once it becomes operational. If substantive mortality does occur and bear mortalities are genotyped then it will also be possible to use these data to provide enhanced survival rate estimates (Barker and White 2001).

It is possible that the spatial scale of movements of bears might change in response to the road, or that the road may not actually influence densities of bears in the entire 20-25 km strata buffer zone (Table 11). For example, more immediate areas might be influenced by traffic volume. Alternatively, mortality of bears could actually increase beyond the 20-25 km zone if the road provides enhanced access for hunters to travel beyond the immediate area of the road. In this case, the "zone of influence" of the road may not simply be defined as the 20-25 km zone. The density surface analyses conducted provide baseline habitat models to estimate density variation throughout the study area. When the road is completed an additional zone of influence term can be added to assess if density changes relative to distance from the road. Baseline analyses for male and females suggest this term is not supported, and that the route of the road has no present effect on bear densities (Tables 6, 8) as indicated by low support of strata as a covariate in density surface model analysis. If the road has an impact on densities, then the support for this term should increase. The main advantage to this approach is that the scale of movement of bears is taken into account in the SECR modeling process. In addition, the response variable is density rather than habitat selection. Therefore, the zone of influence in essence becomes a zone of "density change" which will allow an actual estimate of change in population size due to the road. Many potential zone of influence type shapes including piecewise curves (Boulanger et al. 2012) can be used to assess the effect of the road on grizzly bear density. By using multiple years of data it should also be possible to assess temporal change in the influence of the road by modeling the interaction of distance from road with year of survey.

Sampling Interval for Future Surveys

The Inuvik-Tuktoyaktuk highway was completed and opened to the public on November 15, 2017. The following factors should be considered when determining the optimal sampling interval for monitoring population size, distribution and demography.

1. *Dilution of the number of marked bears when sampling intervals are long.* Estimates of apparent survival from the Pradel model can be used to estimate the relative percentage of marked bears remaining on the grid at various sampling intervals. In this case the proportion of marks remaining is simply φ^t where t is the sampling interval. If the sampling interval is five years, then the proportion of marked bears remaining for females and males would be 77% and 15% assuming apparent survival estimates of 0.95 and 0.68 respectively (Table 12).

2. *Likely rates of change of grizzly bear population and potential effects of the road on mortality and demography.* In general, grizzly bear populations do not exhibit rates of change that are pronounced unless there is substantial adult mortality. Given that annual monitoring is most likely not needed to detect changes in bear population size, bi-annual monitoring combined with active documentation and genotyping of known bear mortalities is adequate for DNA mark-recapture studies (Boulanger et al. 2011).

3. *Adaptive assessment of monitoring strategy as more data is collected.* Current estimates of trend suggest a stable population of bears prior to the road construction. Assessment of change in density and trend during the next survey should help assess whether there is potential for larger scale changes in density, trend, and distribution of bears relative to the road. If this is detected then a more intensive sampling design may be required to further estimate trend and mechanism of change in population trend.

Regardless, it is suggested that sampling should occur in the summer of 2019 to ensure that the interval between sampling does not lead to a dilution of genetically marked bears on the grid (especially males). As it stands, the proportion of males remaining on the grid from 2014 sampling will be reduced simply due to mortality. Estimates from the next sampling effort should provide a better estimate of longer-term trends therefore allowing further refinement of the sampling design.

Future Research

The current research has revealed further topics that could be investigated before the next survey. These are summarized below.

1. *Stable isotope analysis of bears to determine proportion marine diet.* Density surface models were unable to fully explain the clustering of bears in the northwestern section of the sampling grid. One potential explanation is the attraction of marine resources in this area (Edwards 2009, Edwards et al. 2009, Edwards et al. 2010). Stable isotope analysis of hairs provides one potential method to further assess if bears in this area are utilizing marine or other resources unique to this part of the Mackenzie River Delta.

2. *Further exploration of historic mortality and human activity on distribution of bears.* It is possible that historic mortality in some of the areas of the grid might influence present density and distribution. Locations of known mortalities could be overlaid and used as density surface models to determine if there is a correspondence between current density and past documented mortality. One challenge with this analysis will be that recent mortalities will most likely contribute to differences in

distribution than older mortalities. To account for this, various weighting systems will be used to produce mortality risk scores for SECR mask centroids.

3. *Exploration of cabin presence and human activity on bear activity.* As with bear mortality, the locations of active cabins can be used as a covariate to determine if bears are potentially attracted or show aversion to these areas. The current status of cabins, if available, will be considered in the analysis.

4. *Traffic volumes and relative activity on the Inuvik-Tuktoyaktuk Highway.* The relative activity on the road during sampling may provide a method to assess potential movement of bears relative to the road from repeat detections.

5. *Potential paternity analysis using multiple detections at single tripods combined with similarity of genotypes.* It is likely that family groups were detected at tripods. This can be explored further by looking at similarity of genotypes and whether the same individuals were detected repeatedly at the same tripod sites. These results can potentially provide a secondary indicator of rates of additions of new bears in the study area.

6. *Weather effects on genotyping.* The genotyping success varied by year and session with lower rates in later sessions. This is potentially related to precipitation. Weather records could be used to assess whether there is a correspondence as suggested in other studies (Dumond et al. 2015).

7. *Correspondence of radio collared bears with SECR predictions.* The SECR models estimate activity centers and distribution of individual bears as a function of tripods where they were detected. These estimates could be compared to historic telemetry records for bears that were previously collared that were detected during sampling. No bears were collared during sampling so the comparison would be under the assumption of similar movement patterns between years.

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APPENDICES

Appendix 1 Background Information on Mark-recapture Issues

Several fundamental mark-recapture concepts must be defined to ensure adequate understanding of the concepts discussed in this report.

Definition of a Model and Estimator

Mark-recapture estimation represents an improvement from traditional count-based census methods. With traditional methods bears would be counted or trapped and the number trapped would be the estimate of population size. Inherent in this is the assumption that all animals have been trapped or counted, otherwise the estimate of population size would be lower than the actual population size. In mark-recapture estimation the percentage of animals captured is estimated. This percentage is called a capture probability. This concept can be expressed by the following formula:

$$\hat{N} = \frac{\hat{M}}{\hat{p}}$$

In the above formula, M is the count of animals, $\hat{p}$ is the estimate of capture probability, and $\hat{N}$ is the estimate of population size. With traditional census methods $\hat{p}$ is assumed to equal one. An important term can be introduced here. A *model* is a set of assumptions that correspond to an estimation method. In the case of a census, our model is based on the assumption that all animals are caught. Capture probability $\hat{p}$ is rarely equal to one, and, as a result, many models have been formulated that make differing assumptions on how $\hat{p}$ varies. For any model there is a corresponding estimator. An *estimator* is a set of mathematical formulae that allow an estimate using the assumptions of the model. In the case of a count model, the estimate is simply the count of animals caught. The subject of estimation using mark-recapture methods has seen much theoretical attention, and, therefore, many estimators exist which are much more complex than simple counts.

Bias, Precision and Robustness

Estimates of density and population size are evaluated using two principle measures: precision and bias. The best way to conceptualize precision and bias is to consider what a range of estimates might look like if a project was repeated many times (Figure 12).

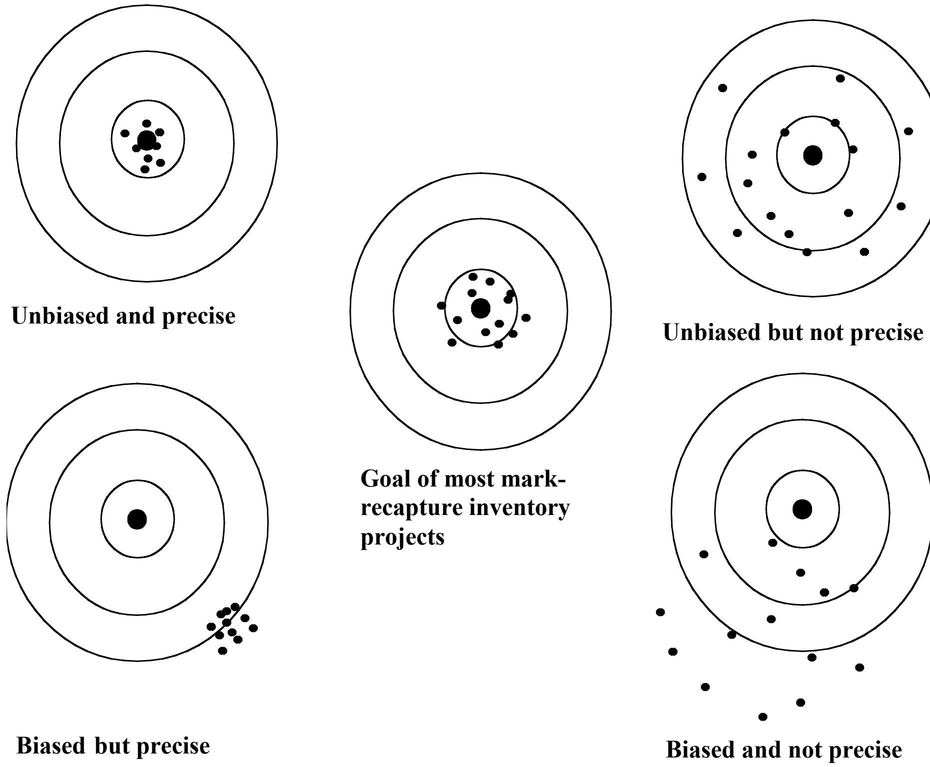

Figure 16. A conceptual diagram of bias and precision. Each target represents a possible set of estimates ("shots") from the mark-recapture experiment, if the study were repeated many times. Lack of precision is mainly caused by low sample sizes, and bias is caused by improper model selection. Unlike this target analogy, most mark-recapture experiments are only conducted once (i.e. one "shot") and the true bullseye (true population size) is not known. Therefore, mark-recapture data should be interpreted cautiously and statistically to avoid erroneous conclusions (target figure from White et al. 1982).

Precision is the repeatability of estimates and is usually estimated by the coefficient of variation and the width of confidence intervals. *Bias* is the deviation of estimates from the true population value and is determined by how well the statistical model and estimator fit the mark-recapture data. The goal of most mark-recapture experiments is to minimize bias and maximize precision therefore minimizing potential error in estimates.

An ideal estimator of population size or density should be unbiased, precise, and robust. *Robustness* is a measure of how well an estimator will perform even when its associated assumptions about capture probability are violated. An example of a robust estimator would be one that assumes equal capture probabilities but still gives unbiased estimates when moderate capture probability variation exists in the data.

Appendix 2: Structural Relationships between Landcover Covariates

Principal components analysis was used to assess structural relationships among the primary habitat covariates. The principal components model explained 57% of the variation in the covariate data with the three principal components. Principal component scores suggested the higher association of shrub and lichen for the first component, closed spruce and deciduous (positive) and non-vegetated/sparse vegetated (negative) for the second loading and low shrub lowland and wet herbaceous for the third component (as determined by loads of greater than 0.5) (Table 8).

Table 14. Standardized component scores for principal components analysis of SECR habitat mask remote sensing data. Significant factors are in bold.

Variable	Factor1	Factor2	Factor3
Closed spruce	0.17	**0.61**	-0.33
Deciduous	0.07	**0.59**	-0.48
Dwarf shrub	**-0.84**	0.14	-0.02
Low shrub lowland	0.47	-0.09	**0.67**
Low shrub upland	**-0.83**	-0.13	0.20
Open spruce	0.32	0.35	-0.06
Tall shrub	0.48	0.38	0.18
Tussock lichen	**-0.71**	-0.18	0.31
Water	0.24	-0.27	-0.18
Wet herbaceous	0.47	0.35	**0.56**
Herbaceous	0.40	-0.45	0.23
Non-vegetated	0.41	**-0.65**	-0.30
Sparse vegetation	0.27	**-0.62**	-0.39

Inspection of principal component plots suggested positive associations of higher elevation communities (dwarf shrub, low shrub upland, tussock lichen) for the first component (Figure 10). The second component was positively associated by closed canopy vegetation (closed spruce/deciduous/closed birch) but negatively associated with sparse/non-vegetation areas. The third component was less associated with any particular class. These results suggest that the dominant gradients are towards association of higher elevation communities (first component) and closed cover in opposition to sparse/non vegetated classes in the second component. The main interpretation of this result is that association of any particular habitat class may indicate a general gradient in the data set as opposed to a single association.

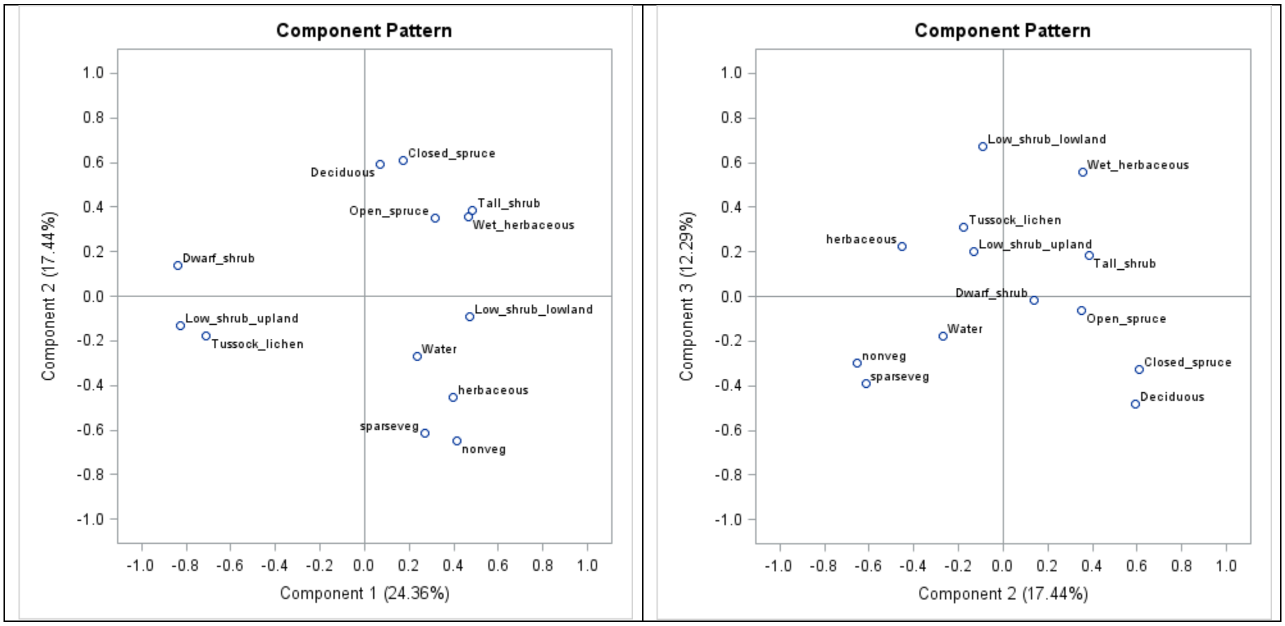

Figure 17. Plots of principal component scores (Table 8) for mask centroid covariates.