YUKON NORTH SLOPE
BASELINE ECOLOGICAL AND CULTURAL CONSERVATION ASSESSMENT

YUKON NORTH SLOPE GRIZZLY BEAR HABITAT MODELS FOR SPRING, SUMMER, FALL AND DENNING:
USING BAYESIAN FRAMEWORK TO INTEGRATE INDIGENOUS KNOWLEDGE AND BEAR GPS LOCATION DATA

FINAL REPORT
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PREPARED BY
MAGGIE TRISKA AND KIMBERLY HEINEMEYER
ROUND RIVER CONSERVATION STUDIES

PREPARED FOR
WILDLIFE MANAGEMENT ADVISORY COUNCIL (NORTH SLOPE)

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Executive Summary

We developed grizzly bear (*Ursus arctos*) seasonal habitat models for the Yukon North Slope (YNS) using Inuvialuit Indigenous Knowledge (IK) and grizzly bear GPS location data for spring, summer, fall, and denning seasons. IK of grizzly bear habitats was obtained through interviews with 18 Inuvialuit experts in the YNS. GPS location data was obtained from a grizzly bear collar study (completed from 2004-2009) in the region and for dens from a compilation of different surveys. These data provide a unique opportunity to combine IK and western science (WS) data into a statistical model to further our understanding of grizzly bear seasonal habitat associations with landscape characteristics such as ecosystem types, topography and hydrological features. To accomplish this, we developed Bayesian Resource Selection Function (BRSF) models that used IK to identify potential landscape characteristics and incorporated IK as covariate priors; thus, integrating IK and WS data into a single model framework.

BRSF models were completed for males and females using IK and GPS collar date for spring (emergence – June 15), summer (June 16 – July 31) and fall (August 1 – denning/end of data); and for one combined-sex denning habitat model using compile den locations, resulting in seven models. Kernel density home ranges were estimated for each individual bear (35), each season (spring, summer, fall only) and each year (183 seasonal home ranges in total), and the boundaries defined habitat availability represented by random points. BRSF models predict relative probability of use, not absolute probability, because used sites are compared to random or available sites, not unused sites. The BRSF models are Bayesian multivariate logistic regression models; we set individual bear, den site, and/or, year of data as random effects to account for repeated sampling within the models. The reported (IK) direction of grizzly bear association (+/-) with IK-derived landscape characteristics was used to inform the prior distribution of the mean within the BRSF framework. All models validated well using leave-one-out validation (Pareto shape (k) values all <0.7), and good to excellent spearman rank correlations values for the k-folds validation (Rho values >.97 for five models, >.82 for one model, >.71 for one model).

During all seasons, the IK indicated that grizzly bears used an array of landscape characteristics throughout the YNS region, which was supported through BRSF modelling with each model having several significant covariate main effects along with interactions between covariates and some covariates showing non-linear responses.

In the spring, IK descriptions of bears included that bears generally tend to move out of the mountains used for denning towards the coast, traveling along river systems and foraging in areas of early snow melt. For both sexes, the model displayed a slight preference for the coastal plain and selection for areas close to rivers and river valleys within the mountains. Females and males significantly selected for lower elevation and increasing slope, while males additionally selected for rounded ridgetops in the coastal plain. The mapped habitat models reflect the use of both mountains and the coastal plain and display a selection for landscapes close to rivers and along the coast. Out-of-sample validation locations (i.e., GPS collar data not used in the modeling) for females were found disproportionately in the highest value habitat class (covering 20% of the landscape), with 62% of locations.

During summer months bears were described by Inuvialuit experts as wide-ranging, often observed traversing the landscape using river drainages in the mountains and coastal plains. In the model, both

sexes weakly preferred mountains over the coastal plains, and both were linked to presence of willows and areas close to rivers. The mapped habitat models reflect the broad use of the YNS during the summer, with the major river drainages having the highest concentrations of high value habitats for both females and males. In summer, males select areas within the summer distribution of caribou. The out-of-sample validation locations of bears shows a strong selection for the highest value habitat; this habitat class covers 20-19% of the landscape with 55% and 64% of female and male validation locations, respectively. Moderate-high habitat class also shows strong selection by both females and males. These validation results indicate that while bears are using a wide range of habitats across the YNS, they are also still highly selective.

In the fall, bears were described in Inuvialuit experts as feeding extensively in areas with high forage (berries, roots) in preparation for denning. Fall models were similar to summer models in some ways: both showed a preference for mountains, with females selecting for shallow and moderate slopes and males selecting for increasingly steep slopes. Covariates characterizing good berry habitats are included in male and female models including areas close to wetlands and specific vegetation classes that have higher berry-producing species. Both male and female mapped model results show the highest concentration of high-quality habitats in the mountainous portions of the YNS, with Ivvavik National Park having the majority of high-quality fall habitats. The out-of-sample validation locations for both females and males show a strong selection for the highest value habitats. Sixty percent of female validation locations occur in moderate to high quality classes (classes 3-5) that cover 60% of the landscape and 53% of female locations occur in the highest class covering 20% of the landscape. Male validation points show males using a broader suite of habitats, with classes 2-5 typically being used more than expected and the lowest value class being strongly avoided.

Den sites were often observed on steep hillsides, often near a water source and often on south-facing slopes. The habitat model above rivers; the den model supported the use of increased slopes and southern aspects by grizzly bears. The habitat model incorporated slope, hillsides and a preference for rivers, but also an avoidance of tundra. The model predicts a fairly narrow suite of moderate and high value habitats, covering 13% and 14% of the study area respectively. These areas are found in the mountains, and most available in Ivvavik NP and also in the southern mountains of eastern YNS.

The results indicate that grizzly bears are highly selective for the identified moderate to high-quality habitats; however, all habitat classes were used to some degree. Grizzly bears may traverse low-quality habitat to reach high-quality habitat or a food source, and connectivity between higher valued habitats is important as bears utilize a wide range of habitats within and across seasons and years.

Acknowledgements

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The effort was based on a foundation of expertise provided by Inuvialuit land users. These experts participated in interviews in 2016 and answered detailed questions about grizzly bear habitat use, documented in WMAC (NS) and AHTC (2018). We are indebted to their generosity in sharing their years of knowledge: Andrew Archie, Billy Archie, Peter Archie, Deon Arey, Jerry Arey, Joe Arey, Larry Arey, Renie Arey, Robert Archie, Annie Gordon, Colin Gordon, Danny C Gordon, Patrick Gordon, Edward Mcleod, Sam Mcleod, Sarah Mcleod, Jonas Meyook Jr., and Lee John Meyook.

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Chapter 1: Introduction, study area and methods

Introduction

Natural systems are complex and poorly understood, challenging our ability to successfully manage and conserve large, natural landscapes and the biodiversity that requires them. Integrating multiple forms of knowledge and information is fundamentally more powerful than limiting interpretation to a single view or type of data. There is a growing recognition by government and non-government institutions of the need to inform environmental management with all information available using multidisciplinary approaches to incorporate indigenous, traditional and local knowledge and western science (Marin, Coon, and Fraser 2017; Huntington 2011; Roux, Tallman, and Martin 2019). Furthermore, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD) (Díaz et al. 2015; Ulicsni et al. 2019) has emphasized the importance of using both indigenous knowledge (IK) and western science (WS) to improve conservation and sustainable use of biodiversity.

Indigenous communities in northern Canada have maintained secure cultural connections to their traditional territories and have a wealth of indigenous knowledge maintained through on-going traditional land, resource and cultural uses within these landscapes over multiple generations. The increasing use of IK with WS by government resource agencies has resulted in improved research studies and an increased understanding of natural history events (Marin, Coon, and Fraser 2017; Roux, Tallman, and Martin 2019). IK used here includes traditional knowledge acquired through observations or passed down via oral tradition or resource use. IK can increase confidence in natural resource or wildlife studies by increasing sample size, providing validation points and covering longer time periods, thus capturing extreme events (Moller et al. 2004; Huntington and Suydam 2004; Gilchrist, Mallory, and Merkel 2005). For example, in northern Canada IK and WS have been used to evaluate migratory movements, species distributions, habitat associations, management and population trends for multiple species (marine mammals, fish and migratory seabirds) (Roux, Tallman, and Martin 2019; York et al. 2016; Lewis et al. 2009; Martinez-levasseur et al. 2016; Furgal and Laing 2012; Gilchrist, Mallory, and Merkel 2005). While WS and management have benefited from increasing recognition and incorporation of IK, it is important to acknowledge the parallel processes occurring amongst Indigenous knowledge holders and communities. As leaders, stewards, and managers, IK holders are incorporating WS into their own knowledge frameworks and applying it in decision-making, from governance to harvesting. Reciprocity and cross-pollination amongst knowledge systems remain important aspects of the expanding collective knowledge base.

Although many researchers and managers increasingly acknowledge the need to bridge IK and WS, some have expressed concerns over the difficulties and challenges of collecting, accessing and using IK within existing WS approaches, particularly for quantitative data analyses and modeling (Ulicsni et al. 2019; Huntington 2000). For example, in wildlife habitat studies that have attempted to use both IK and WS (e.g., wildlife collar data), the most common approach is developing two depictions of wildlife habitat values: one based on IK, one based on WS. By comparing the juxtaposition of habitat associations based on the separate IK and WS models the level of agreement between the two data types are determined (Polfus et al. 2014; Doswald, Zimmermann, and Breitenmoser 2007; Tendeng, Asselin, and Imbeau 2016;

Lewis et al. 2009). IK also is commonly used to assess or validate the results or trends from WS wildlife surveys (York et al. 2016; Roux, Tallman, and Martin 2019). In both cases (comparative and validation frameworks), the data types are handled separately, likely due to the lack of accessible approaches for integrating IK and WS data (Roux, Tallman, and Martin 2019; Huntington 2000).

Bayesian methods are used in ecology to integrate expert knowledge as informed priors in quantitative analyses (Low-Choy, O'Leary, and Mengersen 2009), and offer an exciting and potentially powerful approach to integrating IK and WS. Completed studies incorporating IK via Bayesian belief networks and classification trees (Girondot and Rizzo 2015; Liedloff et al. 2013), indicate it may be possible to develop a Bayesian habitat modeling approach that incorporates IK and WS information to improve wildlife habitat predictions. Resource Selection Functions (RSFs) are considered the WS standard approach to understand and predict habitat use of wildlife (D. H. Johnson 1980; Boyce et al. 2002; Manly et al. 2002; C. J. Johnson et al. 2006). We believe a Bayesian-based RSF provides the opportunity to integrate IK as priors into the RSF to specify the likely influence of landscape characteristics (vegetation type, topography, hydrological features) on the model. Despite the potential of this approach, we were unable to find any examples that integrated IK into a Bayesian RSF.

IK holders are indigenous experts; however, the information they report is often in a different format than reported by WS experts. WS structured expert interviews generally obtain mean and confidence level estimates which readily match required inputs for informed priors of a Bayesian belief network. Most commonly, IK expert interviews focus on more qualitative information based on repeated observations over time and space. While challenging given the different types of information collected, integrating IK and WS through a Bayesian RSF (BRSF) may appropriately leverage the power of each data type and advance our insights into the system of interest. Therefore, we used a BRSF to integrate IK and WS in the development of a grizzly bear (*Urus arctos*) habitat model for the Yukon North Slope (YNS) of northern Canada.

The YNS represents the northern extent of grizzly bear distribution in North America. Grizzly bears are a dominant predator on the YNS, and are also omnivorous and forage heavily on a diversity of plants and berries (MacHutchon 1996, 2001). Grizzly bears are of high cultural value to the Inuvialuit who use the YNS for harvesting. The Inuvialuit harvest grizzly bears for cultural, food, ceremonial and economic purposes, and the conservation management of grizzly bears and their habitats are important both culturally and ecologically on the YNS (WMAC(NS) and AHTC 2008). In 2004, a study was initiated to evaluate grizzly bear population size, health and management by obtaining information from local experts and through GPS collaring of grizzly bears in the YNS (WMAC(NS) and AHTC 2008). Additional IK of YNS wildlife habitat associations, including grizzly bears, was collected in 2016 (WMAC(NS) and AHTC 2018). We used the grizzly bear IK interview data collected in 2016 and GPS collar data collected in 2004-2009 to develop seasonal habitat models using a BRSF framework. The approach has the potential to inform management and provide a framework for future IK and WS studies.

Study area

The YNS is the northern portion of the Yukon that borders Alaska (west), the Northwest Territories (east), and the Beaufort Sea (north; Figure 1.1). It encompasses ~18 225 km^2 and contains Ivvavik

National Park and Herschel Island-Qikiqtaruk Territorial Park. Three mountain ranges, the British, Barn and northern Richardson are within the YNS, as are several small arctic islands in the Beaufort Sea. The coastal plains are a dominant feature of the YNS, extending from the Beaufort Sea south and covering a vast portion of the YNS, particularly in the northeastern portion of the study. These diverse ecological regions support diverse arctic environments. There are no permanent settlements within the YNS, but it is the traditional harvesting area of Inuvialuit who seasonally travel from adjacent areas including the Northwest Territories to harvest plants, fish and wildlife and to visit culturally important places (WMAC(NS) and AHTC 2018).

Three vegetation classes make up >50% of the YNS: tussock, rock-lichen, and mesic sparse low tundra (Ecological Landscape Classification Supervisory Committee 2013). Species in these vegetation classes include grasses, herbs and shrubs such as *Calamagrostis* spp., cottongrass tussock (*Eriophorum vaginatum),* crowberry (*Empetrum nigrum*), dwarf birch (*Betula glandulosa*), saxifrages (*Saxifraga* spp.), mountain avens (*Dryas octopetala*) and horsetail (Equisetum spp. (PEM, Yukon Territorial Government). Trees are limited in the region; however, stands of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and balsam poplar (*Populus balsamifera*) persist in valleys and some south-facing slopes. Willows (*Salix* spp.) occur along rivers, streams and lakes and in shallow depressions at higher elevations where snow patches remain into the summer (PEM, Yukon Territorial Government). Fog is often present during the summer months due to weather systems moving off the Arctic Ocean (Nagy et al. 1983) and precipitation varies from 125mm along the Arctic Coast to 250-380mm in the British Mountains and 500mm in the Richardson Mountains (unpublished report, Parks Canada and the Yukon Territorial Government). The mean monthly temperature ranges from -25^{o}C in January to 12^{o}C in July, with a mean minimum of -28^{o}C in January and a mean maximum of 17^{o}C in July (CCCS 2019).

Information sources for Grizzly bear habitat models

Traditional knowledge

In 2016, 18 Inuvialuit with extensive and long-term experience on the YNS were identified by the Aklavik Hunters and Trappers Committee and interviewed to obtain their traditional knowledge of grizzly bear habitat associations (WMAC(NS) and AHTC 2018). To document their knowledge of grizzly bear habitat use during the spring, summer, fall, and denning periods each individual was asked multiple, open-ended questions (see WMAC(NS) and AHTC 2018 for a list of questions). The knowledge-holder decided which seasons s/he would answer questions about; hence, not all 18 interviewees provided information on grizzly bear habitat use during all seasons. The survey methodology used carefully worded questions to reduced motivational bias and represented an indirect elicitation method. The resulting qualitative information was used to summarize landscape characteristics identified as important components of grizzly bear habitat use. Landscape characteristics that were identified by multiple interviewees were assumed to have greater evidence of broad importance to grizzly bears on the YNS. The collected IK informed two major components of the BRSF models: identification of landscape characteristics considered and the direction of the priors (+/-) representing selection or avoidance of these landscape characteristics by grizzly bears.

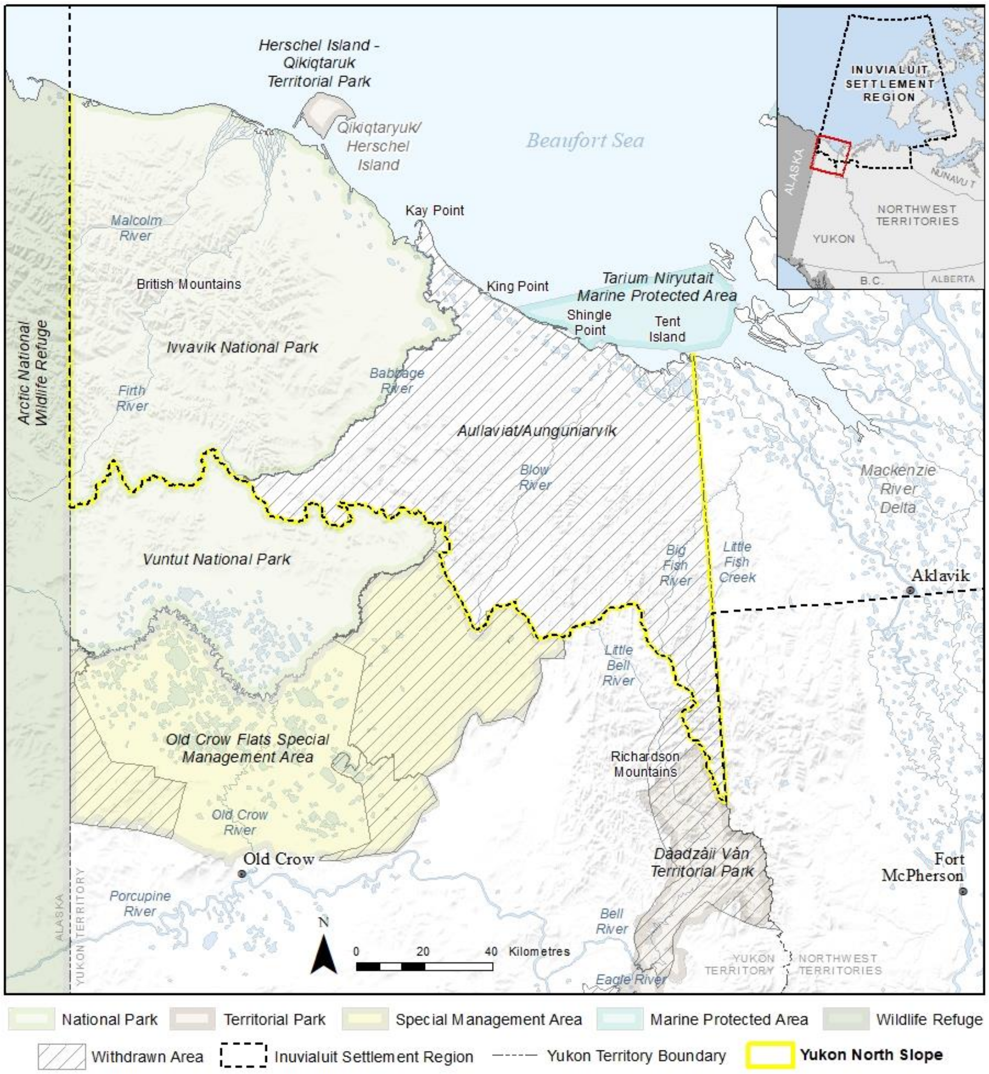

Figure 1.1 Map of the Yukon North Slope (YNS) and surrounding areas. The YNS study area, for which grizzly bear models were produced, is outlined in yellow.

GPS collar data

We used location data from a 2004-2009 YNS grizzly bear GPS collar study to develop seasonal (spring, summer and fall) BRSF habitat models (data provided by: Parks Canada and the Yukon Territorial Government). Thirty-five individual adult bears (18 females and 17 males) were collared, and most bears (*n*=26) had collar data collected for 1-2 years; however, 9 females have multiple years of monitoring (Table 1.1). In most instances, data were collected at 4 hour intervals but some individuals had 1-, 2- or 3-hour relocations; therefore, individual data from all years (2004-2009) were thinned to 4 hour time intervals for consistency in the analyses, except for two individuals for which data was collected at 3-hour intervals.

Table 1.1 A summary of the number of years data were available (Years) and the number of individual bears (No. Females; No. Males). A year was defined as any calendar year that had at least one season with >30 observations.

Years	No. Females	No. Males
0	1	1
1	4	7
2	4	9
3	2	0
4	4	0
5	2	0
6	1	0

Den site data

We received 97 grizzly bear den site locations within the YNS (data provided by: Parks Canada and the Yukon Territorial Government). While most of these locations were opportunistically recorded during surveys for other species; some den site locations were likely from the GPS collared bears, but they were not labeled as such. Dates of the den observations range from the 1990s to present day; however, exact dates were not always available. To reduce the potential for pseudoreplication, possible due to a spatial bias in the data and limited information on the year of observation for some of the den sites, we removed some den sites. A den site was removed if two den sites were: 1) <250m apart and the data was entered in the database in the same year or 2) listed as used by the same bear, were <1km apart and/or had one observation that was listed as 'incomplete' or 'low confidence' by the observer. This procedure resulted in 83 remaining den sites for the habitat model development.

Methods

Landscape characteristic identification scale and selection

Landscape characteristics defined as important by Inuvialuit experts were linked to available potential covariates for inclusion in the seasonal habitat models. Additional potential landscape characteristics were identified from regional biologists, natural history and published literature on grizzly bear habitat relations in other regions. Landscape characteristics were extracted or derived from available spatial data in the study area (i.e., landcover, topographic features, hydrological features) and occasionally combinations of these data (see Appendices 1 and 2 for descriptions of landscape characteristics used in the models and Appendix 3 for visual representations of key layers).

We used a 16m digital elevation model (DEM) to calculate landscape characteristics such as slope, elevation, aspect, solar insolation, topographic position index (TPI), terrain ruggedness index (TRI) and a vector ruggedness index (VRM). We selected predictive ecosystem mapping (PEM) landcover types or the associated IK-based landscape characteristics (WMAC(NS) and AHTC 2018) when these were suggested as important in the IK interviews. We included IK-derived landscape covariates including: distance to multiple water features (wetlands, rivers and streams, small rivers, large rivers, shoreline, coast, and lakes), valley and hillside types (based on combinations of vegetation, hydrology); proxies for barren ground caribou (*Rangifer tarandus granti*) availability and vegetation with high berry potential.

To determine the spatial scale most predictive of grizzly bear use, we generated landscape characteristics inherently scale-dependent (e.g., Topographic Position Index, TPI) at multiple scales (50, 100, 200, 300, 500, 700, 1000, 2000m; and <50m or >2000m when required). For other covariates, we used moving window analyses in ArcGIS to calculate the average value of the landscape characteristic within moving windows of various size to reflect different spatial scales (e.g., percent timber within a 50m, 100m, etc. moving window, DeCesare et al. 2012). We then used univariate logistic regression to select the scale that was most strongly selected by grizzly bears as the scale with the lowest AIC value (see example in Appendix 4). Landscape covariates that were not significantly selected for at any spatial scale were removed.

We screened covariates for collinearity (|r| >= 0.6), and the covariate with the lowest univariate AIC was retained. For spring models, elevation was correlated with slope; however, both covariates were retained as each was identified as an important predictor of spring habitat use for different ecological reasons. Additionally, we evaluated the data for potential non-linear responses (including splines and quadratic transformations), interactions (specifically with the coastal plain) and confounding variables (Hilbe 2015; Hosmer, Lemeshow, and Sturdivant 2013). During all seasons 'distance to' covariates were log transformed prior to analyses to reduce the influence of distant points and aspect was split into the 4 cardinal directions (North, South, East, West).

Modeling framework

We developed BRSF habitat models predicting spring, summer, fall and denning grizzly bear relative habitat use. Covariate selection used univariate and multivariate logistic regressions, including BSRF, to explore and identify landscape characteristics that significantly predicted grizzly bear habitat use based on GPS locations of grizzly bears collected between 2004-2009 and the den site data. In the final model the scale and suite of covariates identified were used within a BRSF framework with IK-informed priors for covariates identified by Inuvialuit experts. As in standard RSF analyses, BRSFs compare landscape characteristics at used GPS locations with random locations (putatively available) to identify landscape characteristics that are used disproportionately more (i.e., selected) or less (i.e., avoided) than available or proportional to availability (lack of selection: Manly et al. 2002). We conducted a 3rd order (Johnson 1980) or home range scale model, which assumes that habitats within individual home ranges are available to that bear to use.

The BRSF models, like standard RSF approaches of using logistic regression, estimate the relative probability of selection rather than an absolute use prediction given we do not have 'unused' locations but rather random, assumed available locations (McDonald 2013). This is achieved by ignoring the intercept. We included individual bear ID and the year as random effects during spring, summer and fall models and den ID as a random effect in the denning model to control for differences in sampling intensity between bears, years and den sites (Gillies et al. 2006). We standardized non-binary covariates values (mean = 0, standard deviation = 1; the covariate value minus the covariate mean value was divided by the covariate standard deviation) prior to analyses which allows us to compare within-model coefficients for their relative influence within the model (Schielzeth 2010). We developed the BRSF using the R package rstanarm (Stan Development Team 2016).

IK provided the information to develop informative priors for IK-identified landscape characteristics. We used the interview responses to define the direction (+/-) of grizzly bear expected selection of each of the IK derived landscape characteristics (see Appendices 1 and 2 for descriptions of seasonal IK landscape characteristics and those retained in the models). Mean prior values included -1 for avoided, 0 for not mentioned and +1 for preferred landscaped characteristics mentioned during IK interviews. ArcMap 10.7 (ESRI 2019) and the program R (R Core Team 2019) were used to generate spatial data and R was used for all data analyses.

Mapping methods and classification

The final model covariate estimates were mapped to allow for visualization of relative habitat use by grizzly bears. To generate these maps, we used unstandardized landscape characterisctic estimates. These were used to calculate the habitat model coefficients for unstandardized covariates, and the unstardardized coefficient values to calculate the relative probably of use for each pixel in the study area (see equation below). This required new rasters to be created for any non linear or interaction terms.

$$TopModelRaster=exp(intercept+LC_{n1}v*LC1_{n1}e+LC_{n2}v*LC_{n2}e+\ldots)/(1+exp(intercept+LC_{n1}v*LC_{n1}e+LC_{n2}v*LC_{n2}e+\ldots))$$

where *exp* = exponential, *LC* = landscape characteristic, *n* = individual covariate, *v* = pixel value and *e* = the model estimate

Each raster (TopModelRaster) generated (in program R) for spring, summer, fall and denning was imported into ArcGIS and classified into five categories using the equal area classification method. This method divides the landscape into categories that represent a similar percentage of the landscape. Therefore, each bin represents an equal area (e.g., ~20% of the landscape), and we refer to these classes based on their relative probability of use as High (class 5), Mod-High (class 4), Mod (class 3), Low-Mod (class 2) and Low (class 1). Denning habitat qualty was divided into three equal area classes: High (3), Mod (2) and Low (class 1). The preponderance of low habitat predictions in the denning model challenged the equa area classification, forcing us to simplify to three classes, which still show a preponderance of low quality habitat.

Model validation

We assessed the final models in multiple different ways. Landscape characteristics within the models were evaluated to verify that their R-hat statistic was approximately 1, indicating model convergence (approximately equal variance between and within chains; Muth, Oravecz, & Gabry, 2018). Additionally, the potential error introduced by Markov Chain Monte Carlo (MCMC) approximation of the posterior was evaluated by calculating the effective posterior sample size: effective sample size (ESS) and Monte Carlo standard errors (MCSE). The ESS represents the number of independent draws with the same estimation accuracy as the sample of correlated draws, and MCSE is calculated by dividing the posterior standard deviation by the square root of the ESS. A low value of MCSE relative to the posterior standard deviation results in a high ESS, which is desired. Large MCSEs may be problematic as they can mask uncertainty in the estimate. None of these pre-analysis values (R-hat, ESS or MCSE) indicated issues with our covariates or models.

We evaluated the models using the 'leave-one-out" (LOO) cross-validation strategy, which sequentially removes one individual from the data, rebuilds the model, and used the excluded animal to validate the new model. This method estimates the expected log predictive density for the dataset and uses a LOO Information Criterion with the same purpose as the AIC in frequentist statistics. Any points that greatly affect the posterior distribution when removed can be identified with a Pareto smoothed importance sampling (PSIS) diagnostic plot. The diagnostic plot fits a Pareto distribution to the upper tail of the distribution of the importance weights and displays the data points and the Pareto shape parameter (k) to determine if the value is larger than a select threshold. In this analysis, observations are flagged when values are >0.5 and assumed problematic when values are >0.7. Values >0.7 return NA values and require further explanation for lack of model fit (no final models contained values >0.7; see Appendix 5 for example plots).

The models were also evaluated using k-folds cross-validation (n=10). Nine-folds were retained to generate the model, and the resulting model was used to predict values for the remaining fold. Spearman's rank correlation rho values with associated p-values were obtained for the fold models. A rho value near 1 and a significant p-value indicated that within that random fold the model predicts habitat associations well.

Last, we assessed the spring, summer and fall models using out-of-sample GPS location data not used in the development of habitat models (thinned data and removed grizzly bears <30 data points) to determine how well models predicted the frequency of grizzly bear relative use (e.g., DeCesare et al. 2012; Holbrook et al. 2017). Relative use was calculated by dividing the proportion of bear GPS validation locations falling within each habitat class by the proportion of habitat available in each habitat class. Habitat classes were defined by five equal area intervals (i.e., each class approximately covered 20% of the landscape); thus, if bear use was random across the landscape it would be expected that approximately 20% of the bear locations would fall within each habitat class. The relative use provided an evaluation of this, with a value of 1 indicating use was equal to availability (no selection), values <1 indicating use was less than available and values >1 indicating use was greater than expected.

Report structure

We developed two different types of habitat models based on the data and information available to us. For spring, summer and fall seasons, we used relocation data of collared bears combined with the IK information on seasonal habitat preferences (presented in Chapter 2). We used opportunistically collected den site data acquired over several years to develop a denning habitat model, which has different assumptions and levels of information that change how we characterized bears, bear use and habitat availability (presented in Chapter 3). These results are discussed in Chapter 4, including a discussion on the novel use of Bayesian approach to develop the habitat models by incorporating IK as informed priors for IK-derived model covariates.

Chapter 2: Spring, summer and fall season habitat models

In Chapter 2, we describe the development and results of grizzly bear spring, summer, and fall habitat models for the Yukon North Slope. These models use IK and WS to inform the identification of potentially important landscape characteristics to predict seasonal habitat use. The models were developed through a Bayesian RSF incorporating IK in both the identification of landscape characteristics and the informed priors of the BRSF.

Data and methods

Chapter 1 provides information about the source of IK information, the identification and development of potential landscape characteristics to predict grizzly bear habitat use, a description of the Bayesian RSF approach, and mapping the resulting model relative probability of use predictions. In this chapter, we supplement the information provided in Chapter 1 with the unique aspects of the data and methods explicitly used to develop the spring, summer and fall seasonal habitat models.

Home range and season definitions

We defined spring, summer and fall seasons using IK and prior research (MacHutchon 2001), and refined the dates by evaluating movement rates of grizzly bear during each proposed season based on location data from the 2004-2009 YNS grizzly bear GPS collar study (see Appendix 6 for details of spring, summer, and fall divisions). The information supported defining spring as den emergence to early June; summer as late June and July; and fall as August to start of denning. The data were split between early (day ≤15) and late June (day >15) to best capture den emergence (Figure 2.1). Additionally, we removed the first two weeks of male spring data to reduce the influence of denning locations on the model (see Figure A6.1); reduced movement for females was not observed in early spring, and thus no data points were removed.

A seasonal home range was calculated for spring, summer, and fall for each bear, and each year the bear was monitored, as GPS points indicated that individual movements were spatially confined both within seasons and across years to what may be considered seasonal home ranges. These home range boundaries defined available habitat. Using the home range, or 3rd order (D. H. Johnson 1980) scale for the BRSF analyses allowed us to account for differences in habitat use and availability across individuals and seasons. We identified individual and year as random effects in the BRSF to account for repeated sampling. These decisions were supported by a study completed in Ivvavik National Park that found that individual grizzly bears have different habitat use strategies that may restrict generalizations about habitat importance at a population level (MacHutchon 1996).

Differences in space use, movements and potentially underlying ecological drivers (e.g., females with cubs) between male and female grizzly bears supported separate seasonal BRSF models for males and females, resulting in six seasonal models: spring, summer, fall models for males and for females.

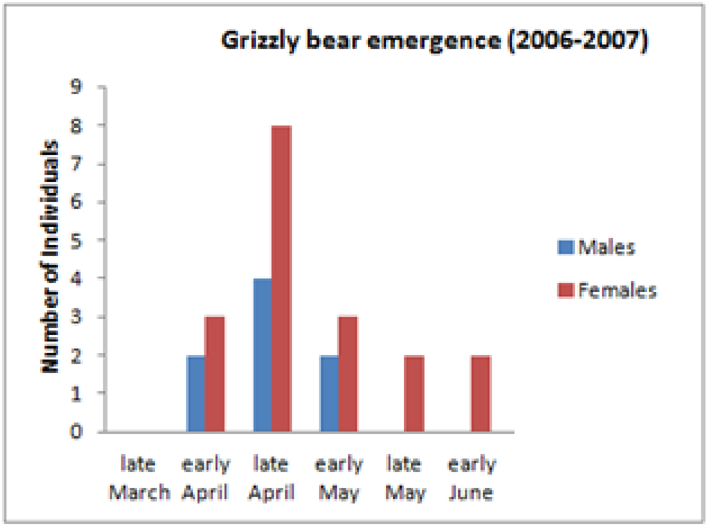

Figure 2.1. Den emergence dates for GPS collared grizzly bears (Ursus arctos) by two-week periods (nFemales=18; nMales=10). "Early" represents days of the month ≤15 and "late" represents days of the month >15.

Grizzly bear GPS location data processing

As previously mentioned in Chapter 1, GPS locations were subsampled to standardize to 4-hour intervals except for 2 animals that had 3-hour intervals. We examined the data for spatial outliers (e.g., due to poor GPS satellite quality) and other anomolies that were removed. Single instance long-distance animal movements outside of general activity areas were evaluated, and if they greatly influenced home range siz, they were removed for the final home range analyses. Individual seasonal home ranges were calculated with the adehabitatHR package in R using 95% adaptive kernel density estimates with the default smoothing factor (Calenge 2006). Kernel density estimates were selected over Minimum Convex Polygon (MCP) as MCP is more sensitive to sample size (Kolodzinski et al. 2010; Mills, Patterson, and Murray 2006). We defined kernel density estimates for all bears with ≥30 locations.

Overall, 183 (125 female, 58 male) seasonal home ranges for 35 individual bears were calculated (keeping each year separate; summarized in Appendix 7). Males had notably larger home ranges than females in all seasons (Table 2.1). Both males and females, on average, had the largest home ranges in the summer but individual seasonal home ranges sizes were highly variable, as indicated by the large standard deviations for all seasons.

In most cases, both the use locations and the estimated home range boundaries fell within the YNS study area boundary. However, in 15 of 183 seasonal home ranges, the animal use locations fell outside the study area and in an additional nine cases, estimated seasonal home ranges extended beyond our study area boundaries but animal use locations did not (i.e., animals were close to the boundary). In all cases, we clipped the use (animal locations) and home range (available habitat) to the study area (e.g., see Figure 2.2 for an example of a home range estimate that was clipped to the study area). No seasonal home ranges had ≤30 data points after clipping to the study area and less than 2% of points were removed during each season (Spring: 1.48%, Summer: 1.12%, Fall: 1.99%). Note that home range estimates that extended into the near-shore habitats on the north were retained and defined as near-shore/ice.

Table 2.1 Average seasonal home ranges for female (F) and male (M) grizzly bears on the Yukon North Slope based on kernel density home range estimates. Individual home ranges are calculated for each individual bear each year of monitoring, thus n depicts # home ranges/#individual bears

	Spring			Summer			Fall		
	mean	**st dev**	**n**	**mean**	**st dev**	**n**	**mean**	**st dev**	**n**
F	726	1454	35/13	1134	3056	46/17	344	481	42/17
M	1574	1472	19/13	2706	3935	21/16	2364	2400	18/15

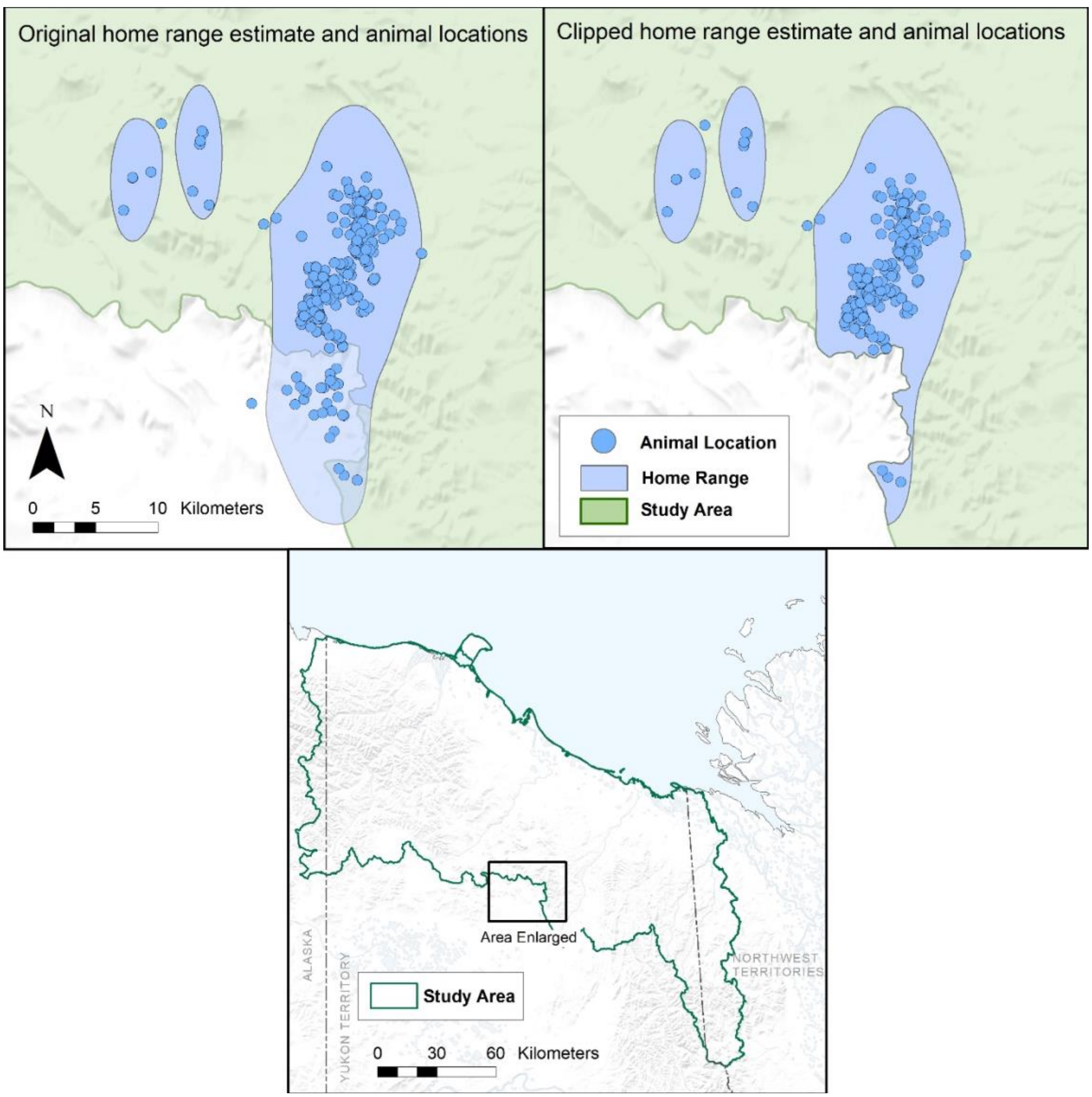

Figure 2.2. Example of an individual female grizzly bear use locations and home range that was clipped to the extent of the YNS study area for habitat modeling.

Once home ranges were defined, we generated random points within each home range at a ratio of 4:1 random:use locations to represent available habitat. Each grizzly bear use and available point was annotated with values of landscape characteristics (see Chapter 1, Appendices 1 and 2) for evaluation and potential inclusion in the BRSF modeling.

Results

IK landscape characteristics

For each seasonal habitat model, landscape characteristics were identified when possible through IK interview descriptions (Appendix 1). A total of 18 individuals completed IK interviews; however, individuals only provided information on grizzly bear habitat use during the seasons they were most familiar with. Therefore, the number of individuals responding per season varied (spring: 16; summer: 11; and fall: 14; WMAC(NS) and AHTC 2018).

The described landscape characteristics were translated into GIS layers (described in Appendix 2) for inclusion in the BRSF analyses as potential covariates. The IK landscape characteristics included in the final female or male models are listed in Table 2.2. Interviewees described the types of habitats they observed bears using and these positive associations between bear use and the IK landscape characteristics was incorporated into BRSF models through priors. The exception was for ‘distance-to’ covariates, as negative selection for a distance-to covariate indicates selection for areas close to the indicated landscape characteristic (e.g., a preference for areas close to rivers and/or wetlands).

Spring IK descriptions

During the spring, the Inuvialuit experts described bears moving from mountainous areas where they den to the coast, and descriptions varied based on whether the Inuvialuit experts described habitat use in the mountains or in the more open tundra and coastal region. Hillsides were described as important because they are clear of snow earlier than other areas, and bears dig for roots or hunt ground squirrels there. Rivers and creeks were described as travel routes for bears as they move towards the coast. Where creeks are narrow with dense vegetation, it was stated that the bears move to higher ground. In comparison, where the river valleys widen and the topography is gentler, the bears move more along the waterways themselves and also across flatter ground, or tundra as described by interviewees. Additionally, bears were described as traveling through tundra and coastal areas and scavenging on whales and hunting seals along the coast itself. Interviewees described bears following caribou in the spring and hunting or scavenging on wolf kills. Interviewees also stated that bears follow muskox during spring when muskox are calving, including on Herschel Island; some felt that muskox might become a more important food source as their (muskox) numbers increase.

We developed 18 covariates to potentially capture the habitat characteristics identified by the Inuvialuit experts in the spring (Appendix 1). Of these, nine were significant in the analyses and modeling (Table 2.2). There are five and seven TK-derived covariates in the final female and male habitat models, respectively (see model results sections below for further information).

Summer IK descriptions

During summer, Inuvialuit experts stressed that bears are wide ranging and move throughout the region, and they acknowledged that their observations were based on where they were within the landscape, which tended to be from a waterway (e.g., boat) or air. They describe bears being found in tundra type ecosystems both in the rolling hills as well as along the flats inland from the coast. They described that bears follow caribou during the summer, including into the calving grounds and as caribou move along the coast. There was again mention of bears following muskox on Herschel Island. Additionally, hillside habitats as well as swamps (wetlands) were identified as areas where bears forage on berries in the summer.

We examined 14 potential covariates to capture the landscape characteristics described by the Inuvialuit experts (Appendix 1). Of these, eight were found to significantly predict grizzly bear habitat use in the models (Table 2.2); all eight are in the final male habitat model, while six are in the final female habitat model.

Fall IK descriptions

Inuvialuit experts described bears using a wide diversity of habitats as they focus on foraging including on berries, digging roots, and hunting for caribou, moose, muskox, ground squirrels and Dolly Varden char (as the fish migrate upstream). Interviewees identified good foraging places or landscape characteristics that supported these foods: swamps for berries; along the coastal plains where caribou migrate; near water for bear root; along rivers with char and for moose. The focus on eating was described as preparation for winter denning, with movement towards the mountainous area for denning.

We examined 13 potential covariates to capture the landscape characteristics described by Inuvialuit experts (Appendix 1). Of these, eight are used in the final habitat models, with seven in each of the female and male final models.

BRSF habitat models

We developed six BRSF models that predict the relative probability of habitat use in spring, summer, and fall for male and female grizzly bears. For each model, we completed landscape characteristic selection, model development and model validation, summarized here.

Covariates that were in the selected model are referred to as main landscape characteristics. In addition to the main covariates, there may be additional interactions between these covariates and/or transformations of the covariates to capture non-linear responses that are included as modifiers in the model. We evaluated multiple potential interactions between covariates but found the most useful interactions were with the covariate that identified broad regions of the study area into coastal plains or mountains (coastal plains covariate; see Fig A3.1 in Appendix 3). When a model includes coastal plain interaction terms the main effect of the covariate is correctly interpreted as the influence of that covariate in the noncoastal mountain region (i.e., when the coastal plain covariate is equal to zero) and the influence of the covariate in the coast is correctly interpreted as the coefficients of the covariate and the interaction term summed.

Table 2.2 IK descriptions used to classify landscape characteristics present in final grizzly bear seasonal habitat models. The number of individuals that completed an interview for the given season is in (#), and the number of interviewees that described habitat that was translated into the landscape characteristic is identified for spring, summer and fall.

	# of Interviewees			
Landscape Characteristic	**Spring (16)**	**Summer (11)**	**Fall (14)**	**IK description**
Coastal plains	11	6	3	Spring: moving to or towards coast from mountains; Summer: move along coastal areas and tundra Fall: On coastal plain, moving into mountains
Distance to rivers	4	1	1	All seasons: areas near drainages/rivers/channels
Distance to wetlands	1	1	2	All seasons: Identified swamps from photos; distance-to metric higher AIC than use of PEM classes
Foothill shrub	6	3	2	Spring: subclass of TK Midslopes identified via photos, dig for carcasses there; Summer: Tundra identified, refined to this PEM group; Fall: good berry habitat
Major river valleys	2		1	Spring: use major river valleys (wider rivers) to travel; Fall: follow fish migration, upstream of major rivers
River beaches		1	4	Summer: photo of class selected; Fall: bears search for carcasses
Willow ecosystems		1	1	Both seasons: eat vegetation near creek beds/water
Heather nivation	5			TK Rocky Mountain Ridges identified via photos, specifically stated the area is generally used by bears (e.g., digging for roots and ground squirrels); heather nivation PEM class part of this group and most influential in univariate tests
Solar insolation	1			South facing/warmer areas
Post-calving caribou distribution		2		hunt caribou
Timber ecosystems	2	1		Both seasons: identified from photos representing IK timber class
Berry habitats			5	Bears seen eating berries or in habitats full of berries

We also found several instances of non-linear responses of bears to landscape characteristics. We fit quadratics or splines to capture changes in bear preference displayed at different values of the landscape characteristic (i.e., non-linear responses). For example, slope is paired with slope^2 in some models. This combination allows, for example, the identification of a preference for shallow and moderate slopes (e.g., selection for indicated by a positive coefficient) that is different from steep slopes (which are captured by the squared term; a negative coefficient for slope^2 would indicate avoidance of steeper slopes). Interestingly, we found multiple instances where the bears exhibited non-linear responses to ecosystem types (i.e., PEM classes) such that a lower density of the PEM class may be selected for while a higher density of this class is avoided; these non-linearities were captured either as quadratics or splines.

The standardized covariates allow for comparisons between covariate coefficients relative to other covariate coefficients in the model. We identify this relative influence through ranking the covariates from most influential (rank 1) to least influential (highest rank). Comparisons can only be made within a single model, and coefficient values cannot be compared across the different models (i.e., cannot compare between seasons or sexes) though the relative ranking of covariates can be compared across models.

Additionally, we highlight landscape characteristics identified through IK and further discuss the use of IK in the modeling effort in the Discussion (Chapter 4).

Female seasonal habitat models: Spring, summer, fall

The seasonal models for female grizzly bears are complex, with each seasonal model having 10-12 main covariates of which some of these covariates interacted significantly with the coastal plain covariate and others included multiple forms (quadratic, splines) to capture non-linear responses (Table 2.3).

The models across the three seasons show both similarities in habitat preferences as well as shifting preferences across the seasons that reflect changes in the ecology of the species (Table 2.6), with seven landscape characteristics shared across all three seasons including a preference for slopes, foothill shrub and areas close to rivers. In spring, female grizzly bears show a moderate preference for coastal plains and slopes, but during summer and fall switch to preferring mountain areas. Spring is also unique in that females display a preference for lower elevation areas, convex slopes (e.g., hill or ridgetops; positive TPI) and a slight avoidance of willow ecosystems while in summer and fall, we see a selection for flat or valley type topography and strong selection for willow ecosystems. In the fall, there is also a strong selection for south aspects and moderate selection for areas with high berry potential. Below we describe each model in more detail.

Table 2.3 The relative importance of the fixed model landscape characteristics (scaled) from the final female models. Interactions with coastal plain are identified by Characteristic:Coastal plain. Landscape characteristics identified during IK surveys have an asterisk (*) after their rank.

	Female Spring			Female Summer			Female Fall		
Landscape characteristics	Estimate	SE	Rank	Estimate	SE	Rank	Estimate	SE	Rank
Slope	0.88	0.03	1	0.6	0.02	2	0.73	0.02	1
Distance to rivers	-0.65	0.05	3*	-0.27	0.01	3*	-0.13	0.01	8*
TPI	0.39	0.02	6	-0.07	0.01	13	-0.11	0.03	11
Coastal plain	0.25	0.07	8*	-0.16	0.04	8	-0.23	0.04	5*
Foothill shrub[a]	0.13	0.04	12*	0.18	0.01	7*	0.24	0.01	4*
Major river valleys	0.08	0.02	13*	0.12	0.01	9	-0.09	0.01	12*
Willow ecosystems	-0.04	0.02	14	0.74	0.02	1*	0.43	0.03	2*
Foothill shrub[b]	-0.23	0.03	11*	0.06	0.02	14*	-0.06	0.02	17*
Heather nivation	0.23	0.05	10*	0.19	0.02	4			
Distance to wetlands				-0.1	0.01	10*	-0.22	0.02	6*
Slope^2				-0.1	0.01	11	-0.12	0.01	10
River beaches				0.06	0.01	15*	0.08	0.01	14*
Timber ecosystems				0.03	0.03	16*	0.03	0.01	19
Elevation	-0.72	0.04	2						
Aspect W:Coastal plain	-0.48	0.08	4						
Aspect W	0.42	0.07	5						
Dist. to rivers:Coastal plain	0.31	0.07	7*						
Heather nivation^2	-0.23	0.04	9*						
Willow:Coastal plain				-0.19	0.02	5*			
River beaches:Coastal plain				0.18	0.03	6*			
Rock Lichen[c]				-0.09	0.02	12			
Solar insolation				-0.03	0.01	17			
Rock lichen[d]				-0.02	0.02	18			
Timber ecosystems^2				0.01	0.01	19*			
TPI^2				-0.01	0.01	20			
Aspect S							0.26	0.03	3
High-quality berry habitat							0.18	0.01	7*
Rock lichen:Coastal plain							-0.13	0.05	9
Dist. to wetlnds:Coastal plain							0.08	0.02	13*
TPI:Coastal plain							-0.07	0.03	15
Rock lichen							0.06	0.05	16
Willow ecosystems^2							-0.05	0.01	18*
Intercept	-1.67	0.11		-1.55	0.10		-1.24	0.11	
Random effect: Individual	0.78	0.28		0.11	0.33		0.28	0.53	
Random effect: Year	<0.01	0.04		<0.01	0.03		<0.01	0.05	

[a] main effect in spring; first spline in summer and fall: <0.17 in summer, <0.18 in fall

[b] secondary effect: power of 2 in spring, second spline in summer and fall: >0.17 in summer, >0.18 in fall

[c] first spline in summer <0.12; [d] second spline in summer >0.12

Female spring model

The spring model contains 13 covariates including 2 covariate interactions with coastal plains (Table 2.3 and Figure 2.3). Females displayed a moderate preference for the coastal plain (rank 8) versus the mountains, and the significant interactions with the coastal plain covariate show that females respond to the different broad regions by shifting some preferences. Still, the two most influential covariates do not interact with the coastal plain covariate, indicating consistent patterns across the study area. These are elevation, for which the negative coefficient showed a strong selection for lower elevations (rank 2) and slope, for which the positive coefficient showed a preference for moderate and steep slopes (rank 1). Within the mountains, areas close to rivers (rank 3; negative coefficient indicates stronger selection at smaller distances) and west aspects (rank 5) were preferred. However, the strong interaction of these covariates with coastal plains (rank 4 and 7 for west aspect and distance to river interactions, respectively) indicate these preferences change when female bears are within the coastal plains region: west aspects are weakly avoided and areas close to rivers is only weakly selected. Female grizzly bears selected for positive TPI (rank 6) at the large neighborhood scale of 3km indicating a preference for convex landforms (e.g., ridges and/or midslopes).

Females also were associated with specific ecosystems types including lower density heather nivation (rank 10) and lower density foothill shrub (rank 12). High densities of these ecosystems were avoided (negative coefficient of the quadratic form, ranks 9 and 11, respectively). Additionally, willow dominated ecosystems were weakly avoided in the spring (rank 14). Females also showed a weak positive selection for major river valleys (rank 13).

While the model results indicate a slight preference for coastal plains in the spring, the preponderance of higher quality spring habitats are in the more mountainous portion of the study area (Figure 2.3). Still, moderate to high quality habitats are broadly distributed with higher density in the coastal plains region south and west of Herschel Island. The noticeable high quality habitat predicted in the McKenzie Delta wetlands in the northeast portion of the study area appears to be due to the strong selection for low elevation, as the specific ecosystems available there are not selected for; thus this may be an artifact and should be interpreted with caution.

<u>Spring model validation:</u> The LOO validation did not identify any issues with the data as the model had a Pareto shape (k) value within the acceptable range (<0.7), suggesting the it represents the data well. K-folds validation resulted in spearman correlation values (Rho-values: 0.98-1.00), which also suggests the model fits the data well.

Out-of-sample validation locations (*n*=1714, representing 8 bears) spearman correlation value shows good fit of the model (r=0.838). Examining these data further by looking at the distribution of animal locations show that female grizzly bears used lower class habitat covering approximately 80% of the landscape (i.e., Low, Low-Mod, Mod and Mod-High) less than or in proportion to expected based on the amount of habitat (Table 2.4). They used higher quality habitats significantly more than expected, with the High class being used approximately 3x more than expected. Bears spent over 60% of their time in the highest value habitat class covering approximately 20% of the landscape.

Table 2.4 Female spring model validation of points not used in the analysis (n=1714). See Chapter 1 Methods for definitions of calculations.

Habitat Class	Proportion Habitat Class		Relative Use	Interpretation of bear use relative to available
	Available	Used		
Low	0.112	0.012	0.110	Used much less than expected
Low-Mod	0.238	0.089	0.373	Used less than expected
Mod	0.239	0.108	0.453	Used less than expected
Mod-High	0.212	0.168	0.792	Used slightly less than expected
High	0.200	0.623	3.109	Used much more than expected

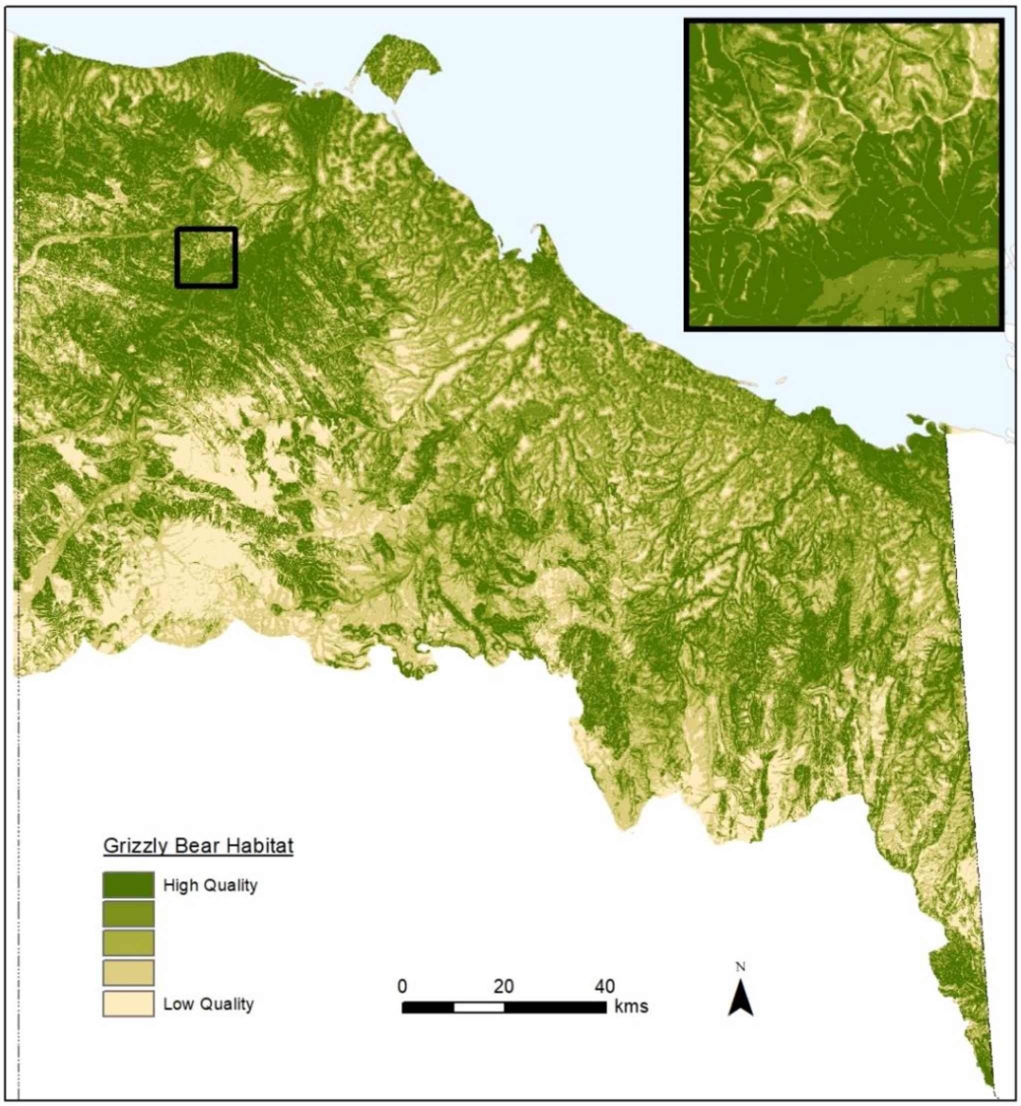

Figure 2.3 Predictive relative importance of habitat for female grizzly bears during the spring season in the Yukon North Slope, classified into five equal-area bins.

Female summer model

The summer habitat model is complex with 20 covariates including 13 main effects and additional interactions and non-linear forms of some covariates (Table 2.3 and Figure 2.4). Female grizzly bears weakly preferred mountains over the coastal plains (rank 8), and again, there were some interactions between covariates and the coastal plain covariate that indicated important changes in how females used certain landscape characteristic based on where they were. A strong preference (rank 1) for willow ecosystems was mediated in the coastal plains (interaction rank 5) but was still selected for. Females also actively selected for areas close to rivers (rank 3) and for gentle and moderate slopes (rank 2) while they avoided steep slopes (negative quadratic rank 11). In addition to willows, females were commonly associated with heather nivation (rank 4) and foothill shrub (rank 7, quadratic rank 14) ecosystems.

Less influential covariates (i.e., lower rank) indicated that females display a slight preference for low TPI (e.g., lower slopes) at the local scale (200m; rank 13, quadratic rank 20). Ecosystem types including major river valleys (rank 9), Timber ecosystems (rank 16, quadratic rank 19), river beaches (rank 15), and areas near wetlands (rank 10) were selected for. Female selection for river beaches increased in the coastal plain (interaction rank 6). Additionally, they selected for areas with low solar insolation (rank 17) and avoided the rock lichen ecosystem (ranks 12 and 18) at higher densities.

The mapped habitat model shows summer higher value habitats broadly distributed across the YNS, with the highest value habitats concentrated along lower slopes of river and drainage systems both within the mountains and in the coastal plains (Figure 2.4). This likely reflects the strong preference for willow habitats and areas close to rivers.

<u>Summer model validation:</u> The LOO validation did not identify any issues with the data as the model had a Pareto shape (k) value within the acceptable range (<0.7), suggesting the it represents the data well. K-folds validation resulted in spearman correlation values (Rho-values: 0.82-0.95), which also suggests the model fits the data well.

Out-of-sample validation locations (*n*=4283, representing 10 bears) spearman correlation value shows very good fit of the model (r=0.794). Examining these data further by looking at the distribution of animal locations displayed that female grizzly bears used lower class habitats covering approximately 80% of the landscape (i.e., Low, Low-Mod, Mod and Mod-High) less than or in proportion to expected based on the amount of habitat present (Table 2.5). They used higher value habitats notably more than expected with the highest value class being used 2.7x more than expected. Female bears spent >50% of their time in this highest value habitat covering approximately 20% of the landscape.

Table 2.5 Female summer model validation of points not used in the analysis (n=4283). See Chapter 1 Methods for definitions of calculations.

Habitat Class	Proportion Habitat Class		Relative Use	Interpretation of bear use relative to available
	Available	Used		
Low	0.112	0.011	0.100	Used much less than expected
Low-Mod	0.245	0.097	0.396	Used less than expected
Mod	0.232	0.149	0.640	Used less than expected
Mod-High	0.209	0.195	0.934	Used approximately as expected
High	0.202	0.548	2.715	Used much more than expected

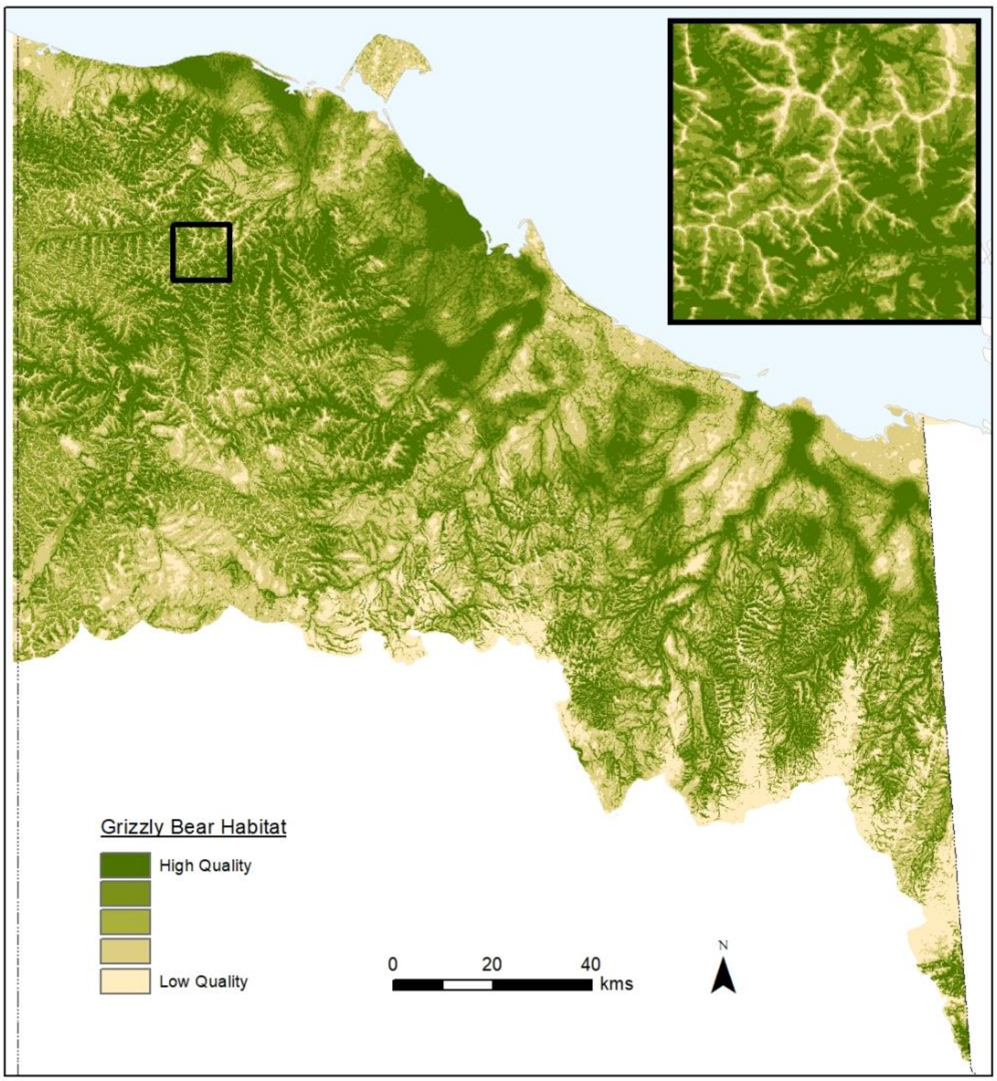

Figure 2.4 Predictive relative importance of habitat for female grizzly bears during the summer season in the Yukon North Slope, classified into five equal-area bins.

Female fall model

The fall habitat model is complex with 19 covariates including 13 main effects and additional interactions and non-linear forms of some covariates (Table 2.4 and Figure 2.5). As in the summer, females avoided the coastal region (rank 5) during the fall and were strongly influenced by slope (rank 1) with a preference for shallow and moderate slopes (positive coefficient for main effect, rank 1; negative coefficient for quadratic, rank 10) and south aspects (rank 3; Table 2.3 and Figure 2.5). Females strongly preferred willow ecosystems (rank 2) as well as lower density foothill shrub (rank 4) but showed weak avoidance of higher densities of both vegetation types (negative coefficients, rank 18 and 17, respectively). They preferred areas close to wetlands (rank 6) though this was weaker in the coastal plains (interaction rank 13). They also preferred areas close to rivers (rank 8) and ecosystem types that contained high-quality berry areas (i.e., dominated by berry producing species; rank 7).

Lower ranked habitat preferences included for areas with a low abundance of the rock lichen ecosystem type (rank 16, quadratic rank 9) in the mountains (avoided in the coastal plains, interaction rank 9), and low TPI values (e.g., lower slopes) particularly along the coastal plain (rank 11 and coastal plain interaction rank 15). They avoided major river valleys (rank 12) and preferred river beaches (rank 14) and timber ecosystems throughout the landscape (rank 19).

Unique covariates during the fall include selection for high-quality berry habitats, rock lichen habitats (in the mountains only), and a preference for south aspects (warmer and drier aspects; also predominately used for denning).

The mapped habitat model predictions show that moderate and high-quality habitat concentrated in the mountainous portions of the study area and particularly in Ivvavik National Park. Additional higher quality habitat follows major river drainages to the coast (Figure 2.5). Similar to females in the summer, this likely reflects the preference for willow habitats and areas close to rivers.

<u>Fall model validation:</u> LOO validation did not identify any issues with the data as the model had a Pareto shape (k) value within the acceptable range (<0.7), suggesting the it represents the data well. K-folds validation resulted in spearman correlation values (Rho-values: 0.97-1.00), which also suggests the model fits the data well.

Out-of-sample validation locations (*n*=4615, representing 5 bears) spearman correlation value shows a good fit of the model (r=0.927). Examining these data further by looking at the distribution of animal locations displayed that female grizzly bears used lower class habitat covering approximately 60% of the landscape (i.e., Low, Low-Mod and Mod) less than or in proportion to expected based on the amount of habitat (Table 2.6). They used moderate to higher value habitats significantly more than expected, with the Mod-High and High classes being used 1.1x and 2.6x more than expected, respectively. Bears spent >50% of their time in the highest value habitat covering approximately 20% of the landscape.

Table 2.6 Female fall model out-of-sample validation of points not used in the analysis (n=4615). See Chapter 1 Methods for definitions of calculations.

Habitat Class	Proportion Habitat Class		Relative Use	Interpretation of bear use relative to available
	Available	Used		
Low	0.106	0.012	0.115	Used much less than expected
Low-Mod	0.248	0.070	0.283	Used less than expected
Mod	0.234	0.157	0.669	Used less than expected
Mod-High	0.209	0.233	1.112	Used more than expected
High	0.203	0.528	2.603	Used much more than expected

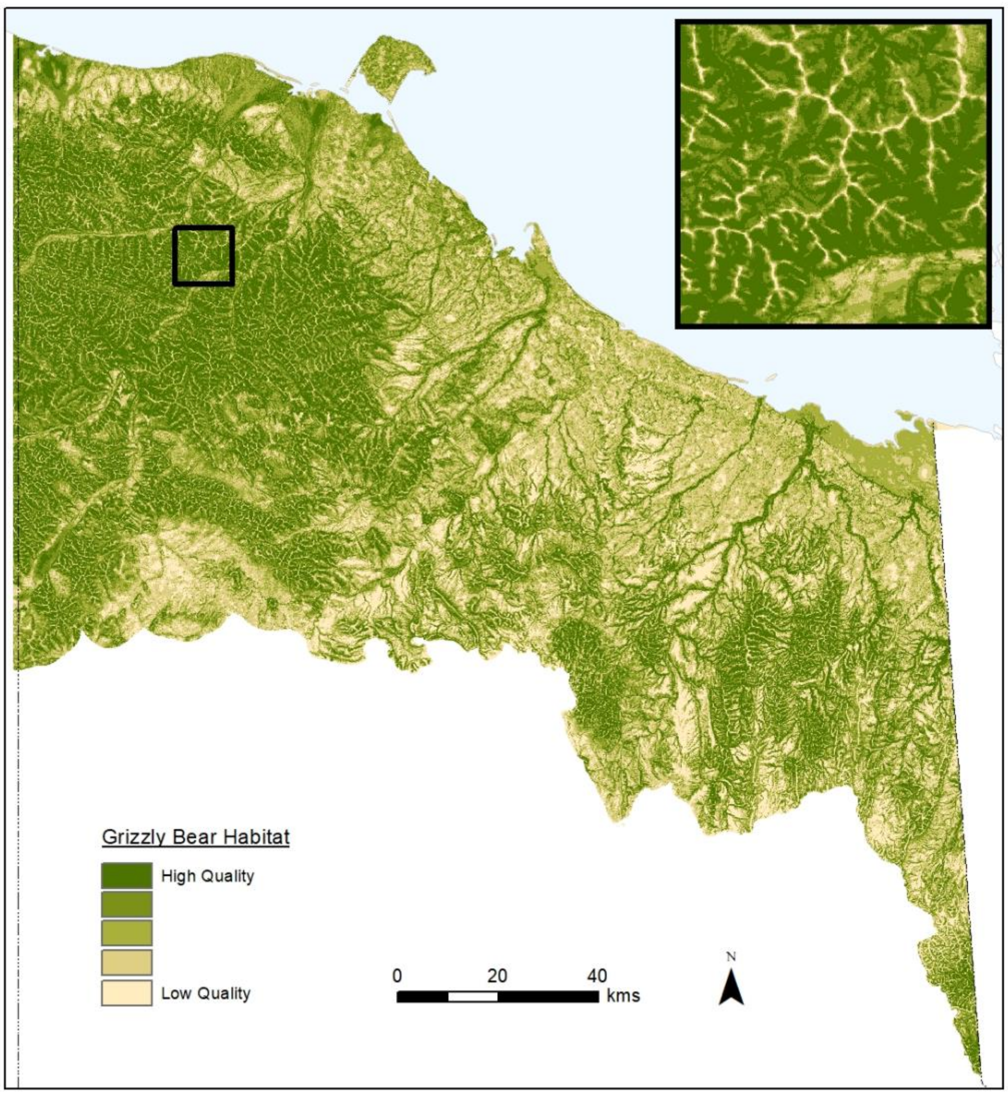

Figure 2.5 Predictive relative importance of habitat for female grizzly bears during the fall season in the Yukon North Slope, classified into five equal-area bins.

Male seasonal habitat models: Spring, summer, fall

The seasonal models for male grizzly bears are complex, similar to females with each seasonal model having 11 main covariates of which some of these covariates interacted significantly with the coastal plain covariate and others included multiple forms (quadratic, splines) of the covariate to capture non-linear responses (Table 2.7). The models across the three seasons show both similarities in habitat preferences as well as shifting preferences across the seasons that reflect changes in the ecology of the species (Table 2.7).

Like females (Table 2.3), males showed a slight preference for the coastal plains in the spring and flipped that preference to mountains in the summer. Whereas females continued the preference for mountains into the fall, males showed a weak preference for the coast in this season. Like female grizzly bears, males show a strong preference for willows in the summer and fall.

The most notable differences between seasonal patterns in the males is between spring season and the following summer and fall seasons. While overall, there are nine landscape characteristics shared in all three seasons, the preference switches on several (e.g., from selected for to avoided). For example, in the spring, male grizzly bears strongly preferred ridgetop habitats in the coastal plains (but not the mountains), and in the summer and fall, they preferred flat, valley, or drainage bottom type areas. In all seasons, they preferred areas close to rivers with steeper slopes. In spring and summer, the river preference dominated while in the fall, slope was the most influential landscape characteristic. Interestingly, post-caribou calving areas are moderately important during the summer, but caribou inputs were not significant other times of the year. In the fall, areas with high berry potential become significant, as they do with females.

Male spring model

Three of the coefficients in spring significantly interact with the coastal plain covariate, indicating that habitat preferences vary based upon the type of landscape the bear is in (Table 2.7 and Figure 2.6). The interaction between TPI and the coastal plain is the most influential covariate (rank 1) indicating a strong preference convex ridges or rounded slopes and ridgetops in the coastal plain, while in the mountains the selection was weak (rank 10). The model indicated that bears preferred steeper slopes (rank 2), warmer areas (positive solar insolation, rank 4) and lower elevations (rank 5). This suggests that male grizzly bears are selecting for lower elevation warm, steep slopes. Additionally, there was a strong selection for areas with low densities of foothill shrub (positive main rank 3, and negative quadratic rank 11). Areas close to rivers were selected for in the mountains but not the coastal plains (negative main rank 13, and positive interaction rank 6) but more broadly, major river valleys were selected for in coastal areas (interaction rank 8) but not in the mountains (lowest rank, 16).

The positive coefficient for the coastal plain covariate indicated a weak preference for the coastal plain (ranked 7 out of 16 in influence in the model). Male grizzly bears also weakly selected for decreased distance to wetlands throughout the landscape (negative main rank 9, and negative quadratic rank 15). Landscape characteristics that are ranked lower but still significant influencers of male grizzly bear habitat use are selection for timber (rank 12) and a weak avoidance of willow ecosystem types (rank 14).

The mapped results display that higher quality habitats are broadly distributed across the YNS, including the coastal plains tundra habitats and Herschel Island. Within the mountains, the larger river valleys and drainages support high value habitats (Figure 2.6).

Table 2.7 The relative importance of the fixed model landscape characteristics (scaled) from the top male models. Interactions with coastal plain are identified by Characteristic:Coastal plain. Landscape characteristics identified during IK surveys have an asterisk (*) after their rank.

	Male Spring			Male Summer			Male Fall		
Landscape characteristics	Estimate	SE	Rank	Estimate	SE	Rank	Estimate	SE	Rank
Slope	0.48	0.04	2	0.66	0.05	4	1.26	0.38	1
Foothill shrub[a]	0.38	0.04	3*	1.28	0.11	1*	0.34	0.02	6*
Coastal plain	0.25	0.08	7*	-0.29	0.06	7*	0.19	0.05	12*
Distance to wetlands	-0.20	0.04	9*	0.06	0.02	15*	0.32	0.03	7*
TPI	0.20	0.02	10	-0.23	0.06	9	-0.3	0.02	9
Foothill shrub[b]	-0.20	0.04	11*	-0.07	0.07	13*	0.1	0.03	15*
Timber ecosystems	0.16	0.02	12*	0.3	0.02	6*	0.17	0.02	14
Distance to rivers	-0.14	0.05	13*	-0.43	0.03	5*	-0.17	0.02	13*
Willow ecosystems	-0.08	0.03	14	0.78	0.02	2*	0.59	0.02	4*
TPI:Coastal plain	1.39	0.10	1	0.18	0.07	10			
Solar insolation	0.37	0.03	4*	-0.16	0.02	11			
Elevation	-0.32	0.06	5						
Dist. to rivers:Coastal plain	0.30	0.06	6*						
M. riv. valleys:Coastal plain	0.21	0.05	8*						
Distance to wetlands[c]	-0.05	0.03	15*						
Major river valleys	0.01	0.03	16*						
Slope:Coastal plain				-0.67	0.06	3			
Post Calving 95%				0.26	0.06	8*			
Heather nivation				0.07	0.02	12			
River Beaches				0.07	0.02	14*	0.2	0.02	11*
Aspect W:Coastal plain							0.66	0.09	2
Rock lichen:Coastal plain							0.62	0.07	3
Dist. wetlands:Coastal plain							-0.57	0.04	5
High-quality berry habitat							0.31	0.04	8*
Aspect W							-0.21	0.07	10
Rock lichen							-0.01	0.03	16
Intercept	-1.21	0.06		-1.81	0.16		-1.96	0.13	
Random effect: Individual	<0.01	0.10		0.10	0.32		<0.01	0.02	
Random effect: Year	<0.01	<0.01		<0.01	0.06		<0.01	<0.01	

[a] main effect in spring; first spline in summer and fall: <0.17 in summer, <0.18 in fall

[b] secondary effect: power of 2 in spring, second spline in summer and fall: >0.17 in summer, >0.18 in fall

[c] power of 2 in spring

Spring model validation: The LOO validation did not identify any issues with the data as the model had a Pareto shape (k) value within the acceptable range (<0.7), suggesting the it represents the data well. K-folds validation resulted in spearman correlation values (Rho-values: 0.95-0.98), which also suggests the model fits the data well.

We were unable to complete out-of-sample validation for the spring male grizzly bear model due to an inadequate number of validation points (<200 points).

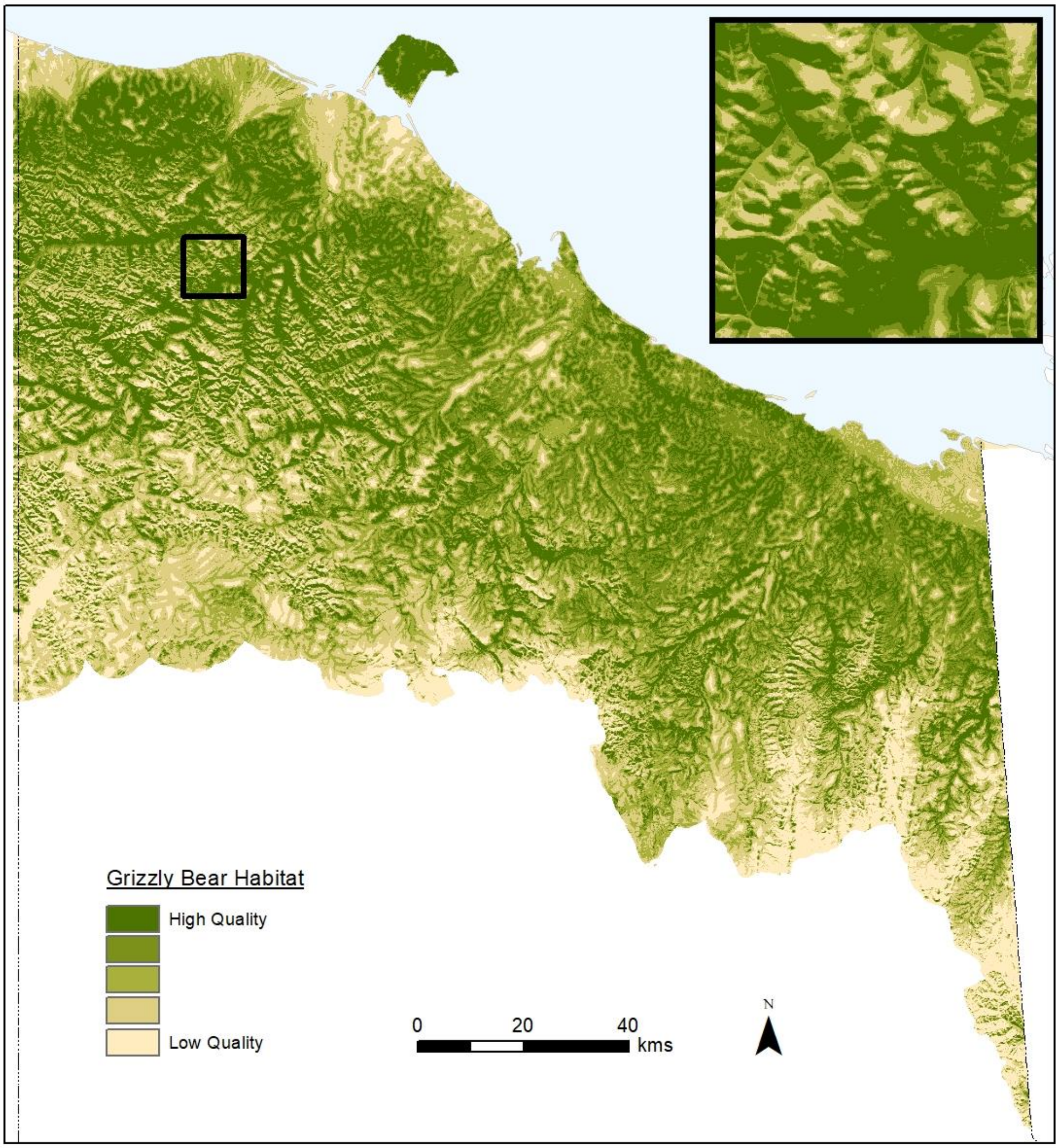

Figure 2.6 Predictive relative importance of habitat for male grizzly bears during the spring season in the Yukon North Slope, classified into five equal-area bins.

Male summer model

The summer model includes 14 significant covariates and modifiers. Although it shares 11 of these with the spring model, landscape characteristic importance and direction for several landscape characteristics changed in the summer season (Table 2.7 and Figure 2.7). Ecosystem classes had the greatest influence on habitat selection in the summer, with selection for areas with low to moderate amounts of foothill shrub and for areas with willow having the highest influence in the model (rank 1 and 2, respectively). Areas with steep slopes (rank 4) are selected for in the mountains (negative interaction with coastal plain; rank 3). In the spring, areas close to rivers are also selected for (rank 5); however, during the summer this selection occurred across the landscape and not just on the coastal plain.

Regionally, the negative coefficient (rank 7) for coastal plain suggests that male grizzly bears display a preference for mountainous areas. They also display selection for areas linked to caribou presence, as indicated by a positive coefficient (rank 8) for caribou post-calving 95% distribution isopleths. There is also a positive selection for areas that are 'concave', such as lower slopes, as indicated by a negative TPI (rank 9). This preference is weaker in the coastal plain (positive coefficient for the TPI:Coastal plain interaction; rank 10). Other landscape characteristics that have a lower but still significant influence on male grizzly bear habitat selection in summer include avoidance of warmer areas (negative coefficient for solar insolation; rank 11), selection for heather nivation ecosystems (rank 12) and river beaches (rank 14) and a slight but significant avoidance of areas near wetlands (rank 15).

The mapped habitat model shows summer higher value habitats broadly distributed across the YNS, with the highest value habitats concentrated along river and drainage systems (Figure 2.7). In the mountains, major river valleys support concentrated high value habitats, and smaller tributaries provide moderate valued habitats. In the coastal plains, the western portion of the study area generally supports higher quality habitats though high-quality habitats are found across the coastal plains along the river systems.

<u>Summer model validation:</u> The LOO validation did not identify any issues with the data as the model had a Pareto shape (k) value within the acceptable range (<0.7), suggesting the it represents the data well. K-folds validation resulted in spearman correlation values (Rho-values: 0.98-1.00), which also suggests the model fits the data well.

Out-of-sample validation locations (*n*=1538, representing 5 bears) spearman correlation value shows a good fit of the model (r=0.793). Examining these data further by looking at the distribution of animal locations shows that male grizzly bears used lower class habitat covering approximately 60% of the landscape (i.e., Low, Low-Mod, Mod, Mod-High) less than or in proportion to expected based on the amount of habitat (Table 2.). They used high value habitats more than expected, with strong selection for the High, class which was used 3.5x more than expected. Bears spent over 60% of their time in this highest value habitat covering approximately 19% of the landscape.

Table 2.8 Male summer model validation of points (i.e., points not used in the BRSF analysis; n=1538). See Chapter 1 Methods for definitions of calculations.

Habitat Class	Proportion Habitat Class		Relative Use	Interpretation of bear use relative to available
	Available	Used		
Low	0.113	0.008	0.075	Used much less than expected
Low-Mod	0.232	0.109	0.467	Used less than expected
Mod	0.246	0.102	0.415	Used less than expected
Mod-High	0.223	0.137	0.613	Used less than expected
High	0.186	0.644	3.462	Used much more than expected

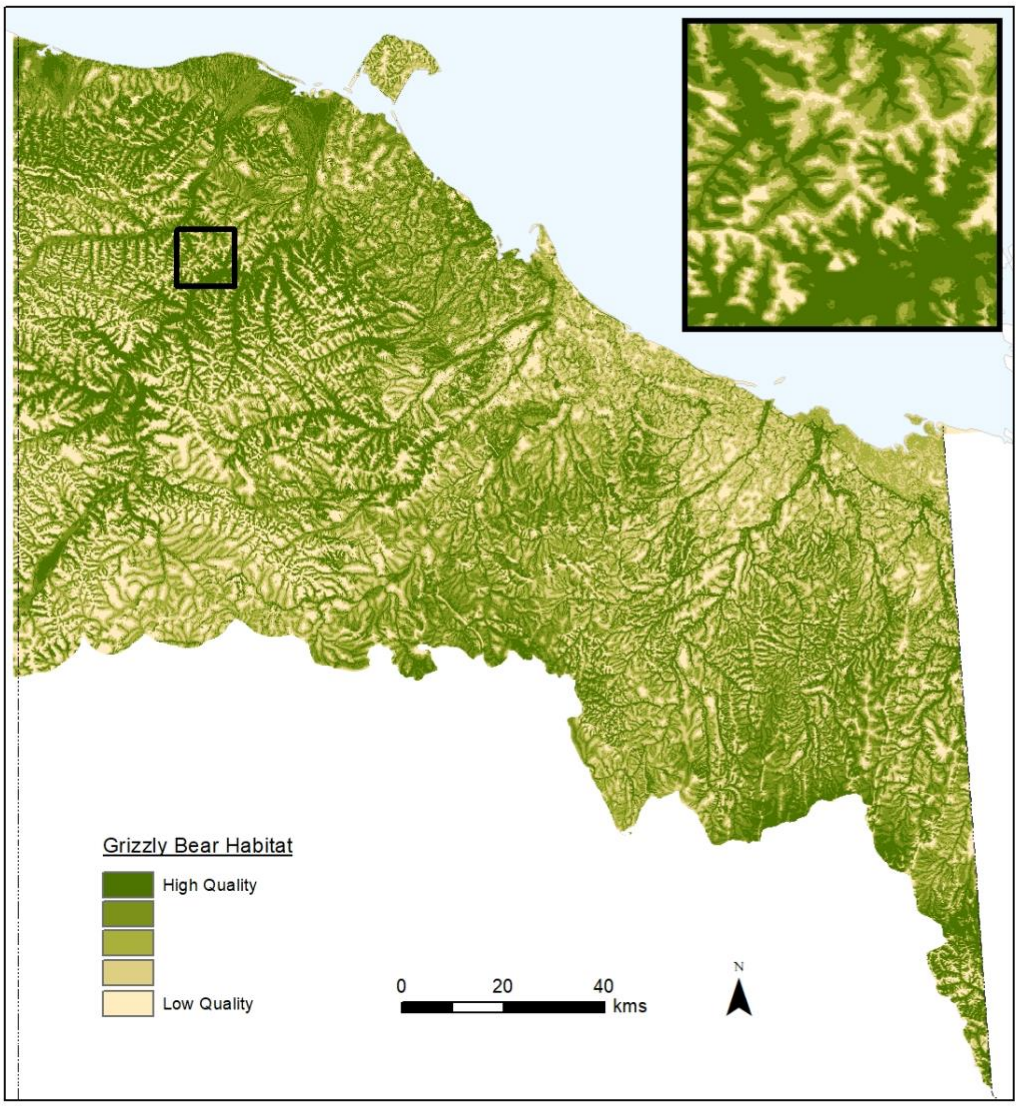

Figure 2.7 Predictive relative importance of habitat for male grizzly bears during the summer season in the Yukon North Slope, classified into five equal-area bins.

Male fall model

The fall habitat model includes 16 covariates, which includes 11 main landscape characteristics and several interactions with the coastal plain (Table 2.7 and Figure 2.8). There are 6 covariates (main or interactions) unique to the Fall model, indicating shifting habitat selection in this season relative to the other seasons. The most important landscape characteristics predicting male grizzly bear use include a selection for slopes (rank 1). There is a slight selection for coastal plain (rank 12 of 15); however, a complex suite of interactions involving coastal plain exist. For example, interactions with coastal plain include selection for west-facing aspects (rank 2) and the rock lichen ecosystem (rank 3) while these are avoided in the mountains. Landscapes with ecosystems containing increased amounts of willow (rank 4), foothill shrub (low values; rank 6 and high values; rank 15), high-quality berry habitat (rank 8), river beaches (rank 11) and timber ecosystems (rank 14) are all preferred. Additionally, a preference for areas close to wetlands on the coastal plain (interaction rank 5) is present, but these areas are avoided in the mountains (rank 7). Areas close to rivers (rank 13) and with concave topography (e.g., lower slopes; low TPI; rank 9) are selected.

The mapped habitat model predictions show the highest value habitats are strongly concentrated in the mountains of Ivvavik National Park, with other concentrations in the southern mountainous regions of the eastern YNS (Figure 2.8). There are also high value habitats along the river systems through the coastal plains, but other coastal plains areas have lower amounts of higher quality habitat. The lowest value habitats are in the southeastern portion of the study area.

<u>Fall model validation:</u> LOO validation did not identify any issues with the data as the model had a Pareto shape (k) value within the acceptable range (<0.7), suggesting the it represent the data well. K-folds validation resulted in spearman correlation values (Rho-values: 0.98-1.00), which also suggests the model fit the data well.

Out-of-sample validation locations (*n*=447, representing 4 bears) spearman correlation value shows a good fit of the model (r=0.829). Additionally, male grizzly bears used lower class habitat covering approximately 20% of the landscape (i.e., Low) very rarely (no locations fell within this habitat class; Table 2.9). They used two other classifications (Low-Mod, Mod-High) more than expected and the moderate habitat class slightly less than expected. The High habitat class was used 1.75x more than expected, and bears >50% of their time in the Moderate-High and High habitat classes covering approximately 38% of the landscape.

Table 2.9 Male fall model validation of points (i.e., points not used in the BRSF analysis; n=447). See Chapter 1 Methods for definitions of calculations.

Habitat Class	Proportion Habitat Class		Relative Use	Interpretation of bear use relative to available
	Available	Used		
Low	0.138	0.000	0.000	Used much less than expected
Low-Mod	0.250	0.295	1.180	Used more than expected
Mod	0.228	0.168	0.735	Used less than expected
Mod-high	0.202	0.213	1.051	Used more than expected
High	0.185	0.324	1.750	Used more than expected

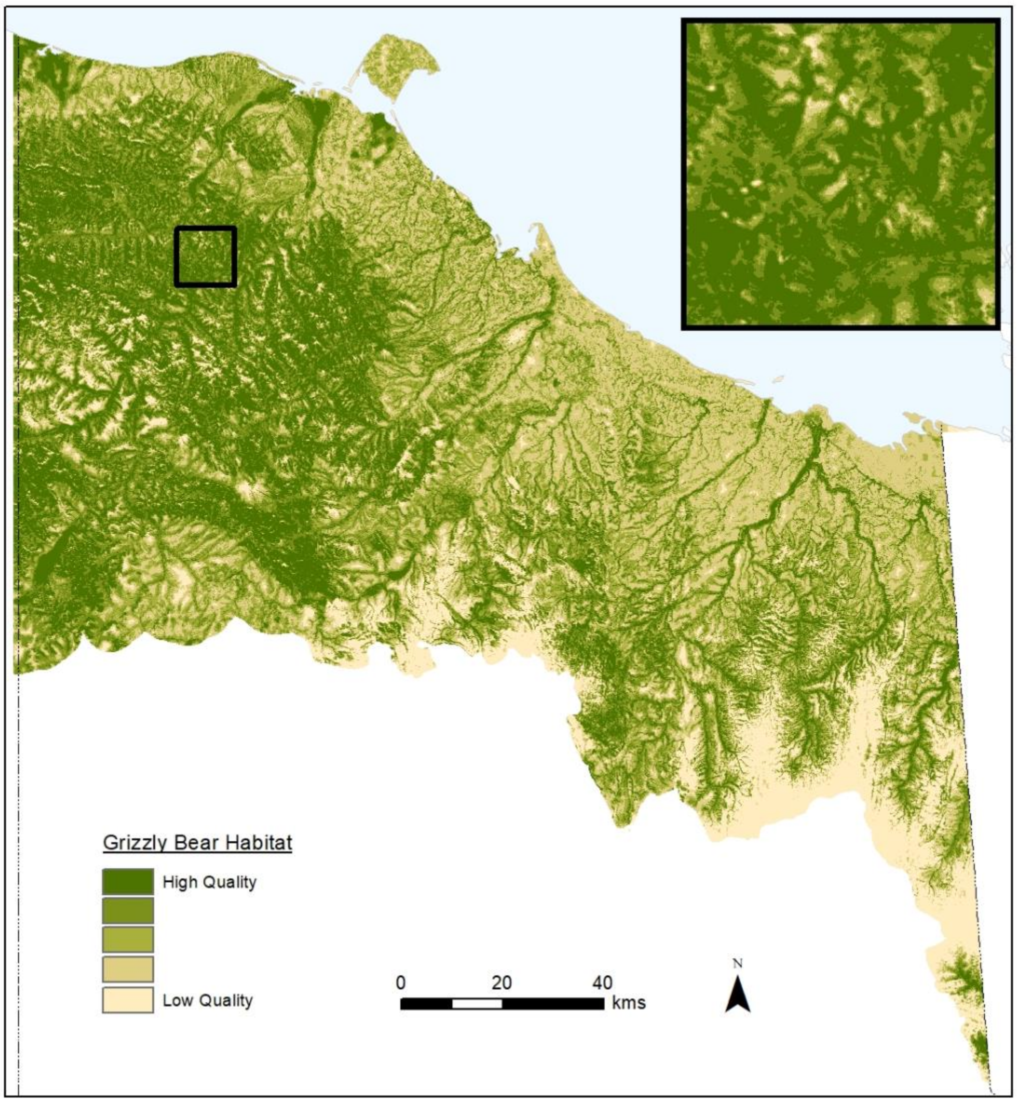

Figure 2.8 Predictive relative importance of habitat for male grizzly bears during the fall season in the Yukon North Slope, classified into five equal-area bins.

Chapter 3: Denning season habitat model

In Chapter 3, we describe the development and results of a grizzly bear denning habitat model for the Yukon North Slope. This model uses IK and WS to inform the identification of potentially essential landscape characteristics to predict denning habitat. It uses a compilation of denning locations recorded during the 2004-2008 GPS collar study as well as denning locations documented over 20 years, identified during research or surveys being conducted for other purposes. The compilation of multiple den locations provided sufficient data to undertake the analyses; any single source of data was insufficient to develop a quantitative model. Given the different types of data available for denning, we approached the denning habitat model differently than the previously described seasonal models. Specifically, available habitat was defined using buffers around dens, as we did not have known home ranges for many of the den sites. Using this modified approach, we completed a Bayesian RSF incorporating IK in both the identification of landscape characteristics and the informed priors of the BRSF.

Data and methods

The data and methods used for all seasons are described in Chapter 1; including the source of IK information, the identification and development of potential landscape characteristics to predict grizzly bear habitat use, a description of the Bayesian RSF approach, and mapping the resulting model relative probability of use predictions. In this chapter, we supplement the information provided in Chapter 1 with the unique aspects of the data and methods used explicitly used in developing the denning habitat model.

Den site data

The 83 den sites used for habitat model development spanned much of the YNS (Figure 3.1), but there are notable gaps, particularly in the southeastern portion of the study area and to a lesser extent in the northwestern portion of the study area.

Available habitat and modeling framework

Den location data from aerial surveys had limited information about the bears using the dens. We did not have information such as sex, age, status or home range estimates. Thus, we pooled all den sites to develop a single den habitat model. In the absence of home range information, we used a buffer around each den site to define available habitat (Elfström, Swenson, and Ball 2008). We selected 25km radius buffers to approximate a grizzly bear home range. The gender of bears was unknown; therefore, we selected a distance that generated a buffer that was greater than the size of the average estimated fall home range for females and less than the estimated fall home range for males in the YNS (Appendix 7). Available habitat was estimated from points obtained by overlaying a 250-x 250-m grid across the study area and extracting the pixel centroids within den site buffers. For each den, the suite of available points falling within its buffer was attributed with potential landscape characteristics (see Chapter 1, Appendix 1 and 2) for den site modeling.

The available locations were compared with the single use site (the known den) through Bayesian RSF modelling (Ciarniello et al. 2005) using IK to inform priors, similar to other seasonal habitat models. The BRSF approach is described in more detail in Chapter 1.

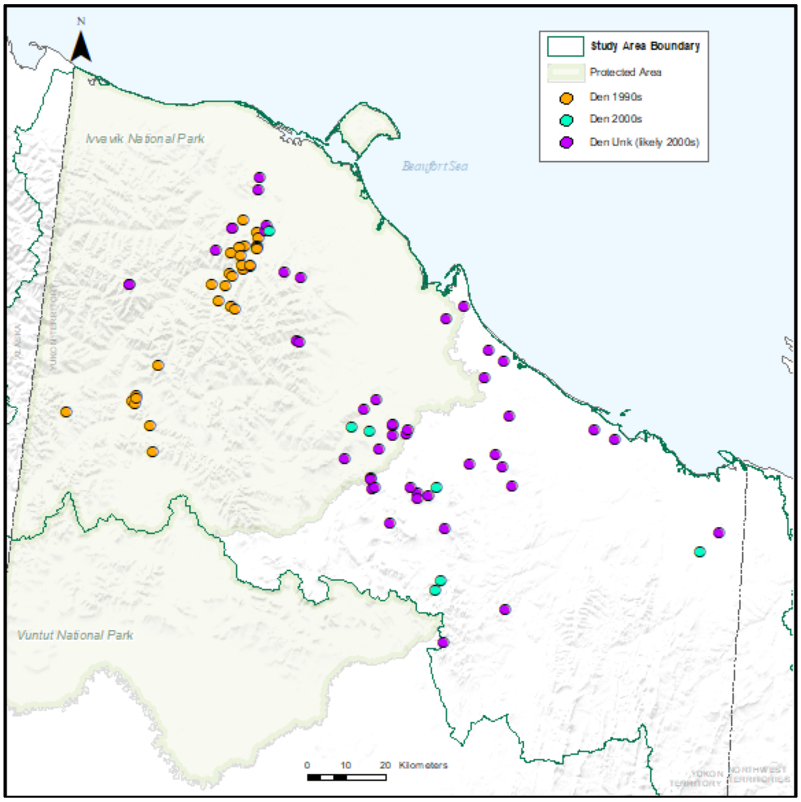

Figure 3.1 Grizzly bear den locations (thinned) observed in the Yukon North Slope during the 1990's (orange), the 2000s (cyan) and during an unknown time period (likely the 2000s; purple).

Results

IK landscape characteristics

Landscape characteristics associated with den sites were identified through IK interview descriptions when possible. These landscape characteristics were translated into GIS layers (described in Appendices 1 and 2) for inclusion in the BRSF analyses, and the IK identified landscape characteristics included in the final denning model are listed in Table 3.1.

Fourteen Inuvialuit experts provided IK on den site habitats during the interviews (WMAC(NS) and AHTC 2018). Inuvialuit experts provided detailed descriptions of den sites that they observed and identified 20 different dens across the YNS with multiple interviewees identifying some of the dens. Twelve of the interviewees described dens as located in the mountains on hillsides. Eight also described these as close to a water source. Seven interviewees described dens as being on south-facing slopes and nine of the 20 dens identified by interviewees were indeed on south-facing slopes. However, this was not universal, and interviewees described 3 dens found on west and one on a northwest aspect, describing these as avoiding the cold south wind that prevails in the region during the winter. Knowledge-holders also said that grizzly bears will occasionally den in lower and flatter areas, and that this has been observed more frequently in recent times by some.

We developed eight potential covariates to capture the landscape characteristics described by Inuvialuit experts (Appendix 1). Of these, four IK-based covariates are in the final denning habitat model. The IK about selection for these characteristics by bears was incorporated into BRSF models through priors. Priors were set to reflect expected selection (either positive or negative) for the IK identified landscape characteristics. All identified IK landscape characteristics, except for distance covariates, had positive priors as interviewees described habitats where they observed bears or den sites. The 'distance to rivers' landscape characteristic had a negative prior to reflect a preference for areas close to rivers (i.e., selection stronger as distances shorter thus inverse relationship).

Table 3.1 IK descriptions used to classify landscape characteristics present in final grizzly bear seasonal habitat models. The number of individuals out of 14 who were interviewed that identified each landscape characteristic in their grizzly bear habitat use descriptions for den site locations.

Landscape Characteristic	# Interviewees	IK description
Hillsides	10	Any hillside steep enough to dig into; small hillsides; hillsides generally
Aspect South	7	Top of hill facing south with good dirt (no permafrost), south facing hillsides
Slope	4	Not necessarily high elevation, but steep bank; steep hillsides
Distance to rivers	4	Above drainage/river; steep riverbanks; hillsides like riverbanks

Bayesian RSF approach

We developed a BRSF model to predict the relative probability of habitat use during the denning season for male and female grizzly bears (combined in one model). Covariates that were significant in the selected model are referred to as main landscape characteristics. In addition to the main landscape characteristics, a nonlinear relationship (spline) was required for one covariate. We standardized the landscape characteristic values before modeling (mean = 0, standard deviation = 1) so that the relative influence of each covariate within a model could be assessed based on the absolute value of the landscape characteristic coefficient relative to other landscape characteristic coefficients in the model. We identify the relative influence of landscape coefficients through ranking them from most influential (rank 1) to least influential (highest rank). Den site ID was included as a random effect in the modeling, associating the individual use site with the available locations within the 25km buffer around each individual den.

Den habitat model

Five main landscape characteristics were retained in the top denning model (Table 3.2, Figure 3.2). Grizzly bears selected for areas with steep slopes (rank 3) and strongly avoided the TK-based ecosystem class called tundra low flatlands (rank 1; they selected for areas with no or low (<15%) densities of the ecosystem, rank 2); this dominant habitat class covers 32.8% of the YNS. Grizzly bears selected south aspects (rank 4), and to a lesser degree they selected the TK-based ecosystem class of hillsides (rank 6), areas close to rivers (rank 7) and flat or concave topography (e.g., lower slopes; negative TPI rank 5); however these two landscape characteristics (distance to rivers and TPI) were not significant.

Overall, this model predicts a narrow suite of habitats that have a relatively high probability of being used for denning by grizzly bears, with the moderate and high-quality classes covering only 13% and 14% of the landscape, respectively even when attempting to classify the model into equal area classes. This indicates that habitats suitable for denning are relatively rare in the study area. These habitats are primarily found in the mountainous regions of the YNS, with the highest density of these potential denning habitats occurring in Ivvavik National Park (Figure 3.2), with some higher quality habitats also predicted on Herschel Island. Potential denning habitats in the eastern YNS are in the southern mountains. These habitats are likely to be of high importance to bears occupying the eastern YNS given their general lower availability in the region. There is a high density of potential denning habitats in the most southeastern portion of the YNS; this area did not have any den sites identified, and therefore it may be worth further research to better understand better the importance of this area for grizzly bear denning.

Table 3.2 The relative importance of the fixed model landscape characteristics (scaled) from the top model. The model contained random effect of Den ID. Additionally, landscape characteristics identified during IK surveys have an asterisk (*) after their rank.

Landscape characteristics	Estimate	SE	Rank
Higher density tundra low flatlands[b]	-2.18	0.92	1
Lower density tundra low flatlands[a]	1.07	0.70	2
Slope	0.72	0.13	3*
Aspect South	0.67	0.24	4*
TPI	-0.23	0.09	5
Hillsides	0.14	0.11	6*
Distance to rivers	-0.07	0.13	7*
Intercept	-11.03	0.23	
Den random effect	402.4	20.06	

[a] Represents lower density of ecosystem, 1st spine <.15
[b] Represents higher density of ecosystem, 2nd spline >15

Model validation

The LOO validation did not identify any issues with the data as the model had Pareto shape (k) values within the acceptable range (<0.7) suggesting the model represents the data well. K-folds validation resulted in spearman correlation values (Rho-values) that also suggest the model fits the data well (0.71-0.97). The denning model had 14 points that were removed; however, their reason for removal (low confidence in location or proximity to other den with potential influences of pseudoreplication) inhibited their use as validation points (as was completed for spring, summer and fall models).

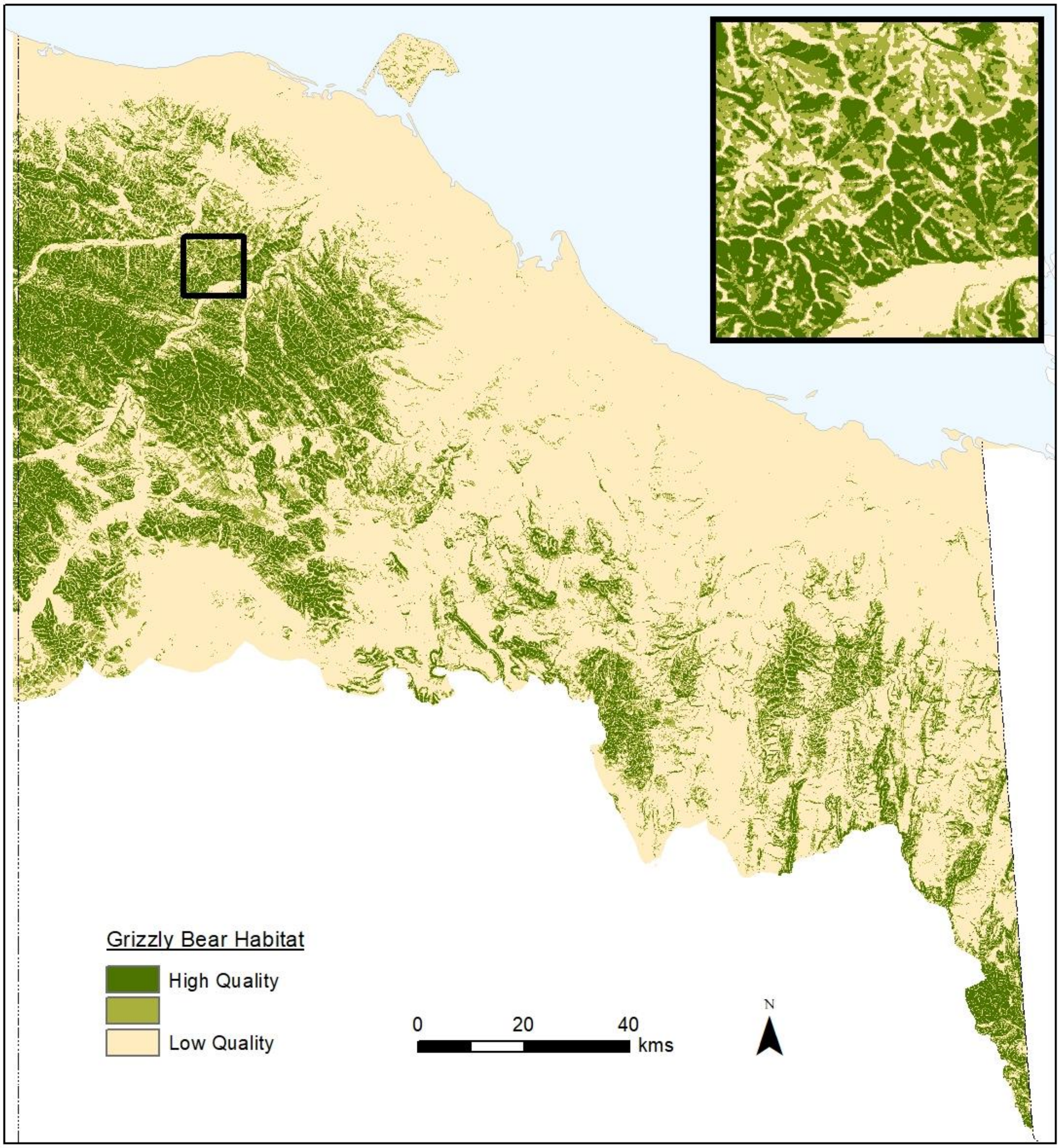

Figure 3.2 Predictive relative importance of habitat for grizzly bear den sites in the Yukon North Slope. The output is grouped into 5 equal-area classes and the green outline indicates the study area boundary.

Chapter 4: Discussion and conclusions

The final models for all seasons (spring, summer, fall, and denning) incorporated IK and WS into one model framework. The BRSF framework provided a way for IK and WS data to complement each other and substantively value and integrate each data source. However, there is still value in comparing the data types as IK can offer additional details and ensure that critical landscape characteristics or other covariates that cannot be represented spatially are not overlooked. Additonally, within seasonal models not all landscape characteristics were mentioned during IK interviews. These landscape characteristics may capture areas or times outside of when harvest typically occurs (i.e., the peak of expert visitation to the region), thus identifying additional important landscape characteristics using a diveristy of valid information sources (e.g., other research or experts) is warranted. This does not suggest these characteristics were not known to Inuvialuit experts, just that they were not mentioned in the open ended format of the interviews. Asking Inuvialuit experts about all potential landscape characterisitics identified from other studies may reduce this discrepancy in future IK studies, but must be done in a fashion that minimizes introduction of restrictive/leading questions or interview designs.

Grizzly bear IK interviews did not ask interviewees to describe potential differences in habitat use between males and females. Therefore, below we discuss what was observed in the region by other researchers (mainly: MacHutchon 1996; Nagy et al. 1983; Nagy 1990; MacHutchon 2001) and knowledge-holders and how this relates to what was predicted in the BRSF male and female models.

Spring

Upon emergence, IK experts described grizzly bears feeding on roots of Alpine hedysarum (*Hedysarum alpinum*) and overwinter berries (e.g., crowberry and bearberries (Arctostaphylos spp.); WMAC(NS) and AHTC 2018), which was similarly described in the YNS (MacHutchon 1996) and neighboring areas in Alaska and the central Arctic (Phillips 1987; McLoughlin et al. 2002). The models developed for male and female reflect what experts describe for bears during this time - use of the coast and foothills (i.e., coastal plain) as well as mountain areas near rivers. Grizzly bear habitat associations are generally believed to be driven by food sources and during the spring these food sources include plants, roots, carcasses and potentially caribou (Phillips 1987). Plants and roots, such as hedysarum, are linked to ecosystem types such as are found in foothill shrub and both sexes selected for this ecosystem type. Both sexes avoided willow ecosystems in the spring, but these habitats represent a food source later in the year.

We note that some food sources are likely challenging to capture via landscape characteristics. For example, IK interviews describe bears using the coast, mainly when there is a whale or seal carcass present. Both male and female models suggest increased use of the coastal plain over mountain habitats, which may encompass this food source indirectly. However, we were unable to capture the direct use of such food sources. Additionally, grizzly bears were reported by experts to be associated with caribou in the spring, but the caribou pre-calving and calving grounds were not significant for either males or female bears during this season. This lack of significance could be a product of the limited number of bears that were collared, or it could be related to the coarse resolution of our caribou layer and its inability to capture the local availability of this food resource to individual bears during this season. There were no collared bears present on Herschel Island, which was mentioned as being used by bears in IK interviews. However, even with a lack of data on Herschel Island, areas of the island were identified as preferred habitat in both male and female spring models.

Summer

Grizzly bear movements are wide-ranging during the summer compared to other seasons (MacHutchon 2001; WMAC(NS) and AHTC 2018) and is reflected in the average home range size which is largest in summer compared to spring or fall for both males and females. This is partially due to bears shifting their diet to a wide diversity of food items (WMAC(NS) and AHTC 2018) including emerging green vegetation (e.g., common horsetail (*Equisetum arvense*) and bearflower (*Boykinia richardsonii*)) which is dispersed throughout the landscape (MacHutchon 1996, 2001). Additionally, interviewees stated that 'grizzly bears are often observed in creek beds eating vegetation/roots in the summer'; this area is likely best captured by willow ecosystems landscape characteristic and both male and females selected for willow ecosystems in the summer, which was represented well in the potential habitat models.

The summer models display that high-quality habitats are distributed across the YNS, with high concentrations along river drainages in the mountains and coastal plains. Both sexes were associated with the presence of willow (as mentioned above) and areas close to rivers. Previous research suggests the increased overlap between male and female locations occurs during the summer season (bears increase activity in general), and in response, females display shifts in habitat use within the landscapes to avoid males (Wielgus and Bunnell 1994). This division may be partially represented by female selection for gentle to moderate slopes and avoidance of steep slopes (males selected for steep slopes).

As in the spring, caribou presence was identified by IK interviewees (WMAC(NS) and AHTC 2018) and previous research in the area (MacHutchon 2001; Reynolds III and Garner 1987) as important to grizzly bears during the summer season. Females did not show a selection for caribou during this time, but males displayed selection for the caribou post-calving distribution. This selection supports that caribou are an important food source for male grizzly bears in the YNS. In neighboring Alaska, grizzly bears have been observed travelling great distances to follow caribou migration routes and access calving/post-calving grounds during early summer (Reynolds III and Garner 1987); therefore, its not surprising grizzly bears in the bordering YNS would utilize habitats associated with this food source.

Again, Herschel Island was indicated as being important to grizzly bears in IK interviews. In both male and female models, areas of Herschel Island contain mainly low-quality grizzly bear habitat; however once again no collared bears traveled there indicating a data limitation in habitat predictions on Herschel Island.

Fall

In the fall, hyperphagia is important for preparation for denning. IK describes bears being focused on feeding, using a diversity of food sources and having a reliance on berry patches (WMAC(NS) and AHTC 2018), and MacHutchon (2001). Areas predicted to be high quality berry habitats was significant in the fall habitat model, including both the covariate 'high quality berry habitat' and the covariate 'distance to wetlands'. During fall, grizzly bear diet likely includes bog blueberries (*Vacinium uliginosum*), crowberries, horsetail, bearflower, alpine hedysarum roots and rodents (MacHutchon 1996, 2001; Phillips 1987). IK interviews also mentioned bears digging roots near water and on the coastal plain and the other landscape characteristics defined in the IK interviews as willow ecosystems, close to rivers and wetlands, foothill sparse shrub tundra, drainages (low TPI) all likely contain increased forage and prey (roots, berries or rodents).

Males displayed a weak selection for the coastal plain, which suggests males may move to the mountains later than females for denning; sex differences in denning time generally show that male grizzly bears den later and emerge earlier than females (Reynolds III 1976; McLoughlin, Cluff, and Messier 2002). Again, females preferred shallow to moderate slopes, whereas, males preferred steeper slopes, possibly due partially to spatial segregation. Females selected for southern aspects which may also be related to den site selection, as den sites predominatly occur on south facing slopes as documented by IK (see Chapter 3) and past research (Nagy et al. 1983; McLoughlin, Cluff, and Messier 2002).

Additionally, IK interviews identified fish holes (i.e., deep pools that don't freeze overwinter and contain Dolly Varden trout, *Salvelinus malma*, in the YNS) as important for grizzly bears in the fall. However, this attribute did not come up as significant for males or females potentially due to limited documentation of fish hole locations, and therefore their limited spatial representation in the models.

Denning

The denning model suggests that bears in the study area avoid tundra (TK class tundra/low flatlands), avoid locally flat areas and prefer to den in areas with high slopes and southern aspects, which is consistent with IK interviews and prior research in the same or similar landscapes (MacHutchon 1996; Nagy et al. 1983; Reynolds III 1976; McLoughlin, Cluff, and Messier 2002). The denning model also predicts den sites are more likely to occur on hillsides close to rivers, reflecting descriptions provided by Inuvialuit experts. A south aspect should be warmer and also may be preferred as prevailing north and northwest winds drift snow on south facing slopes that provide early and deep cover (Nagy et al. 1983). Additionally, the deep active layer above the permafrost on south facing slopes and steep slopes provide well-drained, coarse soil substrates that are easy to dig (Reynolds III 1976). When the model was extrapolated across the YNS study area it indicated relatively high concentration of potential grizzly bear denning habitat in the western portion of the study area as well as the extreme southeast corner of the study area. The extreme southeast corner had no prior den sites documented and this area may warrant future effort to identify bear dens or manage for this value. Additionally, denning habitat was predicted to be low in the coastal plain; however, den sites were documented for this area. This discrepancy may indicate a difference between coastal plain and mountain bears (similar to plateau and mountain bears in British Columbia; Ciarniello et al. 2005); however, additional information on the bears would be required to identify these trends.

General model comments and caveats

Grizzly bear habitat selection is likely to reflect food abundance or availabilty on the landscape (McLoughlin et al. 2002; Phillips 1987; MacHutchon 1996, 2001; Mace et al. 1999). Hence, it's not surprising that the relative importance of landscape characteristics shifts between seasons and in some cases the selection also changes (e.g., from selected to avoided or vice versa). These shifts can be observed in the seasonal model output and associated maps, which provide a good representation of grizzly bear habitat preferences in the region based on strong validation values. The results indicate that grizzly bears are typically selective for the identified moderate to high-quality habitats; however, all habitat classes were used to some degree. Grizzly bears may traverse low-quality habitat to reach high-quality habitat or a food source (calving grounds, vegetation), and these habitats are likely important for grizzly bear survival and movement (Phillips 1987). Hence, the identification of connectivity between higher valued habitats is important as bears utilize a wide range of habitats (low, moderate and high quality); however, they are very selective for relatively high-quality habitats on the landscape overall.

Future models

For the grizzly bear models, we used landscape characteristics that could be defined spatially using GIS layers; however, behavior also influences males and females during certain times of the year. For example, mating behavior may increase male movements in the spring and early summer, females may avoid males, cubs may reduce/alter female movements, etc. (MacHutchon 1996; McLoughlin et al. 2002). However, additional observational data on the bears would be required to assess this and we had limited information on the bear's age, reproductive status and/or observations. Some of this information may exist as part of the larger grizzly bear collar study data which we had limited access to.

The model framework used IK to inform the direction of the prior means in BRSF models. This represents a way to incorporate IK information into statistical models; however, it is only a first step. information on the confidence in the IK predictions can be used to inform the standard deviation priors and thus how far the model searches. For example, larger standard deviations allow the models to explore a larger parameter space indicating less confidence in prior knowledge, whereas smaller standard deviations explore a smaller parameter space indicating more confidence in prior knowledge. Interestingly, other TK modeling efforts used the number of respondents indicating a landscape characteristic as evidence for higher weighting, but several of our significant IK-based landscape characteristics had relatively few or even a single respondent. This may be due to the open-ended nature of the interview structure, which relied upon the land-user to offer information with little guidance on specific landscape characteristics to provide information on. Additionally, this affirms the importance of interviewing several IK experts, as individuals each possess important and unique knowledge of the YNS and its species.

Estimates on mean values may be included to further inform BRSF models; however, this information may be difficult to obtain from traditional knowledge-holders. Therefore, prior estimates of the mean direction and confidence in standard deviation (i.e., low, medium, high) may be most suitable to acquire from traditional knowledge-holders.

Appendix 1: Indigenous knowledge habitat summaries

Features identified as important for grizzly bears during Spring, Summer and Fall during local expert Indigenous Knowledge interviews (IK). The proportion of respondents is equal to the number of responses divided by the number of respondents. Covariates used to represent features are described in Appendix 2. Landscape characteristics were evaluated for inclusion in home range scale models; non-significant results at this scale of assessment does not suggest that the described characteristic is not important at other spatial scales (e.g., at smaller, local scales or at more broad landscape scales).

Spring

16 total interviewees responded to questions about spring grizzly bear habitats

Spring Features	Total number of responses	IK/GIS covariate assessed in the models	Retained/Refine/Removed via model selection	Reason Removed/Refined
Mountains generally	7	Coast and Mountain Regions	Retained	
IK Class Hillsides: low/mid/high slopes	6	Hillsides	Refined: category within retained	Contains Foothill sparse shrub tundra (combination of PEM classes) which had a higher AIC value
Herschel Island	6	Herschel Island	Removed	Non-significant for males and females; no collared bears on Herschel island
IK Class Tundra	5	Tundra/Low Flatlands	Removed	Non-significant for males and females; correlated with Foothill sparse shrub tundra which had a higher AIC value
IK Class Rocky Mountain Ridges	5	Rocky Mountain Ridges	Refined: category within retained	Contains Heather Nivation Slope which had a higher AIC value
Caribou Migration Route	5	Pre-Calving Isopleths 50 and 95	Removed	Non-significant for males and females
Near Shore Ice	5	Near shore ice	Removed	No available layer of ice; no GPS no locations on near shore ice
Shoreline	4	Beach (coastal and river)	Refined: category within retained	Contains River Beaches which had a higher AIC value

Spring Features	Total number of responses	IK/GIS covariate assessed in the models	Retained/Refine/Removed via model selection	Reason Removed/Refined
IK Class Rivers and Streams	4	Rivers and Creeks	Retained	Willows
Rivers Generally	4	Distance to rivers	Retained	
Flats close to the ocean	3	Distance to Coast/Coastal plain-Mountains	Retained	
Fish Holes	2	Distance to fish holes	Removed	Non-significant for males and females
Major River Valleys	2	Major River Valleys	Retained	
IK Class Timber	2	Timber (Spruce Veg)	Retained	
South Facing Hillsides	1	Aspect	Refined: aspect for females; solar insolation for males	Aspect and solar insolation correlated, sig differed between males and females
Smaller rivers	1	Distance to small rivers	Removed	Correlated with distance to rivers and wetlands
Sheep Creek/Firth River Area	1	Specific region: Sheep Cr/Firth River	Removed	Covariate distance to rivers retained
IK Class Upland Ponds and Swamps	1	Swamps	Refined: Distance to wetlands retained	Distance to wetlands contains Swamp information and has higher AIC value

Summer

11 total interviewees responded to questions about summer grizzly bear habitats

Summer Features	Total number of responses	IK/GIS covariate assessed in the models	Retained/Refine/Removed via model selection	Reason Removed/Refined
Herschel Island	3	Herschel Island	Removed	Non-significant for males and females; no collared bears on Herschel island
IK Class Tundra	3	Tundra/Low Flatlands	Refined: Foothill shrub	Non-significant for males and females; correlated with Foothill sparse shrub tundra which had a higher AIC value

Summer Features	Total number of responses	IK/GIS covariate assessed in the models	Retained/Refine/Removed via model selection	Reason Removed/Refined
Shoreline	3	Beach (coastal and river)	Refined: category within retained	Contains River Beaches which had a higher AIC value
Coastal Plain	6	Coast and Mountain Regions	Retained	
Solar Insolation	1	Solar insolation	Retained	South-facing, warmer areas; insolation had higher value than south aspect
IK Class Hillsides: Mid slopes	1	Hillsides	Removed; category within retained	Contains Foothill sparse shrub tundra which had a higher AIC value
Fish Holes	1	Distance to fish holes	Removed	Non-significant for males and females
IK Class Timber	1	Timber (Spruce Veg)	Retained	
IK Class Upland Ponds and Swamps	1	Swamps	Refined: Distance to wetlands retained	Distance to wetlands Contains Swamp information and has higher AIC value and was preferred
Rolling Hills	1	Hillsides	Refined: category within retained	Contains Foothill sparse shrub tundra which had a higher AIC value
Caribou	1	Post-Calving/Movement Isopleths 50 and 95	Retained (Males)/Removed (Females)	Significant for males
Caribou Calving Grounds	1	Calving Isopleths 50 and 95	Removed	Non-significant for males and females
IK Class Coastal Beaches	1	Coastal Beaches	Refined: distance to coast retained	Distance to coast contains coast beach information and has higher AIC value
Creek beds	1	Rivers and Creeks	Retained	Willow ecosystems
IK Class Rivers and Creeks	1	Rivers and Creeks	Retained	Willow ecosystems

Fall

14 total interviewees responded to questions about fall grizzly bear habitats

Fall Features	Total number of responses	IK/GIS covariate assessed in the models	Retained/Refine/Removed via model selection	Reason Removed/Refined
High Quality Berry Habitat	5	Berry Habitat	Retained	
Shoreline	4	Beach (coastal and river)	Refined: category within retained	Contains River Beaches which had a higher AIC value
Fish Holes	3	Distance to fish holes	Removed	Non-significant for males and females
IK Class Hillsides: Mid slopes	2	Hillsides	Refined: category within retained	Contains Foothill sparse shrub tundra (Midslopes) which had a higher AIC value
IK Class Upland Ponds and Swamps	2	Swamps	Refined: Distance to wetlands retained	Distance to wetlands Contains Swamp information and has higher AIC value and was preferred
IK Class Rocky Mountain Ridges	1	Rocky Mountain Ridges	Refined: category within retained	Contains Heather Nivation Slope which had a higher AIC value
Major River Valleys	1	Major River Valleys	Retained	
Coastal Plain	3	Coast and Mountain Regions	Retained	
IK Class Coastal Beaches	1	Coastal Beaches	Refined: distance to coast retained	Distance to coast contains coast beach information and has higher AIC value
IK Class Rivers and Creeks	1	Rivers and Creeks	Retained	Willow ecosystems
Close to water with good vegetation	1	Willow ecosystems	Retained	
Rivers with Char	1	Rivers with char	Removed	Non-significant for males and females
Hillsides near rivers	1	Hillsides near rivers	Refined: category within retained	Contains Foothill sparse shrub tundra (Midslopes) which had a higher AIC value

Denning

8 total interviewees responded to questions about denning grizzly bear habitats

Denning Features	Total number of responses	IK/GIS covariate assessed in the models	Retained/Refine/Removed via model selection	Reason Removed/Refined
South facing hillsides above creek	6	Aspect and hillsides	Both retained	South aspect significant; hillsides not significant, but in top model
Steep riverbanks and hillsides above creeks	4	Slope, distance to river	Both retained	Slope significant; distance to rivers not significant, but in the top model
South facing hillsides, generally	3	Aspect and hillsides	Both retained	Aspect significant; hillsides not significant, but in top model
Hillsides generally	2	Hillsides; Tundra low flatlands	Both retained	Hillsides not significant, but in top model; Tundra low flatlands 100m splines retained
Hillsides above river, West aspect	1	W aspect	Removed	South aspect significant
Southwest facing mound by lake, with willows nearby	1	South aspect, willow and Hillsides	Retained S aspect; hillsides generally	Unable to identify detail of ‘mounds by lake’; willow non-significant
In willows by creek	1	Willow ecosystems	Removed	Non-significant
Flats at the base of the mountain	1	TPI interactions	Removed	Unable to identify flats/mountains accurately

Appendix 2: Landscape features spatial definitions

Description of landscape characteristics used in the top grizzly bear models during spring, summer, fall and/or denning. When appropriate, the model covariate scale is provided for spring, summer, fall and denning models for males (m) and/or females (f) for final models. Elevation derived and PEM/IK classes were at a 6m resolution. PEM classes were defined by the Yukon Ecological and Landscape Classificiaton (ELC) Program (Ecological Landscape Classification Supervisory Committee 2013).

Covariate	Type	Multiple scales tested?	Description/Scaling
Herschel Island	Regional	No	Island area identified from yukon.ca data
Coastal Plains	Regional	No, binary	GIS separation of coastal plain and the foothills from the mountains in the YNS; defined by separating the mountainous region using elevation >250m and terrain compexity (Terrain Ruggedness index (TRI; Riley, DeGloria, and Elliot 1999; @ 1000m > 300) These two variables were merged (Studies Round River Conservation 2018); Figure A3.1
Sheep Cr/Firth River	Regional	No	Extraction of Sheep Creek/Firth River from linear features in the 1:50,000 NRCAN Hydrology network
Pre-calving, calving and post-calving isopleths 50 and 95	Regional	No, binary	Porcupine caribou herd data 2004-2009 (obtained pre-defined isopleth shapefiles from Yukon Territorial government)
Elevation	Elevation, 1:50k	No	Digital Elevation Model (DEM) from: Canada Digital Elevation Dataset (CDED)
Aspect	Elevation derived	No	Downslope direction of the maximum rate of change in value from each cell to its neighbors
Slope	Elevation derived	No	GIS calcuation: rate of change between each cell and its neighbor
Solar insolation	Elevation derived	No	Incoming solar radiation measured in watt hours per square meter (WH/m2); using the solar radiation toolset (ESRI 2019)
Topographic position index (TPI)	Elevation derived	Yes	Compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell (Jenness 2006); Scales: Spring: m 500m; f 3km Summer: m 100m; f 100m Fall: m 3km; f 100m Dn: 100m
Distance to rivers	Other derived	No, linear distance	Linear distance to the nearest river (all linear features in the 1:50,000 NRCAN Hydrology network)
Distance to small rivers	Other derived	No, linear distance	Linear distance to the nearest small river (2nd order; linear features in the 1:50,000 NRCAN Hydrology network)
Rivers with char	Other derived	No, binary	Rivers with char identified from IK interviews and GIS shapefile generated from linear features in the 1:50,000 NRCAN Hydrology network

Covariate	Type	Multiple scales tested?	Description/Scaling
Distance to wetlands	Other derived	No, linear distance	Linear distance to the nearest wetland (PEM Class Hydric Sedge)
Distance to coast	Other derived	No, linear distance	Linear distance to the coastline
Distance to fish holes	Other derived	No, linear distance	Linear distance to the nearest fish hole; fish hole shapefile based on IK interviews
Hillsides near rivers	Other derived	Yes	Refined Hillsides class to within 1km of river
Willow ecosystems	IK class (combined PEM classes)	Yes	IK Class (Rivers and Creeks) defined as PEM Classes Dense Low-Med Shrub, Herb-Willow Riparian, Dense Med-Tall Shrub; (WMAC(NS) and AHTC 2018); Scales: Spring: m 2km; f 300m Summer: m 50m; f 50m Fall: m 50m; f 50m
Hillsides	IK class (combined PEM classes)	Yes	IK Class defined as PEM Classes Mesic Sparse Low Shrub Tundra, Shrub-Sedge Tussock, Subhygeric-Sparse Med-Tall Shrub Herb-Moss (Ivvavik only), Willow - Horsetail (Ivvavik only), Alder-Cottongrass Tussock; (WMAC(NS) and AHTC 2018); Scale: Den: 50m
Tundra/Low flatlands	IK class (combined PEM classes)	Yes	IK Class defined as PEM Classes Tussock, (Shrub) Sedge Fen; (WMAC(NS) and AHTC 2018); Scale: Den: 100m
Foothill sparse shrub shrub (referred to in text as 'foohtill shrub')	IK class (combined PEM classes)	Yes	Contains at least one (but not all components) of IK classes originally defined as 'Hillside – Midslopes'; however, PEM changes resulted in this class containing the specific PEM Classes of Tussock, Mesic Sparse Low Shrub Tundra, Shrub-Sedge Tussock; (WMAC(NS) and AHTC 2018); Scales: Spring: m 2km; f 2km Summer: m 50m; f 50m Fall: m 50m; f 50m
Rocky Mountain Ridges	IK class (combined PEM classes)	Yes	IK class defined by PEM classes mountain avens tundra herb, rock mountain avens dry, heather bearflower nivation slope, birch-crowberry submesic slope; (WMAC(NS) and AHTC 2018)
Beach (coastal and river)	IK class (combined PEM classes)	Yes	IK class defined by PEM classes beach (unknown), dune-arctic dunegrass and em-saline-beach sedge; (WMAC(NS) and AHTC 2018)
Rivers and Creeks	IK class (combined PEM classes)	Yes	IK Class defined by PEM classes willow floodplain, Cottonwood floodplain, alder-grass drainage channel and willow-coltsfoot drainage channel; (WMAC(NS) and AHTC 2018)

Covariate	Type	Multiple scales tested?	Description/Scaling
Timber	IK class (combined PEM classes)	Yes	PEM Classes Subhygric Spruce Tussock, Subhygric Spruce Horsetail, Sub-mesic Spruce, Mesic Spruce, Spruce-Alder (Willow); (WMAC(NS) and AHTC 2018)s Scales: Spring: m 700m Summer: m 200m; f 50m Fall: m 200m; f 100m
Coastal beaches	IK class (combined PEM classes)	Yes	PEM classes beach and dune-arctic dunegrass; Scales: Summer: m 1km; f 2km Fall: m 500m; f 500m
River beaches	IK class (combined PEM classes	Yes	IK class includes PEM Classes Alluvial non-vegetated coarse texture, Alluvial non-vegetated fine texture, Exposed Land/Dead Woody Debris more than 150m from coastline; (WMAC(NS) and AHTC 2018)
Heather nivation slope	PEM class	Yes	PEM class Heather nivation slope (bearflower); (WMAC(NS) and AHTC 2018); Scales: Spring: f 150m Summer: m 1km; f 100m
Rocks and Lichen	PEM class	Y	PEM class rock/lichen; Scales: Summer: f 50m Fall: m 100m; f 50m
Swamps	PEM class	Y	IK class includes PEM Classes Hydric Sedge (WMAC(NS) and AHTC 2018) and Non-vegetated peat (Ivvavik only, unpublished report, Ponomarenko, S., 2012)
Berry quality – high/low	Combined PEM classes	No, high/low categories	From Ivvavik PEM Veg Associations (unpublished report, Ponomarenko, S., 2012): PEM Classes Subxeric Sparse Dwarf Shrub Tundra, Heather Nivation Slope, Mesic Sparse Low Shrub Tundra, Shrub-Sedge Tussock, Dense Med-Tall Shrub, Sub-mesic Spruce, Mesic Spruce, Spruce-Alder (Willow)
Major river valleys	Combined PEM classes	Yes	Valleys and surrounding hillsides (canyons, shallow alleys, u-shaped valleys, open slopes, hills in valleys landform classes) that intersect with NHN's "Major Rivers" (250k) layer (defined in; Round River Conservation Studies 2018); Scales: Spring: m 50m; f 2km Summer: f 40m Fall: f 40m

Appendix 3: Selected landscape feature maps

Maps of (select) important landscape characteristics including the coastal plain division, post-calving caribou 95% isopleths, major river valleys (50m moving window), TK/IK-based ecosystem classes, high (>0.1) and low (<0.1) berry quality, topographic position index (TPI; 300m moving window) and further explanation on the calculation and values of TPI (Figures A3.1-7).

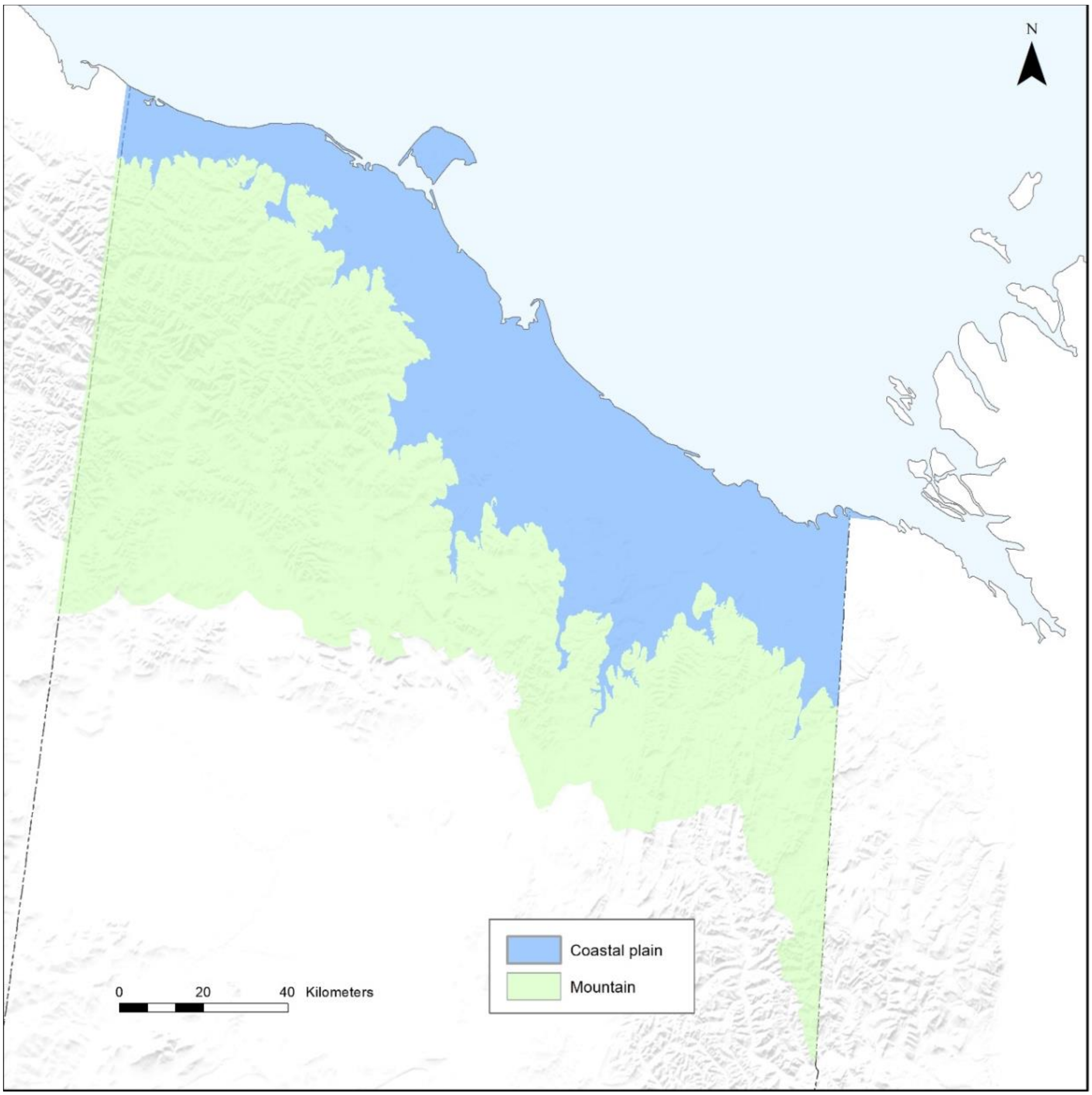

Figure A3.1 The coastal plain and mountain division classified merging elevation >250m and terrain complexity layers (Terrain Ruggedness indes (Riley, DeGloria, and Elliot 1999; @100m > 300).

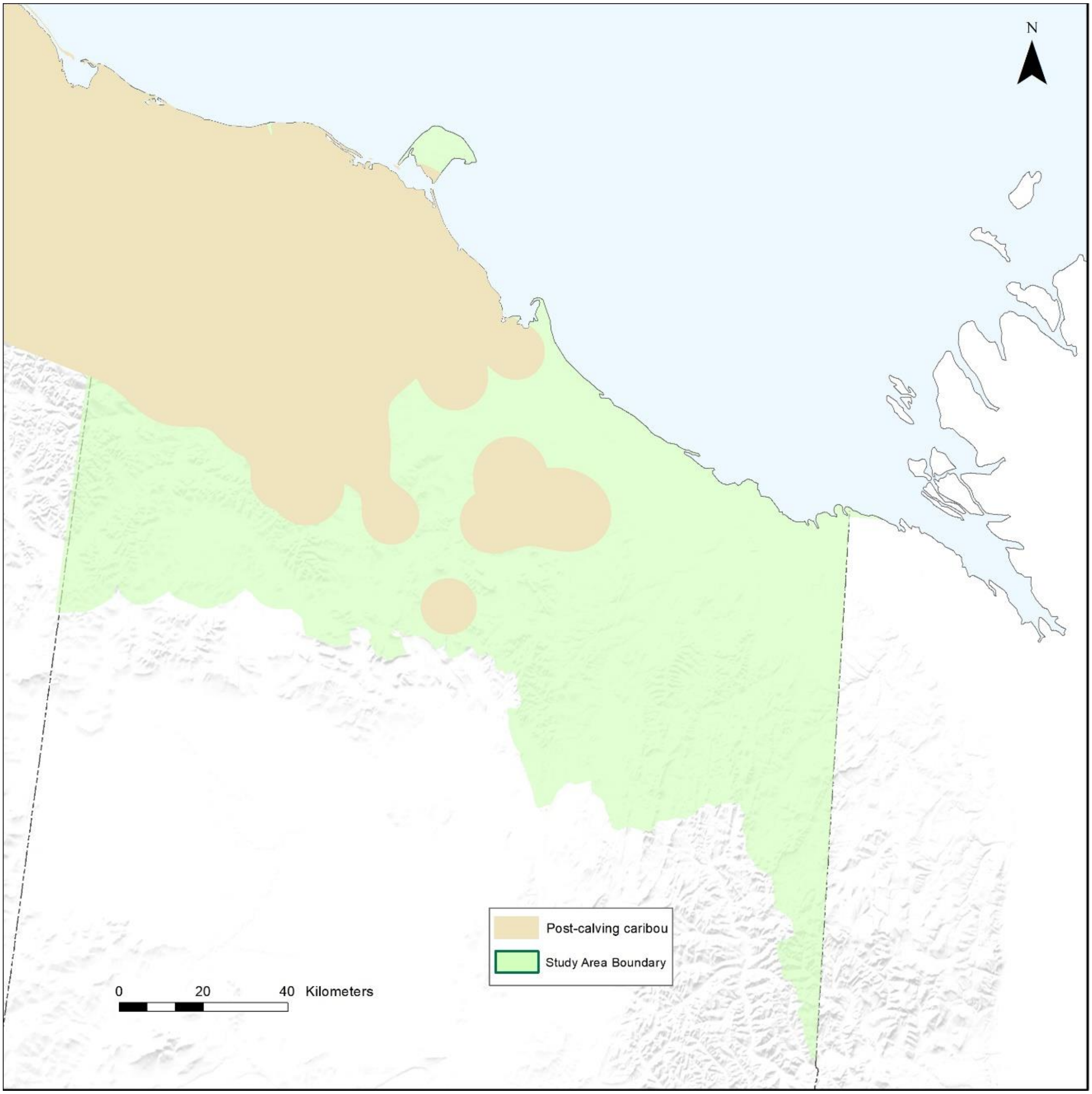

Figure A3.2 The post-calving caribou 95% isopleths from 2004-2009 dissolved into one polygon. A binary layer of the study area was produced with the post-calving caribou isopleth (tan) versus the rest of the study area (green). This layer was assessed in the summer grizzly bear habitat models.

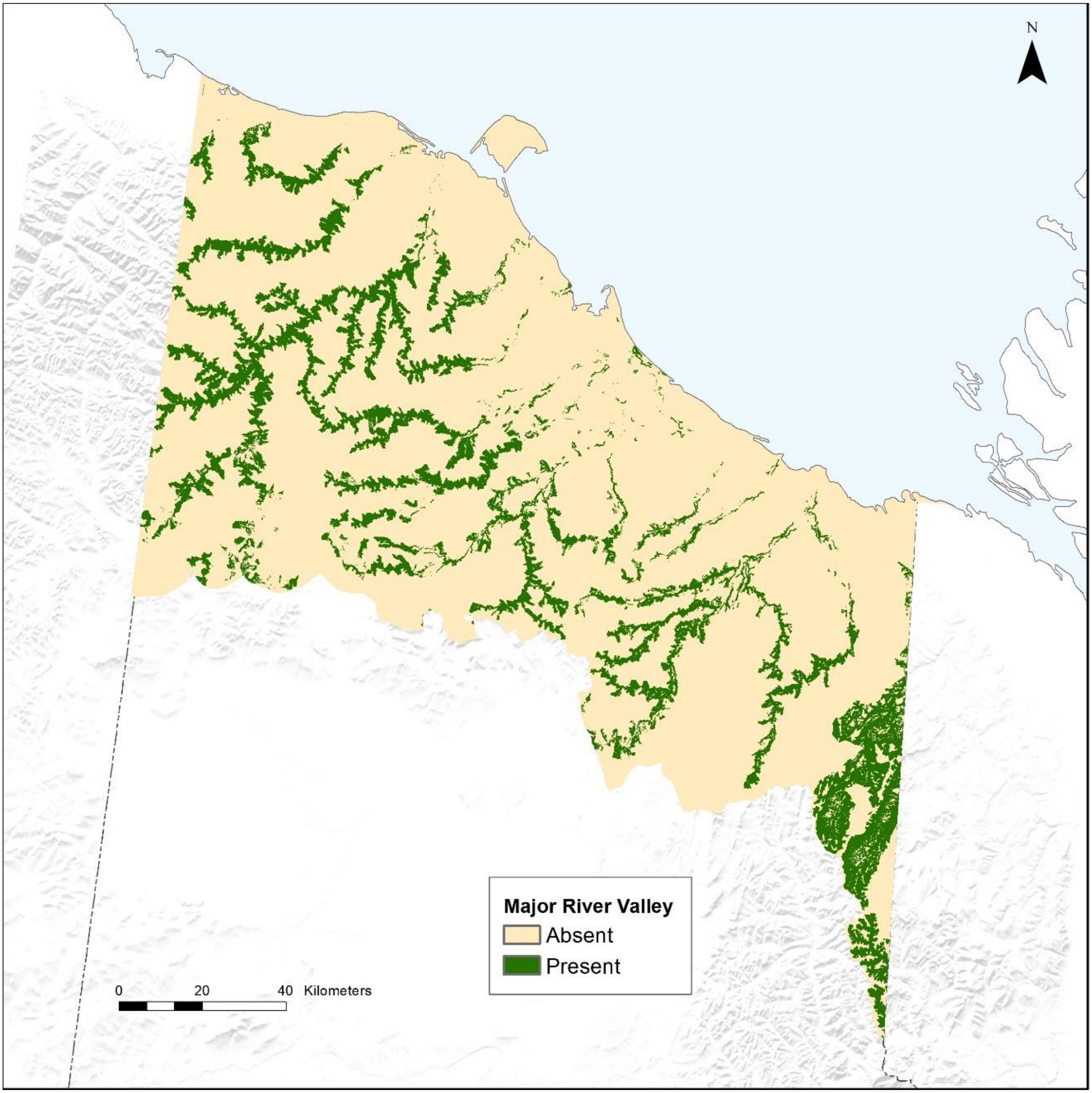

Figure A3.3 The location of major river valleys in the YNS (green). This landscape characteristic was assesed (at multiple scales) in the seasonal grizzly bear habiat models.

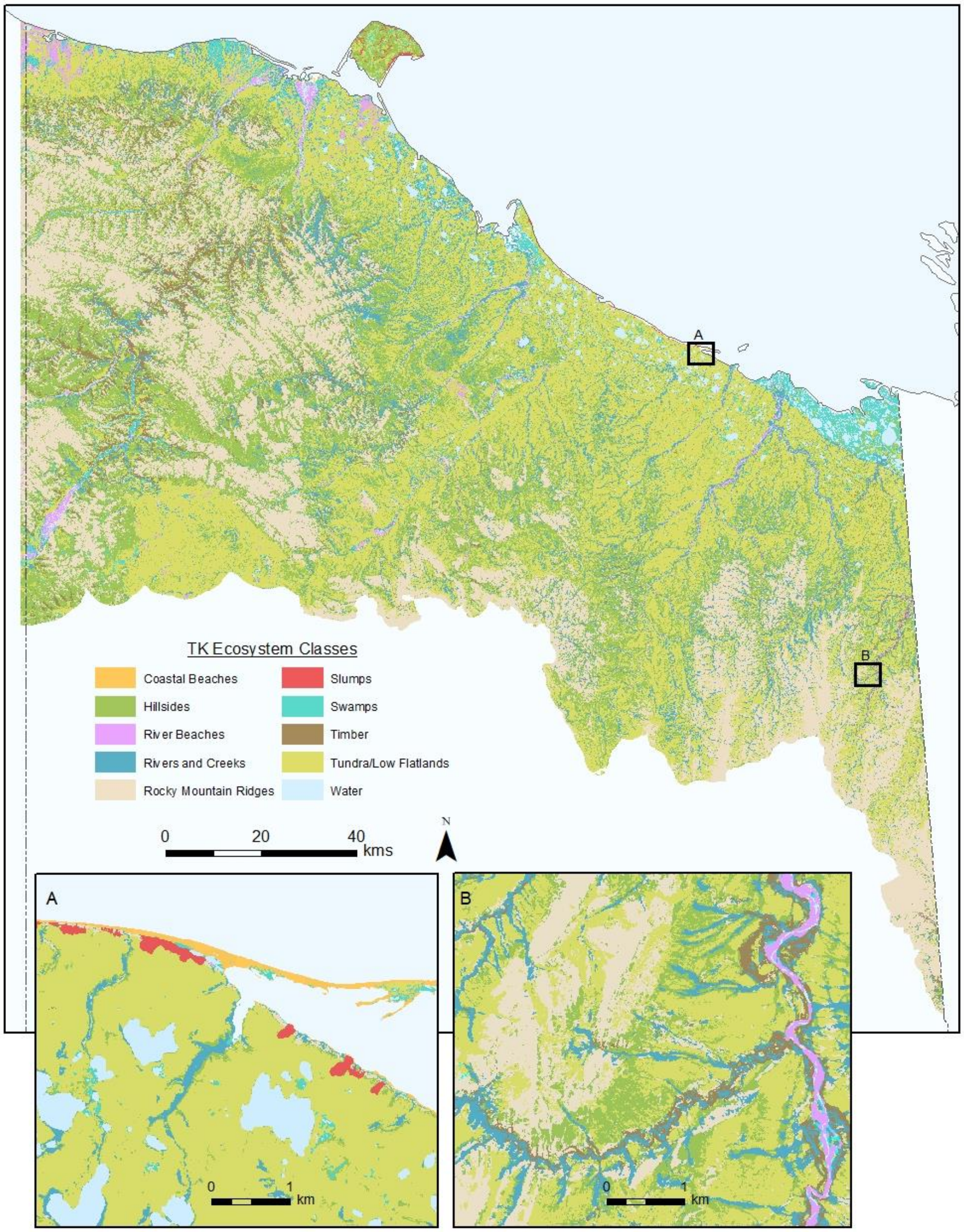

Figure A3.4 The locations of TK, traditional or indginous knowledge (IK) ecosystem classes within the Yukon North Slope.

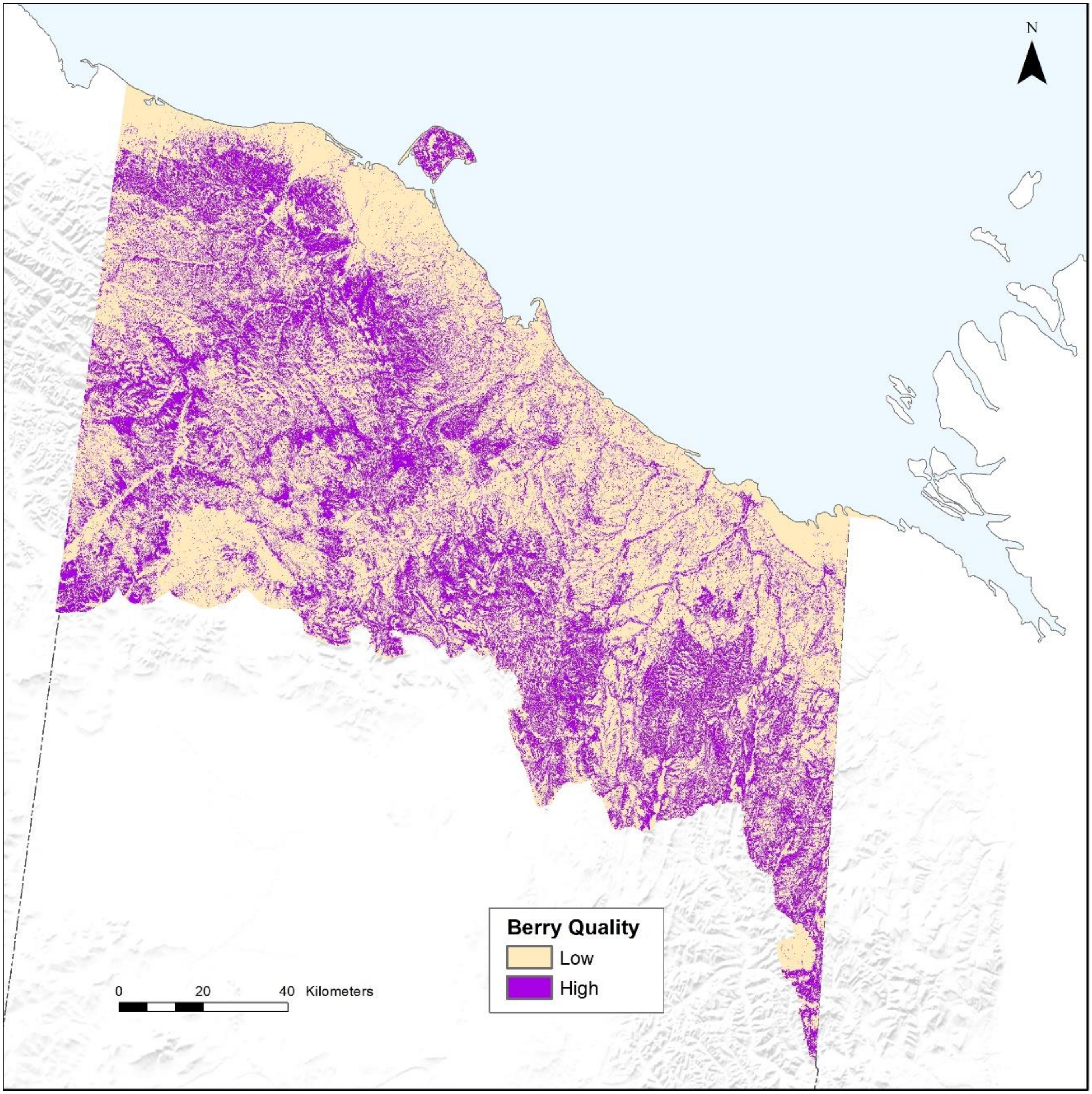

Figure A3.5 The locations of high (>0.1) and low berry (>0.1) quality habitats within the Yukon North Slope. This landscape characteristic was assessed in the fall grizzly bear habitat models.

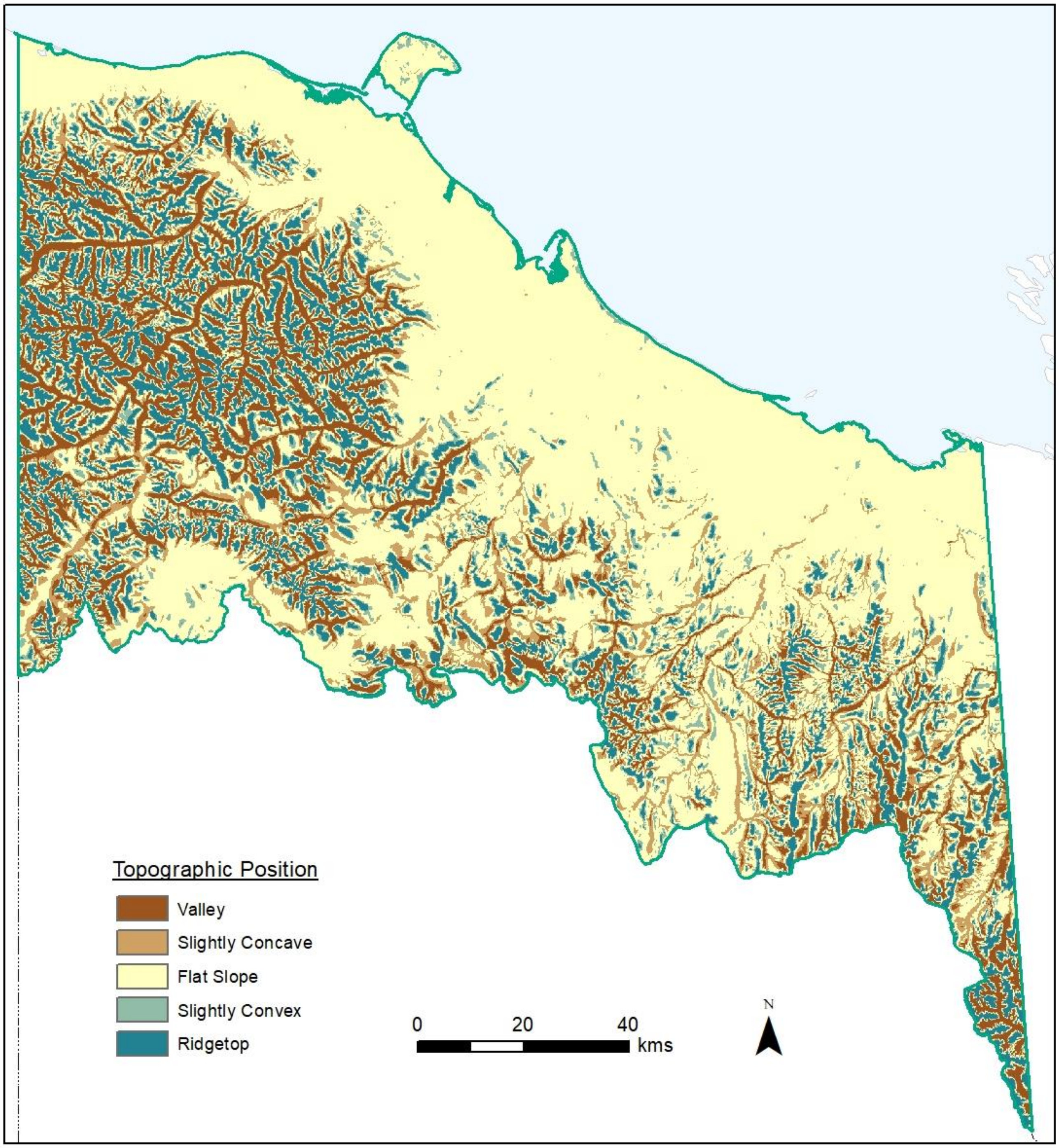

Figure A3.6 Topographic position index (TPI) at 300m moving window across the Yukon North Slope landscape; concave represents values of TPI <0 (e.g., drainages) and convex represents values of TPI >0 (e.g., ridges, middle slopes). This landscape characteristic was assesed (at multiple scales) in the seasonal grizzly bear habiat models.

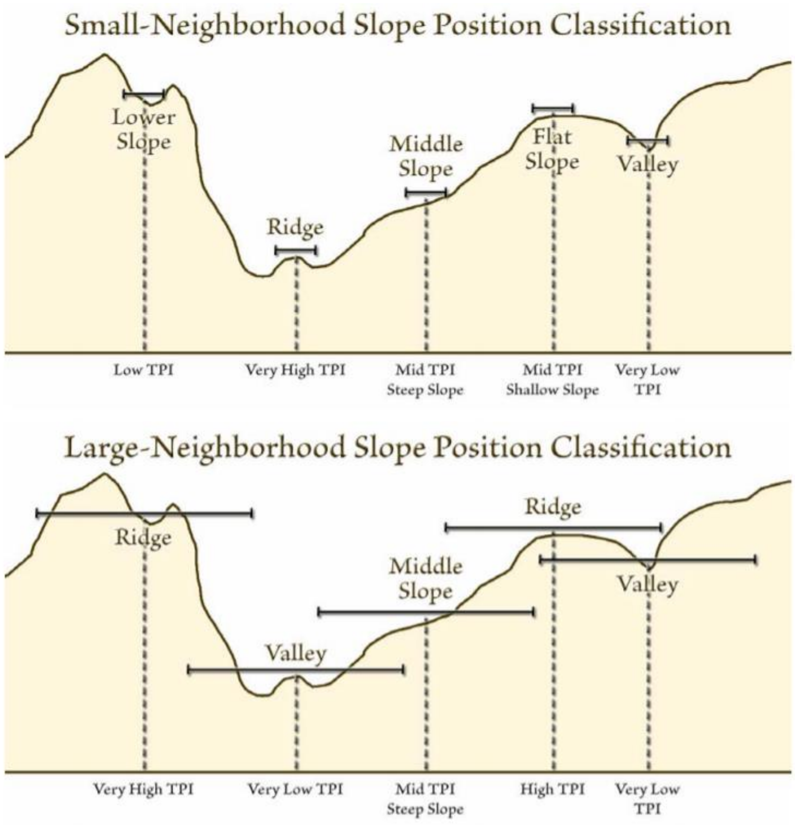

Figure A3.7 Description of topographic position index (TPI) from jennessent.com/downloads/TPI_Documentation_online.pdf (Jenness 2006)

Appendix 4: Analysis for spatial scale of selection

Animals likely integrate knowledge of their habitats at multiple spatial scales (e.g., topographic scales may include the small-scale drainage used for foraging within a larger-scale slope). The spatial scale that is most powerfully representative of animal selection of a landscape characteristic is almost certainly not the same as the spatial scale we may have mapped representations of that characteristics (e.g., vegetation classes are mapped at 6m resolution on the YNS). We assessed landscape characteristics at multiple spatial scales to identify the scale that has the highest selection by grizzly bears following methods in DeCesare *et al*. (2012). For example, the scale of selection for males for topographic position index (TPI) shows the strongest selection for TPI based on a high correlation coefficient (Figure A4.1) and low AIC value (Table A4.1; bold) suggest a congruent scale of 500m.

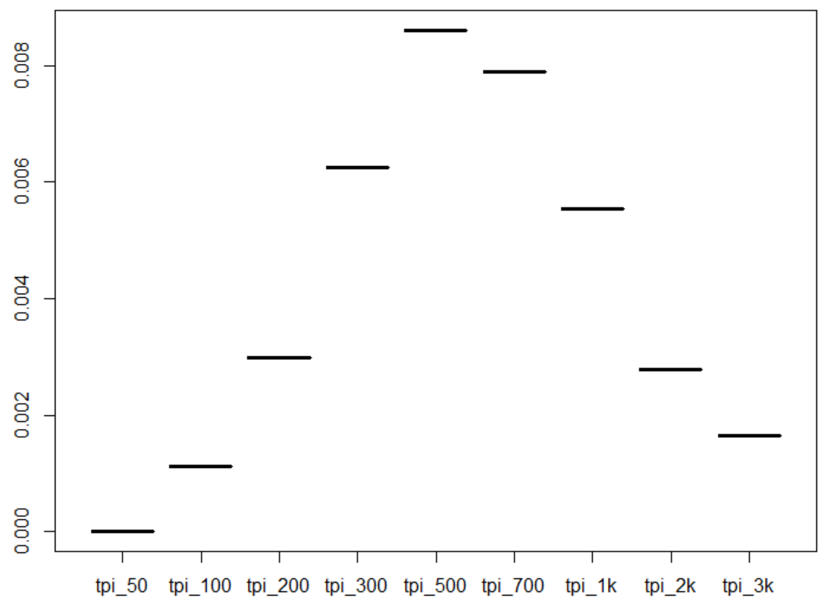

Figure A4.1 The correlation coefficients for male grizzly bear univariate models and the covariate topographic position index and multiple scales. The highest coefficient occurs at tpi_500 indicating the best fit/scale.

Table A4.1 AIC values for binomial univariate models for male grizzly bear use and the covariate topographic position index and multiple scales. The lowest AIC value occurs for tpi_500 indicating the best fit/scale.

SCALE	AIC
TPI_50	12148.57
TPI_100	12135.00
TPI_200	12112.24
TPI_300	12073.71
TPI_500	**12046.70**
TPI_700	12055.28
TPI_1000	12083.21
TPI_2000	12115.65
TPI_3000	12129.11

Appendix 5: Pareto diagnostic plots

Pareto smoothed importance sampling (PSIS) diagnostic plots generated from the 'leave-one-out" (LOO) analyses (Figure A5.1). Values >0.7 return NA estimates and require further explanation for lack of model fit (no final models contained values >0.7).

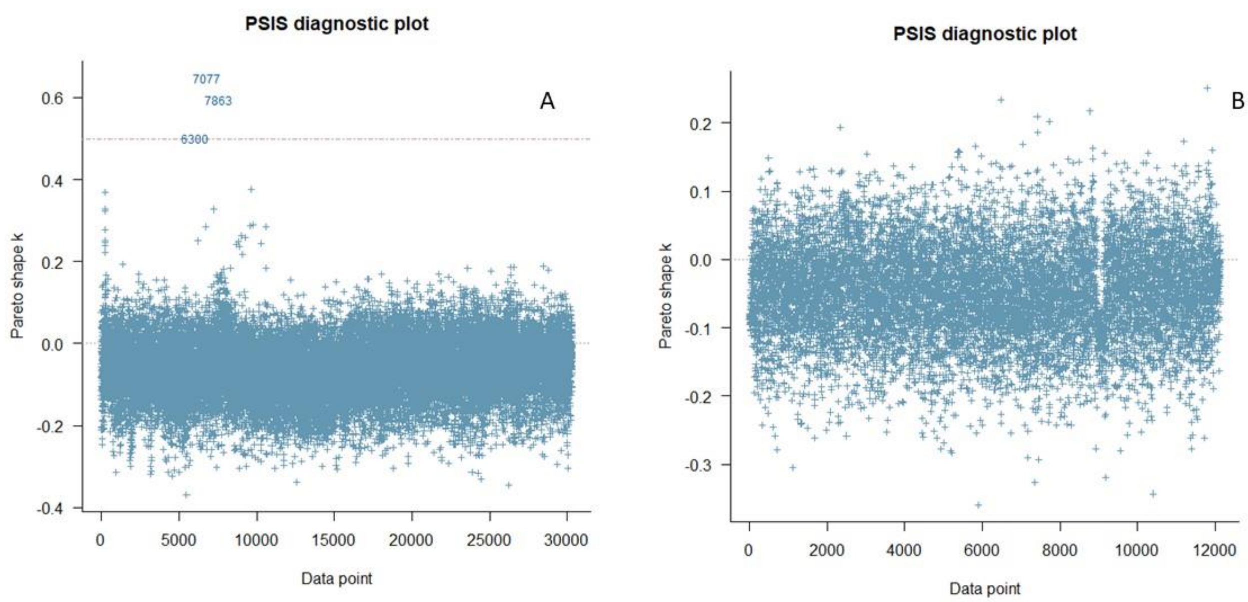

Figure A5.1 Pareto smoothed importance sampling (PSIS) diagnostic plot for the final female (A) and final male (B) grizzly bear Spring models. All data points have Pareto shape (k) values within the acceptable range (<0.7) suggesting the model represents the data well.

Appendix 6: Season definitions

We evaluated various divisions of the data and determined that the best 'seasonal' representation of the data was accomplished by dividing the months in to Spring: den emergence to early June; Summer: late June and July; and Fall: August to start of denning. The data were split between early (day ≤15) and late June (day >15) to best capture den emergence. This closely reflects seasons as identified by the Inuvialuit and by MacHutchon (MacHutchon 2001) who similarly defined Spring (26 May – 15 June), Summer (16 June – 31 July) and Fall (1 August – 4 September) based on shifts in grizzly bear diet determined from observations, phenological plant development and scat analysis. Denning or winter, the fourth season, is defined as the period within the den.

The timing of bear maximum movement events and their mean and maximum log (movement rates) were also used to assess seasonal divisions and suggests different behaviors may be exhibited within the proposed seasonal time periods (Figures A6.1 and A6.2).

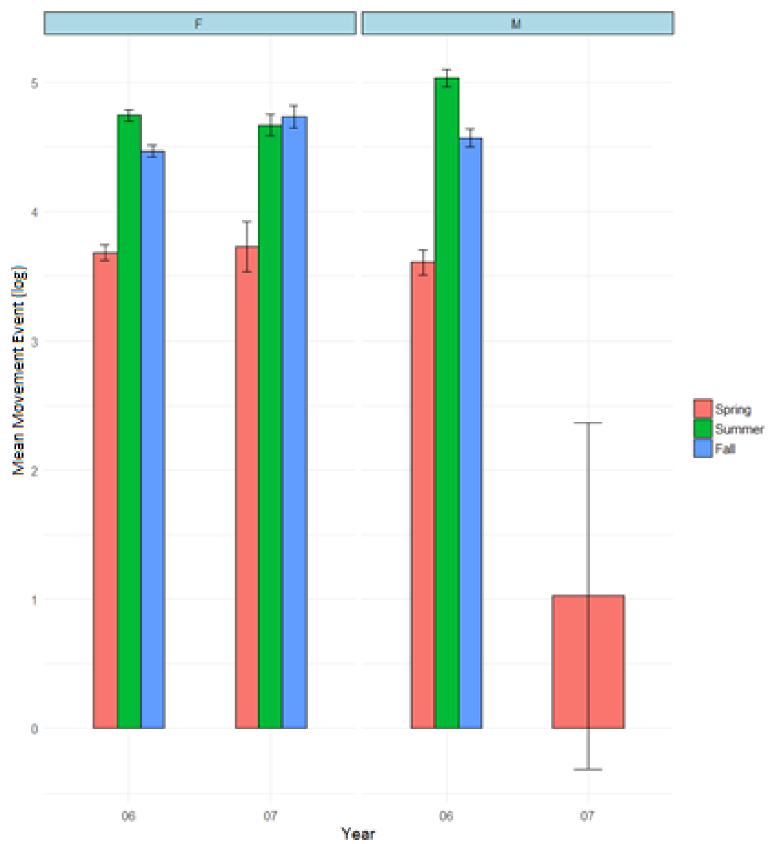

Figure A6.1. The mean movement rates in each season for female and male GPS collared Grizzly bears (Ursus arctos) in 2006 and 2007 (nFemales=18; nMales=10). Standard error bars represent 95% confidence intervals. Spring: April – early June; Summer: late June – July; Fall: August – November.

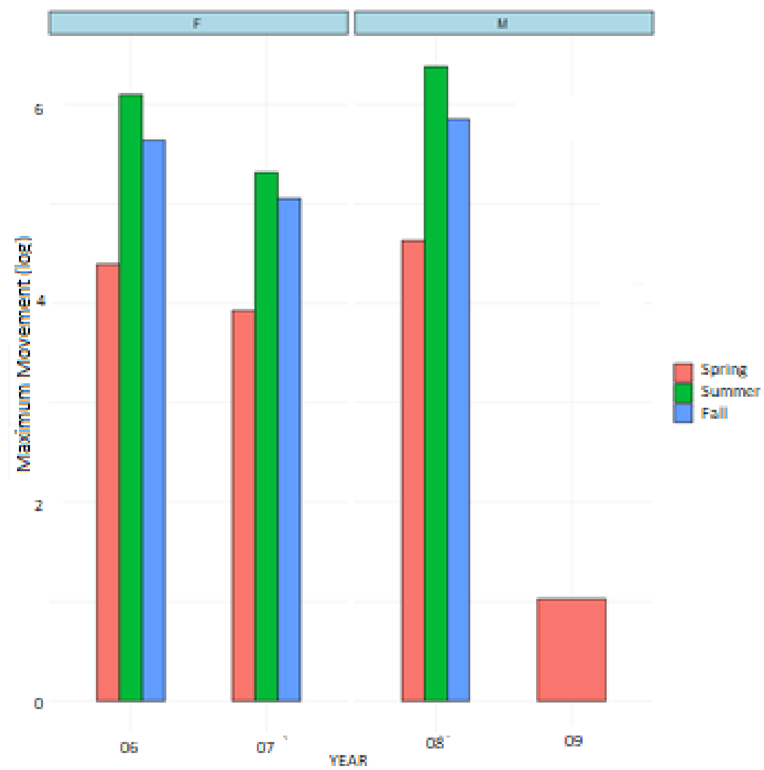

Figure A6.2. The maximum log movement events in each defined season for GPS collared female and male Grizzly bears (Ursus arctos) in 2006 and 2007 (nFemales=18; nMales=10). Spring: April – early June; Summer: late June – July; Fall: August – November.

Assessments of Grizzly bear seasons: Spring and fall

We completed additional assessments of potential within-season patterns of habitat selection that may be influencing model results and/or suggesting different season date definitions. Specifically, we assessed:

- Weekly averages movement rates (Figure A6.1)
- Maps of monthly locations for females and males during spring months to assess visually bear use of coast (Figure A6.2 and 3)
- Univariate regressions of each model covariate by week for spring and fall

to identify if there are alternative range of dates than currently used in the bear modeling that would specifically capture 1) changing behavior as indexed by movement rates, 2) spring movement to the coast and 3) shifts in habitat use just prior to denning in the fall. Movement rates were calculated based on the straight-line distance/time elapsed of consecutive locations after thinning data to 4-hour relocations with 2 animals having 3-hour relocations. Prior to averaging into weekly estimates, movement rates were logged to better conform to a normal distribution appropriate for calculating normal statistics.

The assessments show quite a bit of variation through the seasons and comparing the early spring patterns to later spring patterns is confounding due to small sample size in early spring (e.g., the first couple weeks have just 2 bears and relatively small number of locations). Similarly, late fall sample size is small compared to earlier fall season. Due to the variation and small sample size the divisions in the final report for spring and fall were agreed upon by all collaborators.

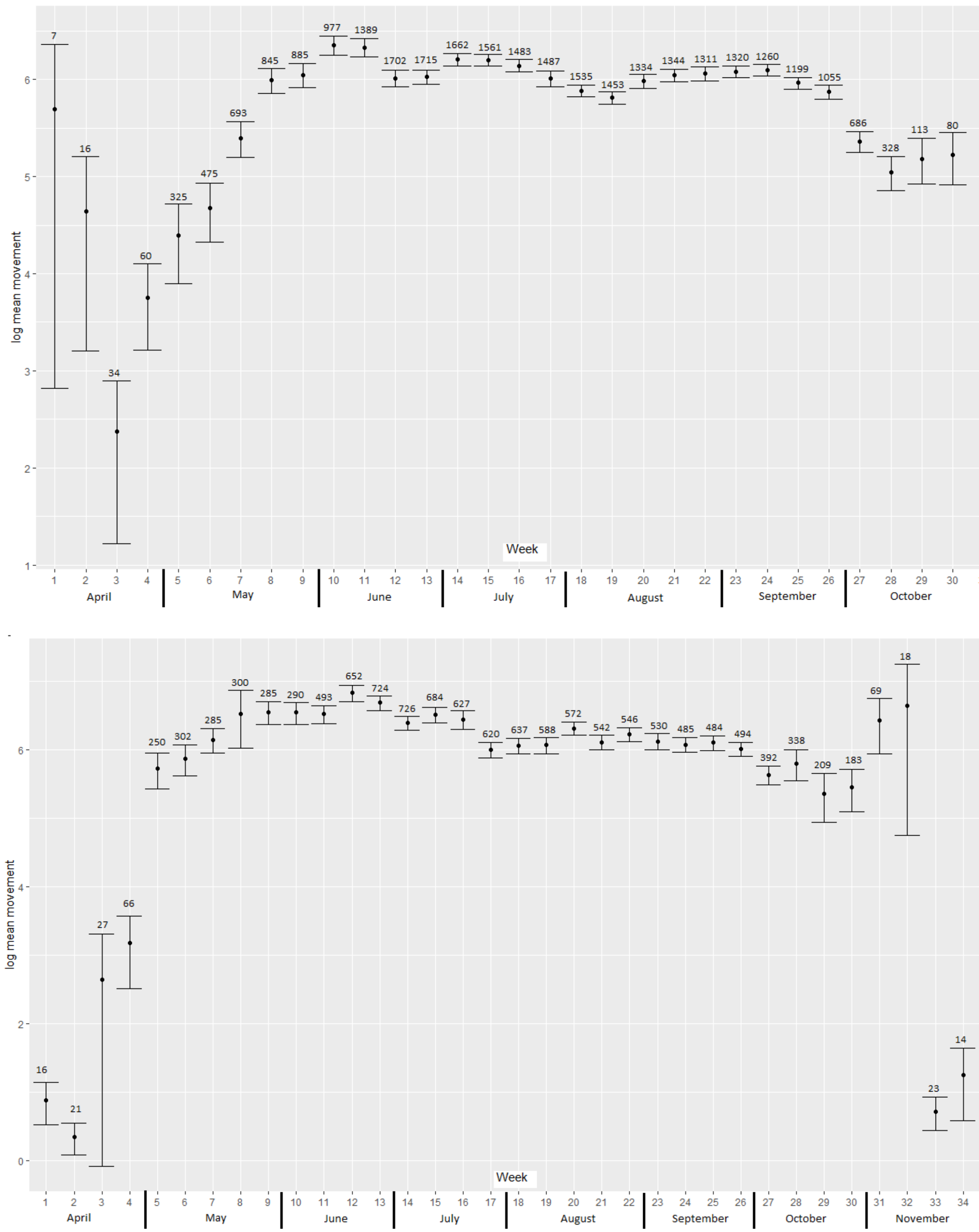

Figure A6.1 Female (upper) male (lower) grizzly bear weekly average of log(movement rate). The number of observations in each week are displayed above the upper confidence limit (horizontal bar).

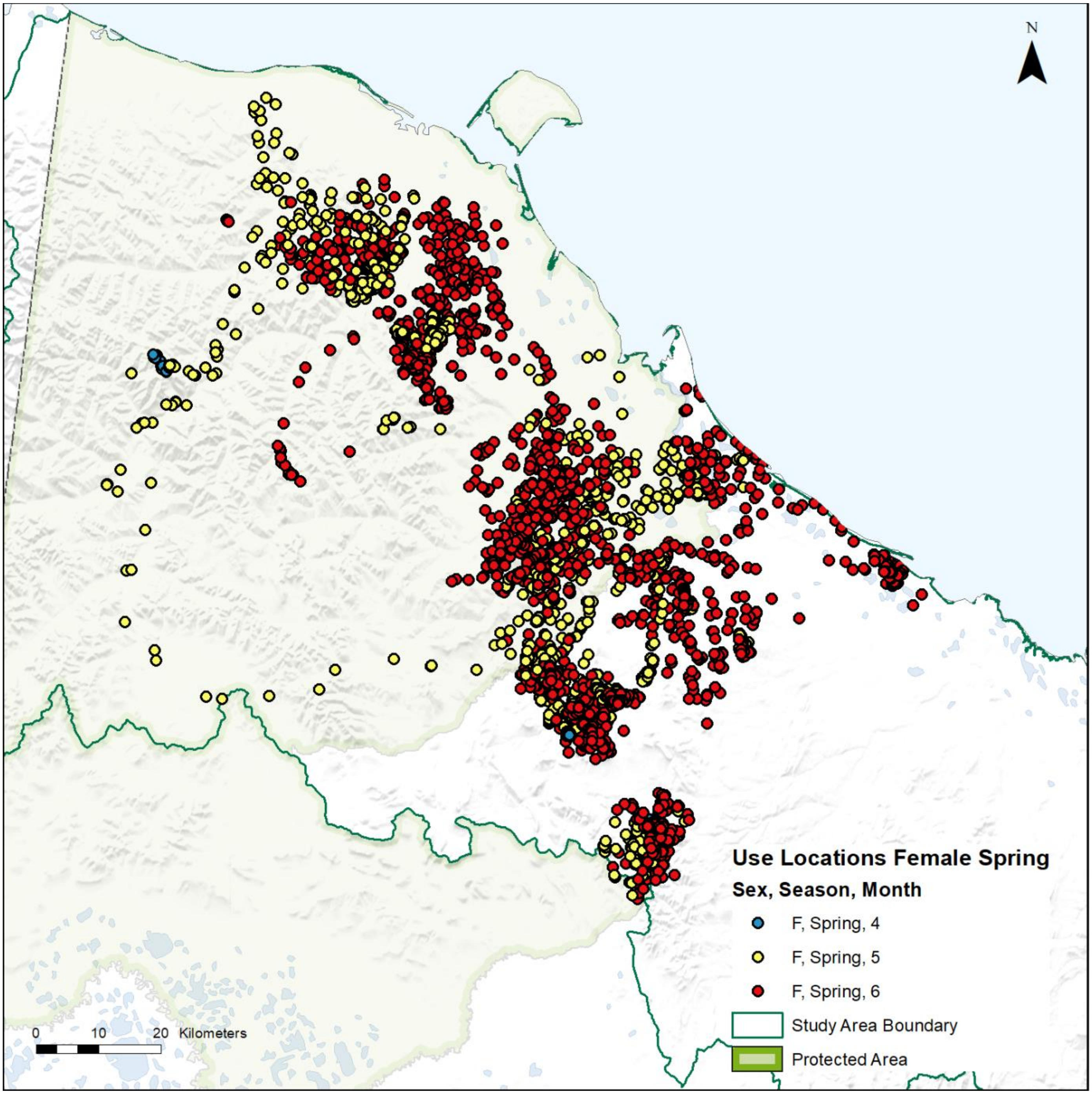

Figure A6.2 Female grizzly bear locations in the spring, themed to show locations in April (4; 10 bears), May (5; 12 bears) and first half of June (6; 13 bears).

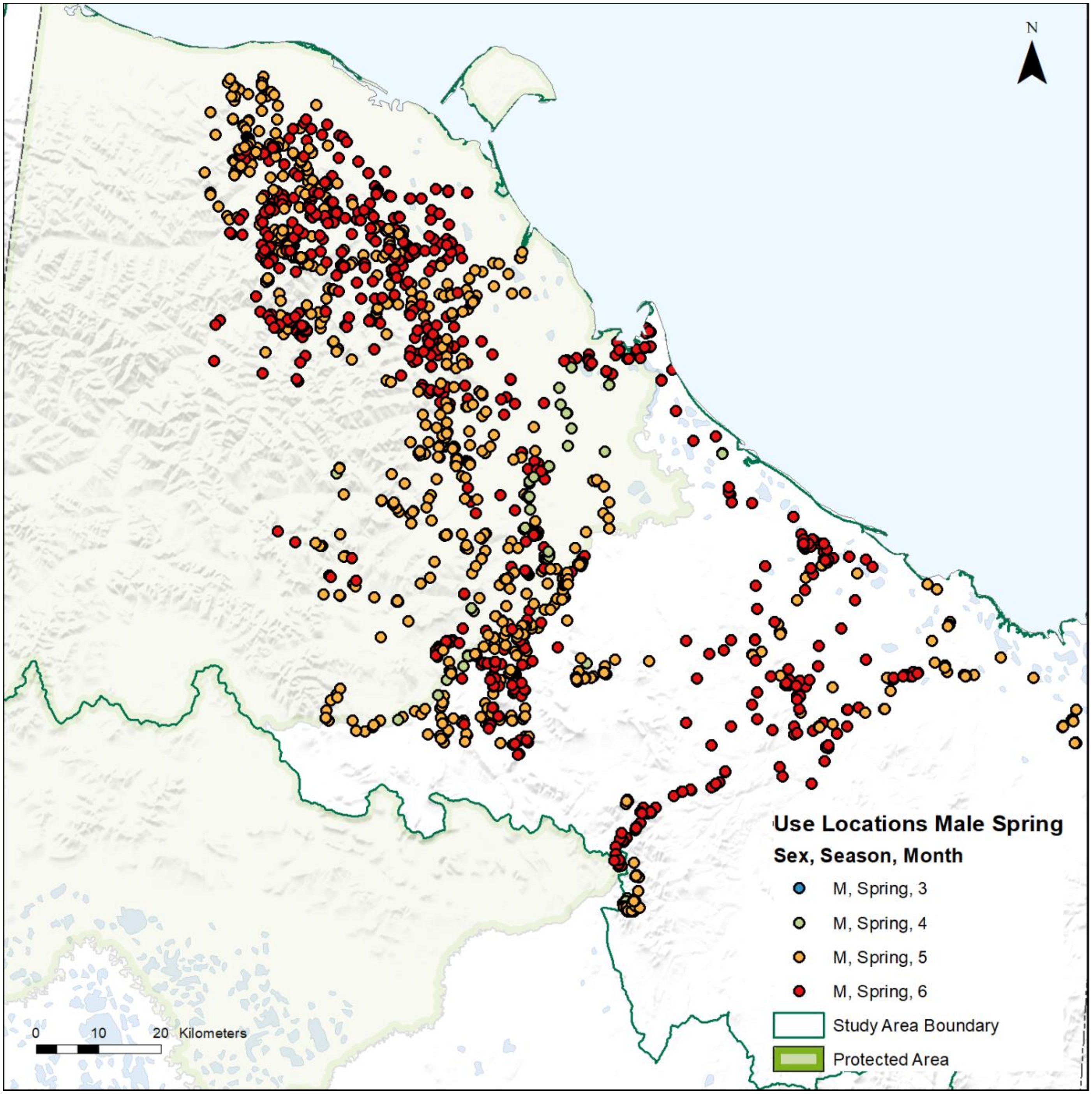

Figure A6.3 Male grizzly bear locations in the spring, themed to show locations in March (3; 2 bears), April (4; 8 bears), May (5; 10 bears) and first half of June (6; 10 bears).

Appendix 7: Average seasonal home range size by year

Annual mean home range estimates, mean (standard deviation), for male and female grizzly bears GPS locations in the spring, summer and fall during 2004-2009 in km^2.

Table A7.1 Average seasonal home ranges for male and female grizzly bears on the Yukon North Slope based on kernel density home range estimates. Individual home ranges are calculated for each individual bear for each year of monitoring; thus, n depicts number of individual bears/year.

		2004			2005			2006			2007		2008			2009		
		Mean (SD)	Mean (SD)*	n	Mean (SD)	Mean (SD)*	n	Mean (SD)	Mean (SD)*	n	Mean (SD)	n	Mean (SD)	Mean (SD)*	n	Mean (SD)	Mean (SD)*	n
Spring	F	1067.9 (716.8)		5	650.3 (763.2)		8	1174.9 (2603.2)	1164.5 (2570.8)	10	358.7 (287.5)	3	180.0 (116.5)		4	442.3 (333.4)	332.6 (442.9)	5
	M	495.3 (106.2)	480.3 (77.8)	4	1964.1 (1782.9)	1960.1 (1783.5)	6	1895.8 (1498.1)	1764.6 (1609.5)	6					1	1165.8 (818.5)	701.7 (162.0)	2
Summer	F	496.6 (374.0)	495.7 (375.0)	6	1830.5 (5474.5)	1198.2 (3127.3)	14	395.0 (395.4)		10	304.7 (269.1)	3	303.7 (345.9)		8	199.1 (105.0)	180.5 (76.3)	5
	M	1947.0 (1229.1)	1939.5 (1241.27	4	3736.5 (7585.4)	2906.8 (5244.2)	8	3594.9 (6264.8)	3034.4 (5015.5)	5			2659.5 (1708.8)		4			
Fall	F	366.8 (271.8)	359.2 (274.6)	6	455.8 (769.1)		13	379.8 (416.0)		9	267.9 (167.9)	3	231.6 (145.7)		7	124.5 (38.6)		4
	M	1542.4 (793.5)	1523.3 (813.7)	4	2408.3 (2603.4)	2102.1 (1995.5)	8	13723.7 (20256.2)	1450.8 (1674.5)	3		0	6332.2 (5088.5)	5094.7 (4136.7)	3			

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