The grizzly dance between berries and bullets: relationships among bottom-up food resources and top-down mortality risk on grizzly bear populations in southeast British Columbia

Michael Proctor
Clayton Lamb and
Grant MacHutchon

REPORT PREPARED BY:
Dr. Michael Proctor
Trans-border Grizzly Bear Project
Birchdale Ecological
PO Box 606
Kaslo, BC
V0G 1M0

PROJECT FUNDED WITH SUPPORT BY
BC Habitat Conservation Trust Foundation and the
Fish Wildlife Compensation Program

EXECUTIVE SUMMARY

Understanding relationships among primary forces driving population process, such as bottom up food resources, and top down mortality events, are important for informing effective management to influence factors driving population dynamics and ultimately conservation status.

Black Huckleberries (*Vaccinium membranaceum*) are the main energy-rich grizzly bear food in much of our south Selkirk and Purcell Mountain study area and drive productivity of the bears. Yet little is known about where and why huckleberries grow into useful patches for grizzly bears or how foraging supply integrates with mortality risk to determine population vitality. Here we developed and evaluated a model for black huckleberries and brought it together with other predictive habitat and mortality risk variables in a series of models that predict several population processes including female habitat selection, female home range selection, mortality risk, density, and fitness.

Our goals were to answer a set of nested questions:

- Could we develop a huckleberry patch model that was more predictive than a generalized huckleberry plant occurrence model?
- Which variables representing both bottom up and top down forces were the most consistent and best predictors across several population processes?
- What was the relationship between bottom up or top down forces driving these process, which was more important for various population processes, or were they both important?

We used our 10 year GPS telemetry data set to identify and map a suite of habitat use clusters that would help us identify huckleberry patches that grizzly bears used. We visited 512 sites over 2 years and identified over 300 sites that were huckleberry patches used by bears. To more broadly predict huckleberry patches we used Boosted Regression Tree (BRT) modeling methods associating geophysical, ecological, soil, climate, and topographical variables to our suite of huckleberry patches. Our resulting predictive model evaluated very well at several levels. The Area under the Receiver Operator Characteristic curve (ROC AUC) score was 0.86 (0.7 is considered good).

We also evaluated our model in the context of a series of multi-variable predictive models of female habitat use and home range selection from GPS telemetry data, and density and fitness (spatialized female reproductive success) from DNA-derived data. These models tested both the predictability of several variables for both bottom up and top down forces including habitat variables, huckleberry occurrence, or huckleberry patch models for bottom up forces, and road presence, road density, distance to road, human access - human population centres related to road networks - and a composite model of mortality risk for top down forces. In most models, distance to huckleberry patches greater than 10 hectares were the most influential bottom up predictor of habitat selection, density and fitness. The best top down predictor was road density. Relative to each other, huckleberry patches were consistently the most influential predictor of habitat selection, density and fitness, however, road densities were also influential and additive. Road density was the most influential predictor in our mortality risk model. Besides supporting the excellent predictive value of our huckleberry patch model, our results suggest that both bottom up and top down forces were important for population process of grizzly bears. Furthermore, the fact that our huckleberry patch model was such a good predictor of population processes, our bear data was from both telemetry and DNA, and that energetic mechanisms underlying the role of huckleberries has been established (McLellan and Hovey 1995, McLellan 2011, 2015), suggests that the relationships we found were real and not an anomaly of sampling bias or chance.

While managing the landscape for huckleberry forage is sometimes a medium to long term option, managing for mortality risk through road density, has potential to be implemented over shorter time scales. We found grizzly bear densities to be almost 3 times higher in habitat with road densities <0.6 km/km^2 supporting the use of this target as is applied in neighbouring jurisdictions.

The top five predictors in our best huckleberry patch model were, in decreasing importance: 1) canopy cover, 2) coarse fragments in soil, 3) slope, 4) precipitation as snow in winter and, 5) average solar radiation. Overall we see that areas of low canopy cover, low angle slope, few coarse fragments in soil, north and east aspects, as well as high winter snow load produce huckleberry patches important to grizzly bears

We also analyzed the relationship between our huckleberry patch model and timber harvest patterns in our region. We found 74% of huckleberry patches were not in cut blocks. The ~26% of huckleberry patches that were in cut blocks occurred where the proportion of our focal area in cut blocks was only 18%. The breakdown by Grizzly Bear Population Unit (GBPU) was variable. In the South Selkirks, 11% of that GBPU has been a cut block, but 3.9% of the area is a huckleberry patch. That contrasts with the Yahk GBPU where 34% of that area has been a cut but only 1.1% on the area contains a huckleberry patch. The South Purcell area was 17% cut block and also only 1.1% huckleberry patch.

Mean cut block age with huckleberry patches was ~40 yrs vs ~25 years for cut blocks without patches. We also found that planted cut blocks were less likely to have huckleberry patches. Slash burning didn't increase the probability of a cut block yielding a huckleberry patch, it was slightly reduced. Fires (not slash burns) were ~3x more likely to yield a huckleberry patch than a cutblock. Our results suggest that in areas with the appropriate climate, soil and topographic conditions, as revealed in our multivariate patch model, that also had canopy cover <30% were more likely to contain a huckleberry patch grizzly bears use.

We attempted translating our results into the BC's Biogeoclimatic Ecosystem Classification system to be relevant for the forest industry. We found that huckleberry patches are more prevalent in the Englemann Spruce Sub-alpine Fir (ESSF) zone and in the wet mild subzones wm3, wm4, and wmw. Site series that favor huckleberry patches were 103 subxeric (dry), and to a lesser degree 101. Old forests (80-250 years old) and early seral stage dominated by shrubs dominated the structural stages with huckleberry patches.

Our predictive model was applied across our focal area in a way to identify future potential areas that after opening of the canopy, have the potential to be a huckleberry patch.

WE RECOMMEND:

- that managers in the southern portion of the Purcell and Selkirk mountains within the Kootenay region where huckleberries are known to be important to grizzly bears, apply access controls around important huckleberry patches that we have identified.
- that the landscape not be managed so that there is an even road density spatially, but in a mosaic of human access levels that includes:
    - approximately 25% of the landscape, particularly portions with important huckleberry fields have no roads
    - that 60% of the landscape be >500m from an open road in patches >5-10 km^2 and those secure habitat patches encompass higher quality habitats such as those identified in Proctor et al. (2012)
    - that the portion of roaded areas be a combination of areas managed to have <0.6 km/km^2
    - Some proportion (~25%) of the landscape have any road density

- that the timber industry test for huckleberry patch genesis in the areas we have identified as good future potential for huckleberry patches when the canopy is opened up (Figs. 20 & 29).
- that our map of important huckleberry patches be incorporated into current logging planning cycles and other land uses in the backcountry to insure that road building, harvest plans, and other development be designed to not destroy or provide permanent access to important patches.
- that forest and ecosystem managers plan for a reasonable huckleberry supply where ecological and climate conditions allow at the stand, landscape, GBPU and ecosystem scales. Such planning can be facilitated through the use of our huckleberry patch future potential map especially in grizzly bear units in the region with a conservation concern such as the South Purcell, Yahk areas, and the western portion of the South Selkirks.
- that Nature Conservancy Canada keep a portion of the canopy open in their Darkwoods property through logging or prescribed burns in several locations to maintain already existing, or to create new, huckleberry patches.
- that appropriate areas be mapped where wildfires will not be extinguished unless conditions are too risky for private property (homes, ranches, farms, resorts etc).
- that management consideration be given to important huckleberry patches in and adjacent to connectivity zones as identified in Proctor et al. (2015). These huckleberry patches are important habitat for female reproduction and low road densities are important to reduce mortality risk and increase female survival.
- that this research be continued to include the entire Kootenay Region 4.
- that similar research be carried out for buffalo berries (*Shepherdia canadensis*)

Citation:
Proctor, M. F, C. T. Lamb, and A. G MacHutchon. 2017. The grizzly dance of berries and bullets: The relationship between bottom up food resources, huckleberries, and top down mortality risk on grizzly bear population processes in southeast British Columbia. Trans-border Grizzly Bear Project. Kaslo, BC, Canada.

Table of Contents

List of Tables

List of Figures

Appendix

INTRODUCTION

Understanding the relationships among forces driving population process, such as bottom up food resources, and top down mortalities are important for informing effective management that can influence factors driving population dynamics and ultimately conservation status (Power 1992, Oriol-Cotterill et al. 2015). Variability across taxa on the relative importance of bottom up vs top down forces is wide (Dyer and Letourneau 1999, Grange and Duncan, 2006, Greenville et al. 2014). In some cases, underlying food conditions have been shown to be most influential and ever present but top down forces can be additively influential with temporal and spatial variability (Grange and Duncan 2006; Pierce et al. 2012, Laundre et al 2014).

Grizzly bears (*Ursus arctos*) are often thought of as being a top predator applying top down control on other species. However, in southeast British Columbia their diet is predominantly vegetation based (McLellan and Hovey 1995, Mowat and Heard 2006) and they are subjected to substantial mortality forces from humans (McLellan et al. 1999, Nielsen et al. 2004*a*, Schwartz et al. 2010) as is the case with many other top predators (Kissui and Packer 2004, Oriol-Cotterill et al. 2015). Furthermore, the typical bottom up - top down interplay in grizzly bear population dynamics can be influenced by humans from both ends and in complex and interacting ways. Humans can have a landscape-level influence on grizzly bear food supplies as timber harvest and forest fires open canopies, and increase grizzly bear forage, while fire suppression can reduce food supplies (Minore 1975, Minore et al.1979, Hamer and Herrero 1987, Nielsen et al 2004*a,* McLellan 2015). Also the interface of habitats that provide foraging resources can interlace with a mosaic of anthropogenic mortality risk that is spatially variable creating a complex assortment of safe, productive, unsafe and unproductive habitats in all combinations (Nielsen et al. 2009). Understanding the relationship between bottom up and top down influence is particularly important for sensitive species or populations that may be threatened, particularly where conservation management is essential yet may be costly to society. The grizzly bear in southern British Columbia, Canada, is extensively fragmented (Proctor et al. 2012) with several fragmented or isolated population units with elevated conservation concern (McLellan 1998, Proctor et al. 2012, McLellan et al. 2016*a*). As the human footprint expands in southern BC, management of grizzly bears would benefit by applying accurate strategies to balance their program that consists of a spectrum of approaches that vary spatially with conservation status. In parts of the province grizzly bear populations are healthy enough to sustain a legal hunt (McLellan et al 2016*b*). In other parts of the province, often the southern periphery of their distribution, overlap with humans for the past century has resulted in large portions of the southern province closed to hunting for conservation reasons (McLellan 1998, Hamilton and Austin 2004). This dichotomy has made for challenging management strategies and controversies related to what is causing conservation concern, low food supplies, or excessive human-caused mortality (whether conflict or hunt related).

Human-caused mortality is commonly the driving factor in large carnivore population dynamics, (Treves and Karanth 2003), however there are many examples where food abundance influences trend, (Fuller et al. 1989, Hilderbrand et al. 1999, Karanth et al. 2004, McLellan 2015). Much is known of grizzly bear ecology and conservation in North America, and until recently much research and management has focused on reducing human-caused mortality (McLellan et al. 1999). This focus was because historically, mortality was clearly the driving factor in grizzly bear extirpation but also many studies from known-fate telemetry work that clearly showed that population trend was most sensitive to changes in adult female survival (Knight and Eberhardt, 1985, McLellan et al. 1989, Eberhardt 1994). While trend estimates incorporate a component of bottom up influence in reproductive rate, this is not a direct measure of the influence of food resources, but a result of available and assimilated food resources (Sinclair and Krebs 2002). To better clarify the role of food resources in trend estimates, Reynolds-Hoagland et al. (2006) linked hard (nuts) and soft mast (berries) production with demographic data in American black bears (*Ursus americanus*) to improve predictability and gain insight as to cause of trend. McLellan (2015) carried out a similar analysis with grizzly bears analyzing changes in vital rates and population trend over 30 years incorporating undulating food resources.

Food resources have been noted as drivers of animal abundance and density for many years (Hilderbrand et al 1999, Sinclair and Krebs 2002, Garbone and Gittleman 2002, Brasher et al. 2007, McLellan 1994, 2011, 2015). Habitat use studies often used habitat-based surrogates for direct food resources and other factors that influence bears (Mace et al. 1996, McLellan and Hovey 2001, Nielsen et al 2002, 2004*a*, Nams et al. 2006, Ciarniello et al. 2007, Milakovic et al. 2014), or ecological strata in which food abundance was estimated (McLellan and Hovey 2001, McLellan 2015). Habitat use analyses have been criticized for not using functional drivers as predictors, (Garshelis 2000, Beyer et al. 2010, Ayers et al. 2012), thus missing direct connections between habitats and population processes. Further, habitat use can be unlinked to real measures of population viability. For example some habitats that see a lot of use, may also be sink habitats where mortality rates are high (Nielsen et al. 2009). More recently, some studies are rectifying these shortcomings as better food models were developed (Nielsen et al. 2004). Recently food occurrence models and mortality risk have been integrated into analyses that use food models perhaps bringing closer the reality of comparing the functional variables that drive grizzly bear populations (Nielsen et al 2010, Braid and Nielsen 2015). McLellan (2015) did not use models but direct measures of foods and numbers and precise locations where radio-collared bears died and a spatial comparison to test the influence of factors influencing grizzly bear vital rates and population size. Nielsen et al (2010) considered both food and mortality risk in Alberta and recommend these more direct drivers be incorporated into habitat and populations studies. Nielsen et al (2010) found that food resources drove habitat selection and that mortality forces were required to understand habitat use at the population level. In contrast, McLellan (2015) found that food abundance along with bear density was far more important to reproductive rates and thus population trend than mortality even when comparing the area with the highest hunter kill density in BC to the adjacent portion of Glacier National Park, Montana where no deaths have been recorded since 1991. Ultimately, analyses to predict habitat use and explanatory covariates for density and trend will only be as accurate as the input data and how well they actually represent factors responsible for the processes that affect population density.

Here we develop several metrics for bottom up and top down factors to test their relative ability to predict within and between these realms. We do this in the context of several population processes in a spatial and causative context for grizzly bears in Southern British Columbia, Canada. That is, we model each process individually using functional bottom up and top down predictors to assess these relationships. Furthermore, we spatialize all variables processes for better integration into downstream management applications.

Specifically, we developed and evaluated a model for grizzly bears most important food resource in our focal area of southeast BC, black huckleberries (*Vaccinium membranaceum* primarily, McLellan and Hovey 1995, McLellan 2011, 2015) and brought it together with other habitat variables and factors that influence mortality risk in a series of models that predict several population processes. Those processes include female habitat selection, female home range selection, mortality, density, and reproductive success or fitness.

Our study focused on grizzly bears living in the south Selkirk and Purcell Mountains of southeast BC. We have previously completed both-sex all-season habitat use models to identify linkage corridors regionally (Proctor et al. 2015) that used surrogates for direct bottom up and

top down forces. As Nielsen et al. (2010) point out, to understand the real drivers of habitat use and population level processes it is important to include in modeling efforts the direct drivers of these processes, food resources and mortality factors. That is what this project attempted.
We asked a series of nested questions:

- Could we develop a huckleberry patch model that was more predictive of grizzly bear use than a huckleberry plant occurrence model?
- Which variables best predict several population processes?
- What was the relationship between bottom up or top down forces driving these process, which was more important for various population processes, or were they both important?

Within our study area, there has been little spatialization of food layers (Flathead Valley food have been mapped), mortality risk, or the population processes they drive, especially within southeastern BC with our extensively fragmented populations of concern (Proctor et al. 2012). Furthermore, we have limited understanding of how bottom up – top down drivers interact to influence habitat use, home range selection, density and fitness. This project explores these processes and spatializes our results with the hope of providing insight for wildlife managers. We hope to:
Discover where the highest quality habitats are, that contain the most important hyperphagia foods?
Where do bears die in the highest proportions?
Where and how might we manage habitats to combine habitat quality and security?
Where are grizzly densities highest and why?
And possibly most important, where and why do females reproduce successfully?

Other local considerations

It is likely that loss of productive low elevation habitats to human settlement has contributed to the threatened status of these populations (Creston Valley, North Arm Kootenay Lake, Kootenay River to Castlegar, Koocanusa Reservoir area south of Cranbook, Hwy 3 & 3A corridors - Castlegar to Cranbrook, Trail-Fruitvale area). Productive riparian habitat and kokanee fisheries have been affected in valley bottoms and spawning streams off Kootenay Lake that were important bear food resources. Riparian habitats are one of the important habitat types because many important spring and autumn bear foods are abundant in these areas (McLellan and Hovey 1995, 2001, Proctor et al. 2015). Many have been compromised by human settlement, highways, resource backcountry roads, and cattle grazing (Proctor et al. 2008, 2015). Therefore, most bears now rely on avalanche chute complexes for similar spring and fall foods (McLellan and Hovey 2001, Serrouya et al. 2011). In late summer, huckleberry patches are the most important locally. Fire suppression has likely had an important negative influence on the region's huckleberry production, as these plants usually produce abundant fruit in old burns (Minore 1975; Minore et al.1979, Hobby and Keefer 2010, McLellan 2015) and explains why these habitats are highly selected for by grizzly bears (McLellan and Hovey 2001). Also, timber harvest has played a role, sometimes positively in the creation of huckleberry habitat when forests are opened up, sometimes negatively by leaving extensive backcountry road networks to increase human access that sometimes degrade habitat effectiveness. Hydro development has likely contributed to the burgeoning human population in the region, likely contributing to the low elevation habitat displacement, and the fragmentation discussed above.

STUDY AREA

Our study area had 2 scales. First, was a finer-scale area where our GPS telemetry and genetic data were collected and huckleberry patch related field-site visits occurred in the South Selkirk, South Purcell, and Yahk areas (Fig. 1). This was also the arena for our population process modeling. Second, was the entire Kootenay Region 4 (Fig. 1) where we modelled and predicted huckleberry occurrence as a first step in this process, and then preliminarily applied our huckleberry patch model to initiate region-wide evaluation and patch model improvement.

The region is mountainous and predominately covered by conifer forests with patches of deciduous forest throughout. It consists of mountain valleys, upland forests, avalanche, riparian, and alpine habitats. The region is relatively wet with much of the annual precipitation received as snow in winter, especially at higher elevations. Summers can be somewhat dry and hot. The predominant ecosystem types are Interior Cedar Hemlock (ICH) at lower elevations, Englemann Spruce Sub-alpine Fir (ESSF) at higher elevations and Interior Douglas Fir (IDF) in the drier eastern portions. Elevations generally increase south to north in each mountain range within our study area. The timber industry operates generally throughout our study area except for a few provincial parks.

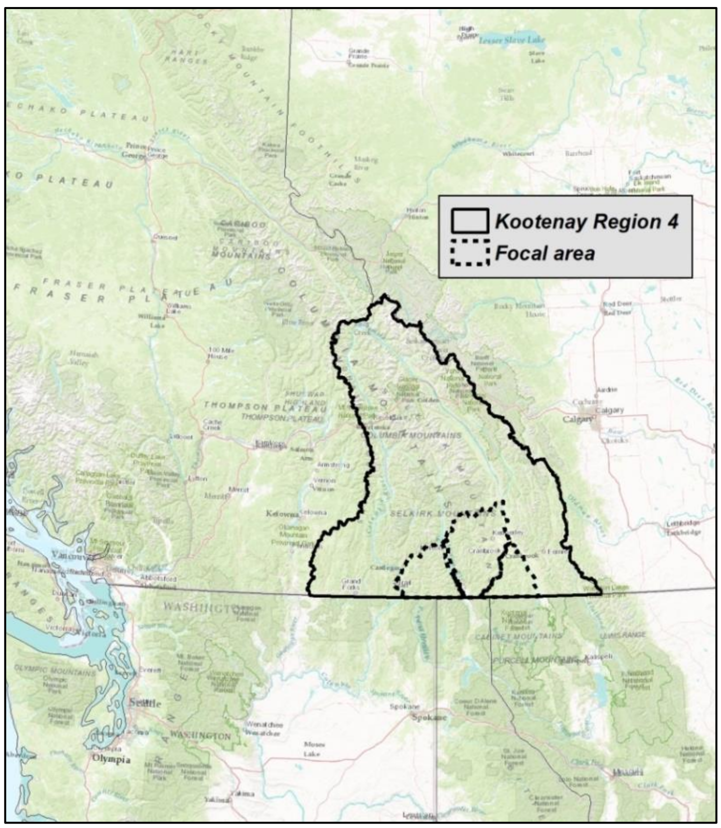


Figure 1. Location of huckleberry investigation in southeast British Columbia, Canada. The dashed line represents the focal region where we identified huckleberry patches through site visits of clustered locations of grizzly bear telemetry data. The solid line represents the boundary of the Kootenay region, where huckleberry occurrence was modeled and the huckleberry patch model was applied preliminarily. These data were used to develop a predictive model of huckleberry patches grizzly bears use that was eventually applied across the region.

METHODS

We describe methods for 3 components of this project.

- Huckleberry modeling, plant occurrence and patches important to grizzly bears
- A thorough huckleberry model evaluation that includes bottom up vs top down modeling for habitat use, home range selection, mortality risk, density, and fitness
- An assessment of our huckleberry patch model and the forest industry

Huckleberry modeling overview

We modelled huckleberries in 2 ways and tested for their relative predictability across several population processes (see below). First, we modeled huckleberry occurrence across the entire Kootenay region (Fig. 1) resulting in a map of where huckleberry plants occur. We modelled huckleberry occurrence from 10,129 ecological/vegetation plots that recorded the presence or absence of huckleberry plants during a program to classify the ecology of the region (Biogeoclimatic Ecosystem Classification (BEC) Program, Fig. 2).

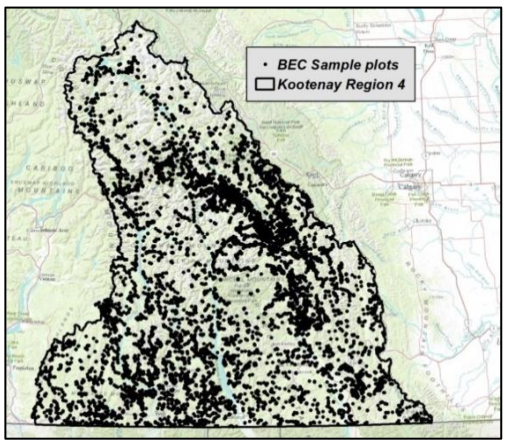


Figure 2. BC's Biogeoclimatic Ecological Classification system forestry plots across Kootenay Region 4 used to model huckleberry plant occurrence.

Second, we modeled huckleberry patches important to bears in our focal study area. We used the huckleberry patches used by bears that we identified through GPS telemetry research and field-site visits. Our ultimate goal was to test our focal area version of this model for predictability across several population processes and then extrapolate this model across the Kootenay Region 4 to identify huckleberry patches used by grizzly bears for future evaluation work of this regional model. Details of this process are described below.

Field site visits

We identified potential berry patches across our study area using our existing 10-year, 44 bears (20 female, 24 male) ~50,000 bear locations GPS telemetry data set to find habitat-use clusters during the berry season, July 15- Sept. 15 (Fig. 3). We had done a pilot test of this method and were quite successful at identifying berry patches. This methodology allows the bears to help us identify the location of important berry patches that they use. In the summers of 2014 and 2015 we visited 512 of the most promising of these habitat-use clusters to determine which ones were in fact huckleberry patches (Fig. 4a & b).

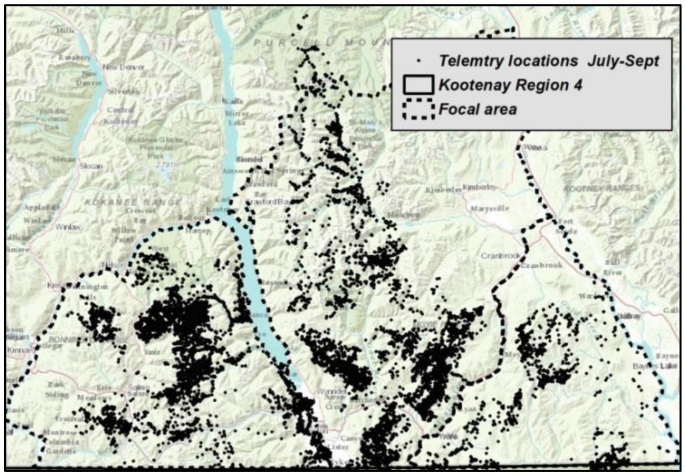
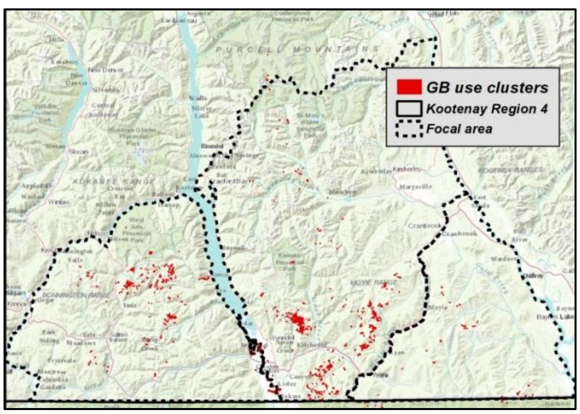


Figure 3. Map of our focal study area with berry-season both-sex grizzly bear GPS locations used to find huckleberry patches in the South Selkirk and Purcell Mts. of southeast BC.

a



b

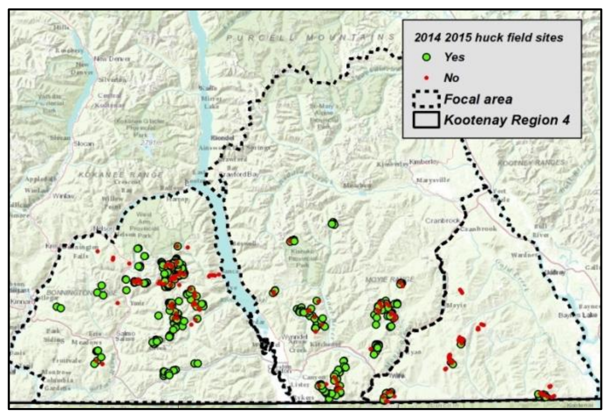


Figure 4. Map of our focal study area with **a)** summer habitat use clusters used to find huckleberry patches important to grizzly bears in the South Selkirk and Purcell Mts. of southeast BC and **b)** the same map with the results of ground truthing site visits. Green circles (Yes sites) indicate the site was a huckleberry patch used by bears. Red circles (No sites) indicate the site was not a huckleberry patch.

We collected relevant ecological data at each site consistent with data gathered in the provincial BEC program. We picked our plot centres to be in the middle of the best local huckleberry patch or, if it was not a huckleberry patch, where there was evident bear sign (e.g., root digs, bear bed), at GPS locations, or in a distinct ecosystem unit (e.g., site series or other ecosystem unit). For all locations sampled, we used the B.C. Government standard 20 m x 20 m plot. We dropped the full BC Government ecosystem plots (MoFR and MoE 2010) in 2015 in favour of the much quicker site assessment technique that we developed and also used in 2014. In this way, we were able to significantly increase the number of sites visited in 2015.

Following are the plot attributes we recorded:

Yes/No – Was it a huckleberry patch or not?
Description – A general description of the vegetation community, major indicator plants, major bear foods, and why a bear likely used area, if it did.
Biogeoclimatic Ecosystem Classification (BEC) zone, subzone, variant, and site series – Zone, subzone, and variant were based on regional BEC mapping. Site series was based on vegetation composition and site characteristics, regional BEC field guides, and our field experience in 2014.
Elevation – At the centre of the plot and read from a hand-held GPS in metres.
Slope – Percent slope gradient of the plot measured with a clinometer.
Aspect – Orientation of slope in degrees; "999" was recorded for level ground. Aspect was a fixed point measurement from the centre of the plot.
Mesoslope position – As per MoFR and MoE (2010), Site Description section, page 25.
Structural stage – As per MoFR and MoE (2010), Site Description section, page 21.
Site disturbance – As per MoFR and MoE (2010), Site Description section, page 27.
Canopy cover – Estimate of the percent tree canopy cover.
Huckleberry fruit abundance – As per MoFR and MoE (2010), Vegetation, page 17.
Huckleberry patch quality – A subjective assessment value between 1 and 10, where 1 was lowest quality & 10 was highest quality.
Huckleberry modal height – Measured height in centimetres.
Huckleberry cover – Estimated percent cover of black huckleberry.
Huckleberry fruit phenology – Recorded as “green”, “reddish hue, not quite ripe”, “generally ripe”, “overripe”, or “finished”.
Bear sign - Old or recent bear sign within or in the vicinity of the plot.

Environmental Predictors for huckleberry occurrence modeling

Environmental variables hypothesized to limit the occurrence of huckleberry (Table 1) include soil pH (Barney 1999; Barney et al. 2006), soil texture (Habitat Management Branch Province of BC 2000; Barney et al. 2006), climate (Holden et al. 2012), forest fires (Nielsen and Nielsen 2010), canopy cover (Minore 1984) and topography (Roberts et al. 2014).

We constructed ecologically meaningful derivations of all the hypothesized drivers of huckleberry occurrence mentioned above and produced spatial surfaces in 100- 300m resolutions across the entire study area for each predictor.

SOIL- Soil data was obtained from the BC government. These data are comprised of a categorical classification of soil type across the province as well as approximately 5,000 soil pits used to evaluate and refine these classifications. The soil pits include empirical information on the pH, texture, and composition of soil within each categorical soil type. We used the soil pits dug across the province to produce a spatial representation of the soils across the Kootenay region, including the pH, % sand, % silt, % clay, % coarse fragments and % organic matter of the soil. We only used the top 40 cm of each soil pit to derive our soil measures as we didn’t believe soils deeper than 40 cm would have a large effect on huckleberries, which are generally rooted quite shallow. In some cases, no soil pits were dug for specific soil types so we lacked empirical measures for this soil, which we remedied by interpolating information from similar soils across the province. We first classified the province into regions that shared the same biogeoclimatic zone (BEC), soil development type, and geologic parent material. We then calculated the soil characteristics for each region using soil pits from across the province and filled holes in our soil surface of the Kootenays with these data.

CLIMATE- We gathered climate variables using the Climate BC desktop application produced by the Centre for Forest Conservation Genetics at the University of British Columbia (http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna/#ClimateBC). Climate variables included Frost Free Period, Mean annual Temperature, Mean Summer Temperature, Mean Winter Temperature, Mean annual Precipitation, Mean Summer Precipitation, Mean Winter Snowfall. We produced a grid of points spaced 300 m apart in ArcMAP 10.1 (ESRI) and extracted the climactic information to these points using Climate BC, and then converted this information into a raster surface with a 300 m resolution.

FIRE- Spatial information on forest fires was acquired from the Wildfire Management Branch of BC (data from 1920-2014, https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=57060) and used to calculate time since last fire for each plot, and produce a time since last fire surface. We calculated time since last fire as the date the plot was conducted minus the date of the last fire that occurred prior to the plot being conducted. For our final map, we built a time since last fire surface across the region using 2015 as the current date and subtracting the date of the most recent fire from 2015. In many cases across the landscape a fire had not occurred (or not been recorded) in the last ~90 years, so we opted to bin the time since last fire variable into ecologically meaningful bins. We created 5 bins, 1) 0-20 years since last fire, 2) 20-50 years since last fire, 3) 50-80 years since last fire, 4) 80+ years since last fire, and 5) never burned.

CANOPY COVER- We gathered information on canopy cover from the Vegetation Resource Information data from the BC government and missing data was filled with cover information from industry partners.

TOPOGRAPHY – We calculated global radiation, compound topographic index (CTI) and slope using a digital elevation model and ArcMap 10.1.

Huckleberry Occurrence modeling

Records of huckleberry presence and absence were acquired from vegetation plots conducted by the Biogeoclimatic Ecosystem Classification (BEC) Program, which was a joint venture between the University of British Columbia and the Provincial Government of British Columbia. The project don classifying British Columbia into ecologically meaningful zones based on topography, geology, vegetation and climate. To quantify vegetation across the province, intensive sampling of vegetation plots was conducted, which we used to model huckleberry occurrence. Within the study area, 10,129 vegetation plots (30 x 30) were conducted within the region (Figure 1, study area map) between 1980 and 2013, of which, huckleberry was detected at 4,297 plots (~42% of sites).

Table 1. Environmental variables used to predict huckleberry patches used by grizzly bears. Full descriptions of each variable can be found in.

Abbreviation	Name
aspect	Aspect
Canopy_cov	Canopy cover
CMD	Hargreaves climatic moisture deficit (mm)
cofrag_utm	Coarse Fragments in soils
cti	Compound Topographic Index
DD5	Degree-days below 5°C
FFP	Frost Free Period
fire_cnt	Number of fires in a region since 1900
globlrad	Global radiation
Last fire binned	Time since last fire binned into 5 categories
MAP	Mean Annual Precipitation
MAR	Mean annual solar radiation (MJ m-2 d-1)
MAT	Mean Annual Temp
MCMT	Mean coldest month temperature (°C),
MSP	Mean annual summer (May to Sept.) precipitation (mm),
MWMT	Mean warmest month temperature (°C),
NFFD	Number of frost-free days
orgcarp	Organic carbon % in soils
PAS	Precipitation as snow
PAS_wt	Precipitation as snow (Winter)
ph2	Soil ph, dissolved using water
phca_utm	pH of soils
PPT_sm	Precipitation in Summer
SHM	Summer heat-moisture index
slope	Slope
Tave_wt	Average Temperature- winter
tcaly_utm	% clay in soils?
tclay	Clay % in soils
Tmax_sm	Maximum Temperature - summer
Tmin_sp	Minimum Temperature - spring
Tmin_wt	Temperature Minimum - winter
tsand	Sand % in soil

Huckleberry Patch Modeling

For both occurrence and patch modeling we used boosted logistic regression trees (Elith et al. 2008) and functional environmental response variables (Table 1) to discriminate between the huckleberry patches used by grizzly bears and the available huckleberry shrubs across the landscape. Boosted Regression Trees (BRT) are an advanced form of a generalized linear model (GLM) and are increasingly used by ecologists, although they have been used in other fields for much longer (Elith et al. 2008). GLM's use individual covariates as terms in a model, whereas BRT's build regression trees (models that relate a response to their predictors by recursive binary splits) and use these trees as terms in a GLM framework. In a BRT, many trees are fit to the data, where an initial tree is fit to the data such that it correctly classifies as many observations as possible and subsequent trees focus on classifying those observations poorly predicted by previous trees (Shirley et al. 2013).

BRT's were well suited to our application as this method could handle the complex, non-linear relationships we expected to find with these data, and BRT's are known to provide greater predictive performance than GLM's (Elith et al. 2006). In addition, compared to GLM's, BRT's do not face the same issues when fitting models with multicollinearity between predictors because trees are fit with recursive partitioning algorithms instead of matrix inversions (Shirley et al. 2013).

To fit the BRT we used the 'gbm' package (Ridgeway 2015) in Program R (R Core Team 2016). Another advantage of BRT's is that a priori model definitions are not required. Instead BRT's fit the meaningful ecological variables included to the data, and those variables that predict poorly do not affect results as these variables contribute very little to the model predictions. However, these variables that contribute little to model predictions can be removed from the model using a k-fold cross-validation and iteratively removing variables until an optimum is achieved.

A BRT is fit to data using three main parameters 1) Learning rate: the contribution of each tree to the model. Smaller learning rates result in relatively more trees required to fit the model, with each tree contributing a relatively small amount to the predictions providing a better fit of the model to the data. In general, a lower learning rate is preferred, such that at least 1000 trees are generated (Elith et al. 2008). 2) Tree complexity: The number of nodes or splits allowed in each tree, where trees with more nodes are more complex, and 3) Bag fraction: % of data used to train (those data used to build the model) and testing (data used to test predictions that were not involved in model creation) the model for each iteration (new tree).

We tested a number of learning rates (2,4,6,8) and tree complexities (0.0005,0.001,0.01) and selected as our top model, the model that minimized predictive deviance (Elith et al. 2008). Because we sampled more than one site in some clusters to produce an accurate representation of that cluster, we weighted observations inversely to the number of observations in each cluster, such that clusters with many samples were not over-represented in the data. Finally, we simplified our model using k-fold cross validation to remove uninformative parameters.

Using the gbm package, we calculated the relative influence of each predictor for producing huckleberry patches used by grizzly bears, and the marginal effect of each predictor across it's range.

Spatial projections of huckleberry models

Because the logistic regression formula provides a continuous occurrence probability between 0-1, a cut off value was generated where predicted values larger than the cut off were considered to be a presence and smaller values an absence. Cut point values were calculated for the huckleberry model by determining the cut point value where the product of sensitivity and specificity are maximized, which is also analogous to minimizing the distance between ROC curve and point 0, 1 on plot. Predicted values from the logistic regression greater than the cut point value are consider to be huckleberry presence and values less than the cut off to be absences.

In addition, species presence rarely translates to sufficient berry presence to be attractive to grizzly bears. Therefore, we applied a canopy cover rule where occurred sites with less than 50% forest canopy cover were considered to have fruit producing shrubs (Nielsen et al. 2004*b*) while occurred sites with greater than 50% canopy cover were considered to be absent of fruit, or have fruit densities below what is biologically meaningful to bears. Further, we constrained the prediction only to areas where huckleberry occurs using the occurrence predictions. These refinements allowed us to test this model against the clustered GPS locations we visited and rated as potential huckleberry plots (described above).

An occurrence surface was generated for fruit-producing huckleberry using Program R and the best fit occurrence model for that species in combination with the canopy cover rule.

Mortality risk modeling methods

Mortality risk modeling was done with methods similar to those of Proctor et al. (2015) and for female habitat use modeling described below. Input variables included the full complement of predictor variables we used for our habitat use models described below, including human disturbance variables that have been shown to influence human-caused mortality (Nielsen et al. 2004*b*). Our database is a combination of bears killed (149) while wearing a radio collar and reported mortalities including management kills, a few illegal kills, and vehicle kills. We tried to verify locations as well as possible. Our Canadian database is skewed towards reported mortalities and therefore doesn't perfectly represent the spectrum of unreported mortalities.

Model Evaluation

Huckleberry occurrence model

Models were evaluated using the receiver operating characteristic (ROC) and the area under the ROC curve (AUC, Pearce and Ferrier 2000). The AUC is a measure of the discriminatory power of the model, and is interpreted as the probability of correct classification of the binary (1, 0) response variable. AUC values of 0.5 represent the same discrimination as a random guess, values >0.7 and <0.9 represent good model accuracy, and >0.9 represent high model accuracy (Nielsen et al. 2005). To calculate AUC, testing data (those data not used to build the model) were substituted into the model and the model predictions were evaluated by comparing the "predicted" and "true" values for each presence/absence. This process was repeated 100 times with randomly drawn training and testing data and resulting AUC values averaged. We also tested our huckleberry occurrence model against our patch model across several population processes to see which was more predictive (see details below).

Huckleberry patch model

We evaluated our best huckleberry patch model in a number of ways. First we examined how well it predicted the data that were used to develop the model with the ROC AUC score (as above). Then we tested how well the huckleberry patch model was influential in predicting a series of population characteristics and processes in the context of multivariate modeling exercises with other competing variables. Specifically, we wanted to see how well our huckleberry model competed with a spectrum of influential variables in the context of a bottom up (our huckleberry model) vs top down (mortality risk) approach, within a suite of other predictive habitat variables. This entailed looking at female habitat use, home range selection, female and both sex density, and fitness, or spatialized female reproductive success. Below we describe these various approaches.

Partitioning Field-Truthed Data - When fitting models to data with many predictor variables over fitting is always a concern (Serrouya et al. 2011). We sought to reduce and assess over fitting so that our predictions represented the general trends in the data, and thus the ecology we were attempting to elucidate, instead of a detailed description of these data that was not general. To do this we partitioned our data into training (bag fraction= 60%, those data used to build the model) and testing data (40%, data used to test predictions that were not involved in model creation) for each iteration (new tree). We used the testing data and model predictions to calculate predictive accuracy using the area under the receiver operating characteristic curve (ROC AUC), which represents the probability of correct classification (in our case as either an available or used point). A model that predicts well on data not used for modeling (typically ROC AUC >0.7) represents a model with general predictive performance on the data considered.

Hybridizing Ground-Truthed and Expert Patches

To further test the generality of our model we collected locations of huckleberry patches known to be used by grizzly bears outside of our focal area. We compared the locations of known patches to those predicted by the huckleberry patch model developed using the south Purcell and Selkirk data. We then experimented with including the known patches in our "used" set of response variables to produce a more general, region-wide model.

Evaluation with female habitat use modeling and home range selection

Because females are the reproductive engine of a grizzly bear population (Eberhart et al. 1994, McLellan 1989, Garshelis et al. 2005. Mace, et al. 2012) we focused on female berry season habitat use (July 15- Sept 15) when hyperphagia is in full swing allowing fat deposition important for reproductions and hibernation (Robbins, et al 2012, McLellan 2011, 2015). For these same reasons we also focused on female home range selection, density and fitness,

Habitat use (Female berry season, July 15 – Sept. 15)

We developed sex-specific Resource Selection Function (logistic regression) models to determine, explain, and spatialize female habitat-use across our multi-mountain range study area (Boyce and McDonald 1999, Manly et al. 2002, Nielsen et al. 2002). One of our goals was to explore the relative influence of individual variables within our multivariate models at 2 levels, within bottom up and top down variables and the between these categories. Bottom up variables we were testing consisted of our huckleberry occurrence and patch models, other habitat use variables that we found to be predictive in previous efforts (Proctor et al. 2015), including greenness, canopy openness, riparian and alpine habitats (see descriptions below). Top down variables included road presence and absence, distance to roads, road density, human access (see details below), and a composite mortality risk layer we developed. These variables were also used/tested in the density and fitness modeling process describe below.

Our first level of test, was whether or not any of these variables made it through our model selection process (described below) into our best model. Then we tested for relative importance of all variables within those best models. To determine the relative importance of each variable in our best models, similar to Schwartz et al. (2010), we removed each variable, one at a time, and reran the model to determine the change in predictability. We used the log likelihood as our measure as it underpins that AIC model selection routine. Input data came from our 10-year GPS telemetry data base that were compared to random points (available). Data were subsampled to equalize the influence across bears.

Grizzly Bear GPS Location Data

We deployed GPS-telemetry collars on 27 female grizzly bears in 2004–2015. We captured bears with Aldrich foot snares and occasionally with culvert traps. In Canada, our bear handling procedures were in accordance with the Canada Council on Animal Care Standards. We used Telonics Inc. (Mesa, AZ) Spread Spectrum radio-collars (and occasionally store-on-board collars) and remotely downloaded bear locations on a periodic basis.

To maximize our spatial coverage with our sparse density of bears (Proctor et al. 2007, 2012), we balanced collaring effort between trapping in areas with high bear use and thus high likelihood of captures, areas where low densities constrained trap success, and areas accessible by road. Fortunately, many bears have large home ranges which helped us attain broader spatial coverage.

Most of our collaring was May or June and we monitored them for 1–3 years with monitoring usually spanning at least 2 non-denning periods (i.e., spring summer, fall). The collars were programmed to collect locations every 1–4 hours depending on collar size (smaller bears carried smaller collars with less battery life) and age of bears (subadult bears carried collars designed to drop off earlier so as to not interfere with neck growth). Because we used only 2D and 3D fixes, overall fix success (the proportion of 2D and 3D fixes relative to fix attempts) was 84%. Mean positional dilution of precision (PDOP) was filtered for values <10 to improve accuracy (Lewis et al 2006), and our mean value was 3.9 (SE = 0.018) for all 2D and 3D locations. Our final dataset had an average of 8.7 locations per day per bear across the non-denning (active) period. We also assessed potential location bias for canopy closure, which was the variable with the most potential for low fix success rate (Frair et al. 2004). We placed 13 GPS radio collars at ground level in conifer forest with canopy cover from 0 to 75% canopy and found no relationship between fix rate and canopy closure ($R^2 = 0.07$; regression significance, $P = 0.64$).

Because unequal observations among animals can lead to biased population-level estimates (Gillies et al. 2006) and most bears had 500–1,000 berry season locations (July 15 – Sept. 15), we used a maximum of 1,000 locations from all bears by removing every nth location from any 1 bear with >1,000 locations. We also used data from 10 bears with <500 locations to maximize our spatial coverage and the number of different animals in the dataset.

Habitat use modeling

We used modeling techniques very similar to those published in Proctor et al. (2015). We compared ~12,000 summer GPS locations (use) from 27 bears to 20,250 random points (available) generated within GIS. We divided grizzly bear GPS telemetry data into 2 groups. We used an 80% random sample for model training, and withheld the remaining 20% of bear locations for model evaluation (Boyce et al. 2002, Nielsen et al. 2002). We used a *k*-fold cross evaluation method where $k = 5$ (Boyce et al. 2002) partitioning the data into 80% - 20% 5 times.

We estimated the parameters of the exponential RSF using logistic regression (Manly et al. 2002) and transformed predictions from the RSF using the logistic function to normalize the right skewing of exponential RSF values, and then mapped predictions at a 100-m scale in ArcGIS 10.1 (ESRI, Redlands, CA). We performed logistic regression using the statistical software package STATA (Intercooled 9.2, College Station, TX). Model building was based on the principles of Hosmer and Lemeshow (1989) and more recently referred to as purposeful selection of variables (Bursac et al. 2008). We tested all predictor variables for pairwise correlations (Chatterjee et al. 2000) and only terrain ruggedness and compound topographic index were correlated and therefore not used in the same model during the stepwise process. We fit all variables and their quadratic relationships individually (uni-variable analyses) and ranked them for their explanatory power (pseudo R^2) and significance. We then built multi-variable models by adding non-correlated variables in a forward stepwise fashion starting from higher to lower pseudo R^2. We compared models sequentially by explanatory power (pseudo R^2) after each variable addition to decide if a variable improved model predictability. When a variable increased the pseudo R^2 by at least 5%, we retained that variable in the model; when a variable increased the pseudo R^2 <5% we did not retain it to favor a parsimonious model. To ensure that final variable selection was not unduly influenced by the order of variables added to the model, we also applied a reverse stepwise model procedure.

We used the Huber-White sandwich estimator in the robust cluster option in STATA to calculate standard errors because non-independent locations can lead to biased standard errors and overestimated significance of model parameters (White 1980; Nielsen et al. 2002, 2004*c*). Because the bears were the unit of replication, we used individuals to denote the cluster, thus avoiding autocorrelation and/or pseudo-replication of locations within individual bears

Environment Variables (Habitat, mortality, density and fitness modeling)
We used variables that were most consistently measured across the study area including human-use, terrain, forest cover, and other ecological variables (Table 1). Ecosystem characteristics and human uses in the adjacent south Selkirk and south Purcell Mountains are similar (Meidinger and Pojar 1991) allowing development and prediction of models to these areas. Lowlands are dominated by cedar–hemlock (*Thuja plicata–Tsuga heterophylla*) forests and upland forests are dominated by Engelmann spruce–subalpine fir (*Picea engelmannii – Abies lasiocarpa*). Douglas fir (*Psuedotsuga mensiezii*) forests are somewhat more common in the southern portions of the Purcell range (Meidinger and Pojar 1991). Human uses are relatively similar across the region and include timber harvest, some mining, ungulate hunting, and other forms of recreation. Grizzly bears were not hunted in the South Selkirk and Yahk portion of our study area as they are is considered to be "threatened" (Hamilton and Austin 2004), but the South Purcells, north of Highway 3 had some open grizzly bear hunting areas.

Habitat variables
We used our huckleberry patch models (occurrence and patch) described above to represent direct food resources grizzly bears use regionally. We tested for the influence of huckleberry patch size by developing 3 patch variables, one with all size patches, another filtered for patches >5ha, and another all patches >10 ha. We also tested these versions of the huckleberry patch model as a distance to huckleberry patches and as huckleberry patch presence.

We then included a suite of potential predictor variables used by Proctor et al. (2015). We obtained baseline thematic mapping land-cover variables (recently logged, alpine, avalanche, and riparian), vegetation resource inventory variables (dominant tree species forest cover types, canopy cover) from the BC Ministry of Forests, Lands, and Natural Resource Operations in Canada. Alpine, avalanche, burned, and riparian habitats contain a variety of grizzly bear food resources (McLellan and Hovey 1995, Mace et al. 1996, McLellan and Hovey 2001, Proctor et al. 2015). We used forest cover variables (Table 2) because they often have been found to influence grizzly bear habitat selection (Zager et al. 1983, Waller and Mace 1997, Apps et al. 2004, Nielsen et al. 2004*a*). Greenness, an index of leafy green productivity, correlates with a diverse set of bear food resources and is often found to be a good predictor of grizzly bear habitat use (Mace et al. 1996, Nielsen et al. 2002, Proctor et al. 2015). We derived greenness from 2005 Landsat imagery using a tassled cap transformation (Crist and Ciccone 1984, Manley et al. 1992). We derived terrain variables of elevation, compound topographic index (CTI), solar radiation, and terrain ruggedness from a digital elevation model (DEM) in ArcGIS. The CTI is an index of soil wetness estimated from a DEM in a geographic information system (GIS) using the script from Rho (2002). We estimated solar radiation for the summer solstice (day 172), using a DEM, and the ARC macro language (AML) from Kumar (1997) that was modified by Zimmerman (2000) called shortwavc.aml. Finally, we estimated terrain ruggedness from the DEM based on methods from Riley et al. (1999) and scripted as an ArcInfo AML called TRI.aml (terrain ruggedness index) by Evans (2004). These terrain variables have been shown to influence the distribution of grizzly bear foods (Apps et al. 2004; Nielsen et al. 2004*b,* 2010) and also affect local human use. We included elevation as a variable because grizzly bears in our region use high country extensively, which may be for a variety of reasons (e.g., high elevation habitat types, thinner forest cover with more edible ground-based vegetation, human avoidance).

Human disturbance variables

We used backcountry resource roads (i.e., associated with timber harvest, mining) from the BC Ministry of Forests, Lands, and Natural Resource Operations in Canada in various forms including road presence/absence, distance to roads, and road density. Distance to the nearest roads was derived within GIS as was road density through the use of a moving window and recorded in km/km^2. We digitized highway and human developments from 1:50,000 topographic maps and ortho-photos (Table 2). We buffered highway, human developments, and backcountry roads by 500m on either side to reflect their influence on grizzly bear habitat use (Mace et al. 1996). The human-use variables have been demonstrated repeatedly to correlate with habitat selection by grizzly bears (Mace et al. 1996, 1999; Nielsen et al. 2002; Apps et al. 2004). We included a human access variable develop by Apps et al. (2004) and improved by Apps et al. (2016). This variable was developed using a decay function over travel distance from human populations centres weighted by size, in and adjacent to our study region over the open road networks that included front and backcountry forestry roads. We also tested the mortality risk model developed within this project (see Mortality Risk Modeling Methods).

Female home range selection

We carried out a female home range selection analysis, essentially asking the question: how do bottom up vs top down variables influence home range selection? This analysis compared home range characteristics of our collared female sample between 95% kernel home ranges (KHR, clustered areas of concentrated use) with Minimum Convex Polygons (MCP a larger coarser home range descriptor) and ecosystem-wide characteristics. This was a computationally simple analysis as we measured the habitat characteristics within GIS within the 2 types of home range (MCP & KHR) and compared them to each other using t-tests, and then compared them to ecosystem wide values for compared characteristics. The comparison between the MCP and KHR provided insight into habitat displacement. Were bears avoiding, or being displaced from, certain habitat characteristics within their MCP home ranges? We found a pretty strong pattern, that is every female used habitat that contained lower road densities within their smaller KHR than was available in their larger MCP home range. It is possible that all that habitats away from roads contained more foods, but the fact the every female showed this pattern suggests that some level of road avoidance was occurring. The comparison between KHR and ecosystem averages provided insight into both habitat displacement and potentially survival, as a mechanism of habitat selection. In other words, female bears may be surviving better in habitats with certain characteristics (e.g. such as habitats with lower high road densities as per Schwartz et al. 2010, Boulanger and Stenhouse 2014).

Top down, human disturbance variables we measured included road densities, human access, and the proportion of area in individual female home ranges that were >500m from an open road. Bottom up habitat variables included our bear huckleberry patch model and our best multi-variate female summer habitat use model that included a combination of huckleberry patches, greenness, riparian, road densities, and a combination variables between huckleberry patches x distance to road where bears were selecting huckleberry patches further from roads.

Table 2. Description and data ranges of predictive variables used to develop a multi-variable resource selection function model of summer female grizzly bear habitat selection, female and both sex density, and spatialized reproduction success (fitness) in the South Selkirk and Purcell Mountains of southeastern British Columbia.

Variable category	Variable	Units	Data range
Forest cover			
	Canopy openness	Percent	0–100
	Recently logged	Categorical	0 or 1
	Lodgepole pine	Categorical	0 or 1
	Douglas fir	Categorical	0 or 1
	Spruce-fir	Categorical	0 or 1
	Deciduous	Categorical	0 or 1
Forest age class			
	0-20 years	Categorical	0 or 1
	20-60 years	Categorical	0 or 1
	60-80 years	Categorical	0 or 1
	80-100 years	Categorical	0 or 1
	100-250 years	Categorical	0 or 1
Land cover			
	Alpine	Categorical	0 or 1
	Avalanche	Categorical	0 or 1
	Riparian	Categorical	0 or 1
Ecological			
	Greenness	Continuous	0.002–0.997
	Elevation	m	271–3,732
	Terrain ruggedness	Unitless	0–1,008
	Wetness (CTI[a])	Unitless	3.4–27.2
	Solar radiation	kj/m^2	218–29,494
Food resources			
	Huckleberry patch	Categorical	0 or 1
	Huckleberry patch >5ha	Categorical	0 or 1
	Huckleberry patch >10ha	Categorical	0 or 1
	Distance to Hpatch	km	0-12
	Distance to Hpatch >5ha	km	0-12
	Distance to Hpatch >10ha	km	0-12
	Huckleberry plant occur	Categorical	0 or 1
Human			
	Highway	Categorical	0 or 1
	Human development	Categorical	0 or 1
	Forest roads	Categorical	0 or 1
	Distance to road	km	0 - 25
	Road density	Km/km^2	0-5
	Human access	Unitless	0-32000

[a] compound topographic index.

Independent model evaluation using DNA data collected on grizzly bears

Density (Both sex and female only)

To further explore the relationship between bottom-up and top-down forces we reanalyzed the results from 6 DNA-based abundance survey previously reported in Proctor et al. (2007, Fig. 5). This improved analysis allowed for inferences that would be much more relevant to bear ecology, conservation, and management. DNA surveys consisted of a systematic grid of scented sampling sites. Sampling sites are a barbed-wire corral that sampled a bear's hair as they investigate the scent (Woods et al. 1999). The hair follicles were a source of DNA used to genetically identify individuals. Capture histories of bears across 4 sampling sessions informed a mark-recapture abundance estimate. We used abundance estimates from Proctor et al. (2007) as our primary focus was not the absolute density values (as those estimates are currently over 10 years old) but the explanatory analyses to understand the relative influences of bottom-up and top-down forces. These data were published within a larger regional wide analysis in Apps et al. (2016), but not in the context of bottom up vs top down variables as we carried out here. Our current analysis was designed to test hypotheses about competing forces of population processes related to conservation.

Extrapolation of abundance estimates to density entails using the logistic regression to compare ecological and human use variables at DNA sampling sites that detected bears to those that did not (Apps et al, 2004, 2016). We used our best the logistic regression resource selection function models to extrapolate abundance across the area. Our modeling techniques were very similar to Proctor et al. (2007 and 2015) including purposeful selections of variables to develop a suite of competing models that were compared using AIC model selection methods (Burnham and Anderson 1998). Models with a ΔAIC value less than 2 were considered the best representations of the data.

Predictor variable data were scaled (similar to Apps et al. 2004 & 2016 and Proctor et al 2007). because our response data, detected bear presence at DNA sites spaced 1/25-50km^2, cannot represent the habitat areas used by any particular animal, it is often 1-4 capture points within their home range. To make the predictor relevant to those thinly sampled bears, we averaged the value of each predictor's values around each pixel (100x100m cells of area) across a larger area. These scaled data are then the predictor inputs for a logistic regression. First, we scaled predictor data at a 3 km radius to reflect an area that a bear likely uses in 1 day. The second scale was a radius of 8 km approximately the mean female home range size for our area as our main focus here is female grizzly bears. Models were evaluated using the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) scores. Models with ROC AUC scores > 0.7 were considered predictive.

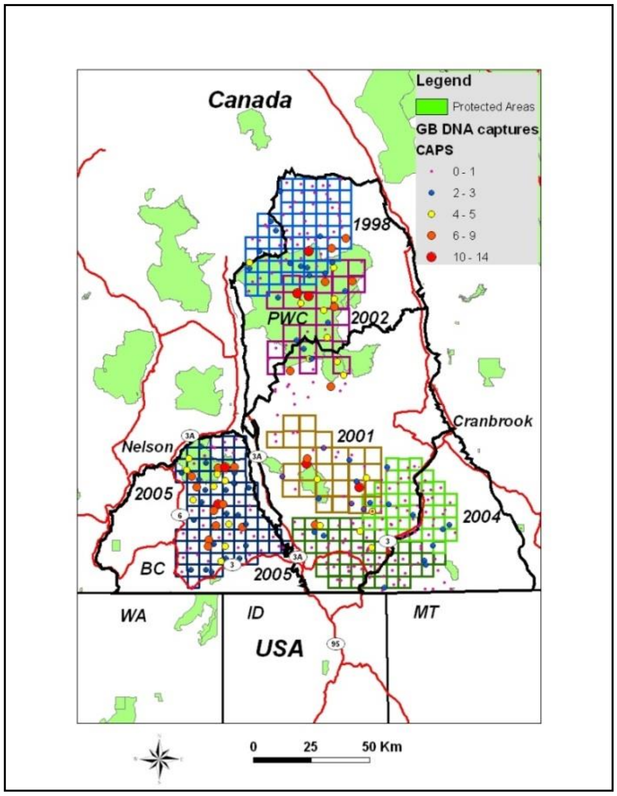


Figure 5. DNA surveys between 1998 - 2005 where capture data has been re-analyzed for an exploration the relative influence of bottom up vs top down predictor variables.

Female reproduction (fitness)

And finally, we carried out an analysis of the driving variables for female reproductive success, or fitness. This analysis was a logistic regression similar to the density analysis described above but with using the locations of all detected reproductive events (79 mother-offspring events) compared to random points across the study area. Mother-offspring events were identified using 21 locus microsatellite genotypes (DNA fingerprints) where we only used mother-offspring relationships that were determined by identification of a perfect triad family group – mother-father-offspring. Perfect family group triads occurred where the offspring shared an allele with each the mother and father and the mother's and father's allelic contribution to the offspring were complementary. We also developed 2 predictive models for the fitness analysis, one at the daily movement scale (3 km) and the other at the average female home range scale (8 km). As in our density modeling, we used purposeful selections of variables as in Proctor et al. (2015), and developed of suite of competing models that were compared using AIC model selection methods (Burnham and Anderson 1998). Models were evaluated using ROC AUC scores. Models with ROC AUC scores > 0.7 were considered predictive.

In the above analyses (female habitat use, density and fitness) the primary goal was to determine the relative influence of bottom-up and top-down forces on each process. We primarily used multi-variable logistic regression analysis methods. In all modeling arenas we compared competing models using a combination of purposeful model selection (described above) and AIC model selection methods (Burnham and Anderson 1998) using models with various combinations of our best predictor variables. The AIC model selection method allowed us to infer the relative important of variables within our best models. As our primary goal was to understand the relative influence of bottom-up and top-down forces of various population processes, we used model building techniques designed to yield the best model in a multi-variable context. That is, we wanted to see what the most significant driving variables were, and then see their relation to each other within that multi-variable universe. Winning multi-variable models (that were most supported by the data) were examined for the relative influence of each contributing variable by removing just one variable (one at a time), and comparing the resulting model's log likelihoods, the measure used to compare predictive ability as per Schwartz et al. (2010). Models with higher log likelihoods account for more of the variation in the data and are considered more predictive. Variables that do not increase the log likelihood significantly were not included in winning models. So, removing variables that lowered the log likelihood the most were deemed the most influential in a multi-variable context. We spatialized all resulting Best Models within GIS. When analyses used models developed at both the daily movement (3km) and female home range (8km) scales, spatialization was the 2 Best Models for each scale averaged in GIS.

Huckleberry patches and forestry

We used our final huckleberry patch model and field site visit results to assess the relationship of timber harvest and huckleberry patches important for grizzly bears.

We developed a target image of where future potential huckleberry patches might develop with the appropriate site conditions and harvest protocols. First we applied the best huckleberry patch model across the entire region and looked for underlying ecological, climate, soil and topographic conditions that were conducive to huckleberry patch development and simulated opening the canopy, through timber harvest or fire, inside and outside of the timber harvest operability zone. This resulted in a future predictive huckleberry patch map where underlying site conditions might focus activities that open the canopy.

Second, we attempted to translate the results of our site visit data into the BC Biogeoclimatic Ecological Classification (BEC) language so as to be more relevant and understandable to foresters. We did a statistical comparison of sites with and without huckleberry patches to find patterns in influential variables around disturbance and timber harvest. We also subcontracted a BEC specialist who also knows grizzly bears to link our huckleberry patch predictions and site visit data to the BEC system (See APPENDIX I)

Third, we explored cut block data from provincial records and more detailed records within the Nature Conservancy Canada's Darkwoods property which has been harvested for many decades that also has many huckleberry patches. Here we looked for patterns in factors that might influence huckleberry production, including type of disturbance, clear cut, selective cut, planting, slash burning, time since disturbance, fire (not slash burn), shrub cover, herb cover, and canopy cover.

RESULTS

In the summers of 2014 and 2015 we visited 512 of the most promising habitat-use clusters to determine which ones were in fact huckleberry patches (Fig. 4a & b).

Huckleberry occurrence model

Our BC plot-derived model predicted huckleberry occurrence very well with an ROC AUC value of 0.87 [0.866-0.870, 95% CI's], representing a very accurate model with a high probability to correctly assign presence/absence (Fig. 6a). To our knowledge this is the most predictive model of huckleberry occurrence for the Kootenay region. Our model may be more predictive than others as we were unable to find models of huckleberry occurrence in the literature with higher predictive accuracy than ours (max=0.79, Nielsen et al. 2010; Roberts et al. 2014). We believe this difference is rooted in the use of soil variables, which are strong drivers of huckleberry occurrence (Barney 1999; Barney et al. 2006), yet have not been previously incorporated into landscape-level predictions for this species.

Precipitation as snow dominated the variables for influence in our top huckleberry model followed by mean annual precipitation, canopy cover, maximum summer temperature and elevation in order of influence (Fig. 9b).

To produce a spatial representation of the occurrence of this species we calculated an optimal cut point at an occurrence probability of 0.48, and also applied a 50% canopy cover rule. As a result, all occurred pixels had to have a predicted probability of occurrence >0.48, and be under <50% canopy cover.

a b

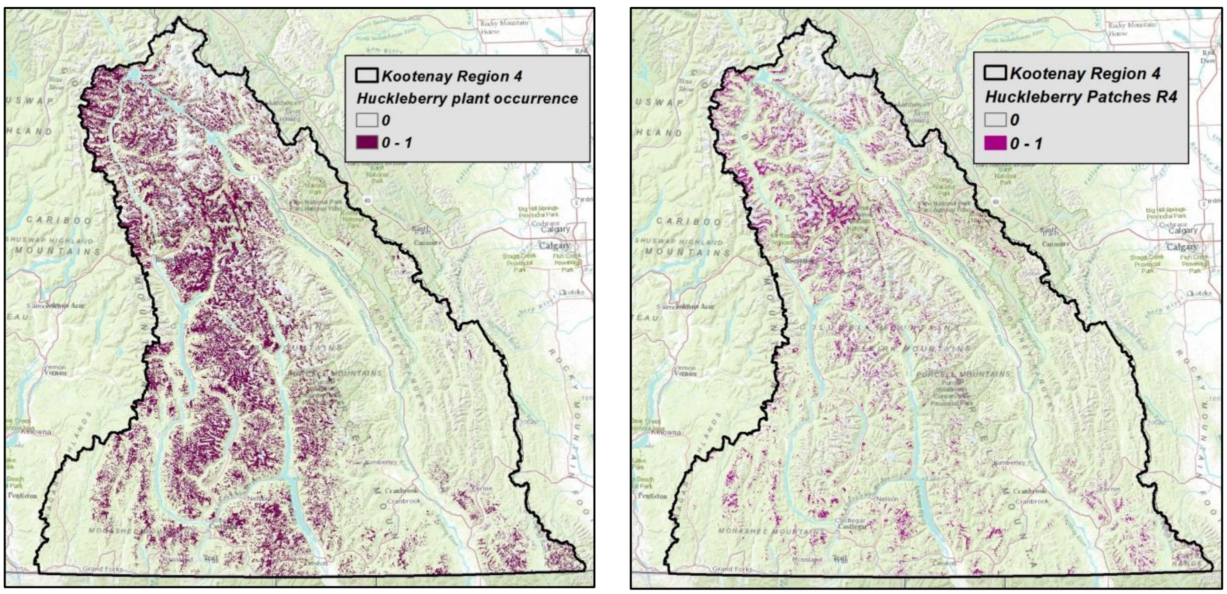


Figure 6a. Predicted occurrence surface of fruit producing huckleberries across the Kootenay Region 4. Sites with huckleberries had a >0.48 probability of occurrence and <50% forest canopy cover, and b) predicted huckleberry patches-important-to-grizzly-bears surface across the Kootenay Region 4. The huckleberry patch surface (b) is a smaller subset of the occurrence model (a), suggesting that patches that grizzly bears use, need to be more productive in terms of huckleberries and energy to build fat reserves for reproduction and hibernation.

Huckleberry patches important to grizzly bear model

Predictive success for our top huckleberry patch model (learning rate = 0.001, tree complexity = 8, predictive deviance = 0.27, was high; ROC AUC = 0.86 (95% CI: 0.83 - 0.89, Figs. 6b & 7). Top five predictors were, in decreasing importance: 1) canopy cover, 2) coarse fragments in soil, 3), slope, 4) precipitation as snow in winter, and, 5) average annual radiation (Fig. 9). Overall we see that area of low canopy cover, low angle slope, few coarse fragments in soil, north and east aspects, as well as high winter snowload produce huckleberry patches important to grizzly bears (Fig. 9 & 10). Berry patch predictions (Fig. 7a) were also strongly associated with summer female GPS locations (Fig 7b) and reasonably associated with a previous both-sex, all season habitat use prediction to underpin identifying linkage corridors from Proctor et al. (2015, Fig. 11).

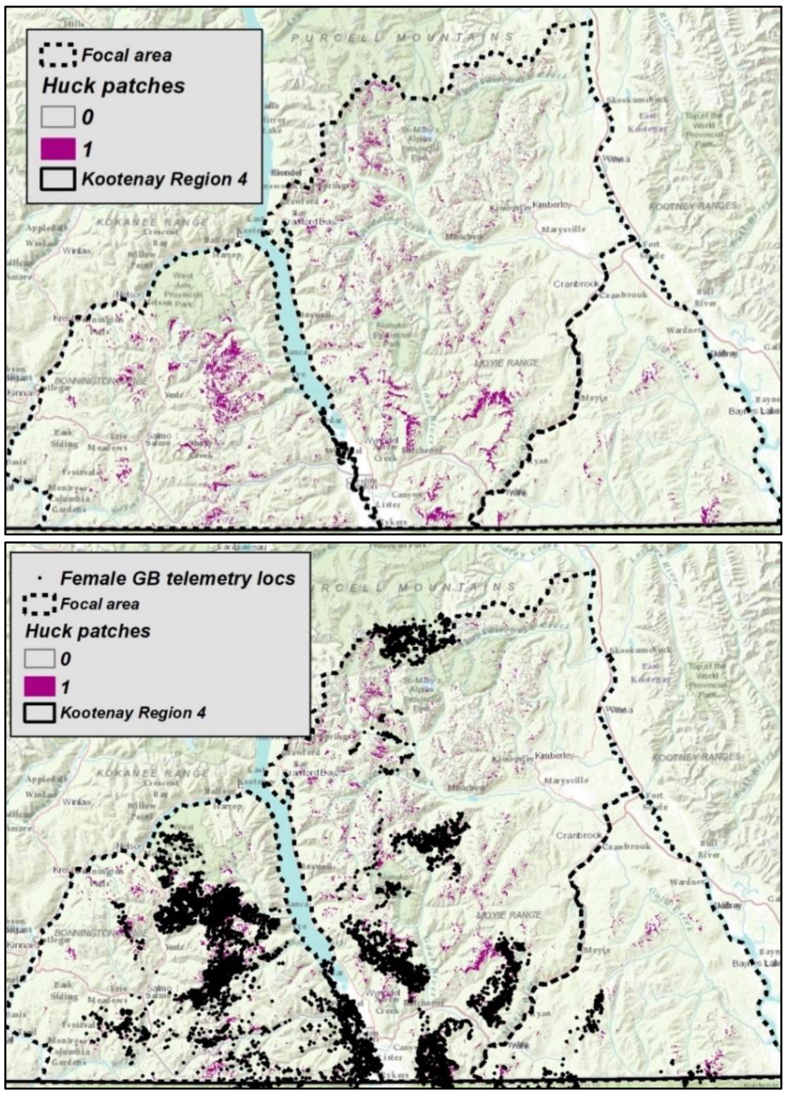


Figure 7a) Predictions of huckleberry patches important to grizzly bears in the South Selkirk and Purcell Mts. of southeast BC, **b)** the same map with summer female GPS locations.

Hybridizing Ground-Truthed and Expert Patches

Including the 23 known patches as "used" locations in our model produced similar predictive accuracy for testing data. As expected this model better predicted known patches (as they were included in model development), such that the BRT model that included the known patches as well as the south Selkirk and Purcells data correctly predicted the occurrence of known huckleberry patches for 96% (22/23) of these patches, while patches of comparable area randomly placed across the landscape would only be occupied 25.3% of the time

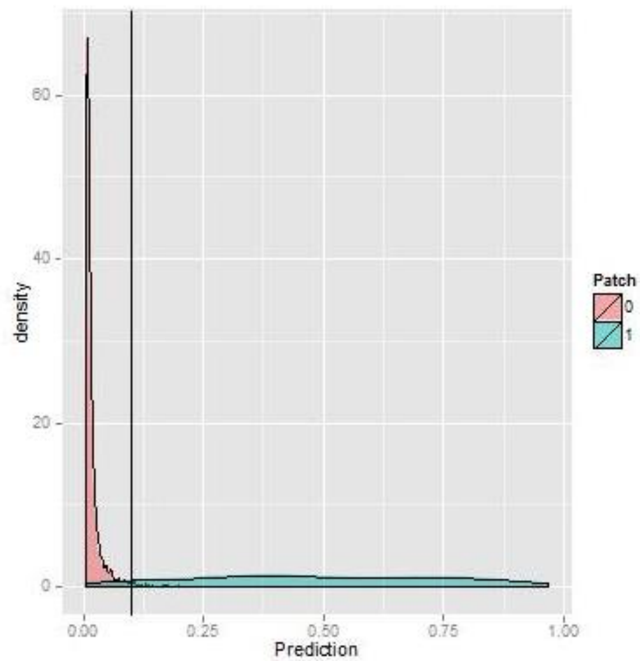


Figure 8. Top model discrimination plot, for used (Patch = 1) and available points (Patch = 0). X axis represents predictions from top model and Y represents the relative density of these predictions (Patch= 0,1). The vertical line depicts the cut point where sensitivity and specificity are maximized. Good discriminatory power results from little overlap between the distributions of used and available points, as can be seen here.

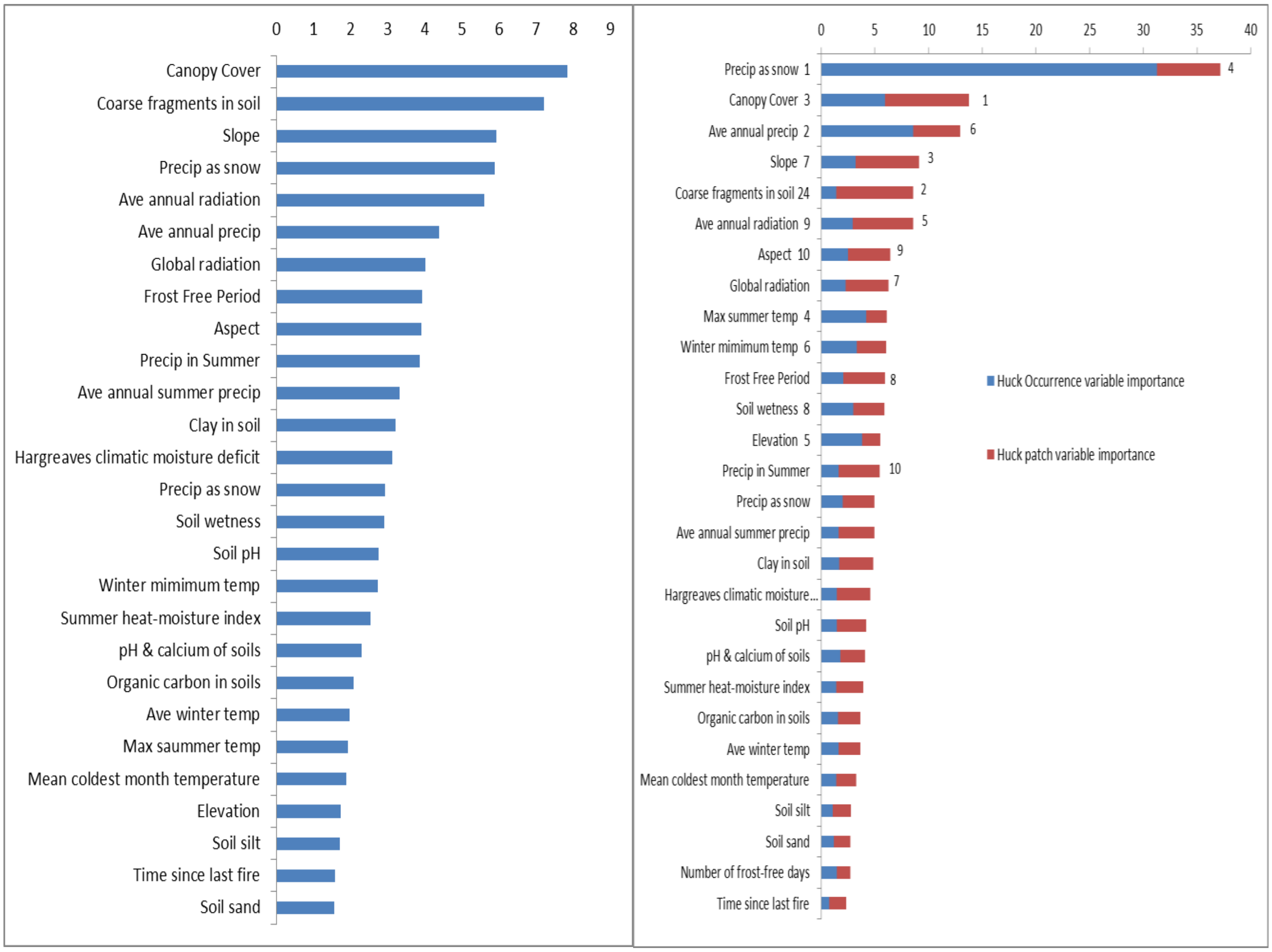


Figure 9a) Relative influence of twenty-six predictor variables for our top Huckleberry patch model was calculated as the relative number of times each variable was included in a tree, scaled such that the relative influence of all variables summed to 100% and **b)** the combined variable important for the huckleberry occurrence model (blue bars) and patch model (red bars). The patch model was a nested model within the occurrence model, that is, we modelled patches as conditions within the occurrence model – patches were a subset of occurrence. Numbers to the left of the bars are the ranks of the huckleberry occurrence variables in order of influence. Numbers to the right are ranked variables for our top huckleberry patch model.

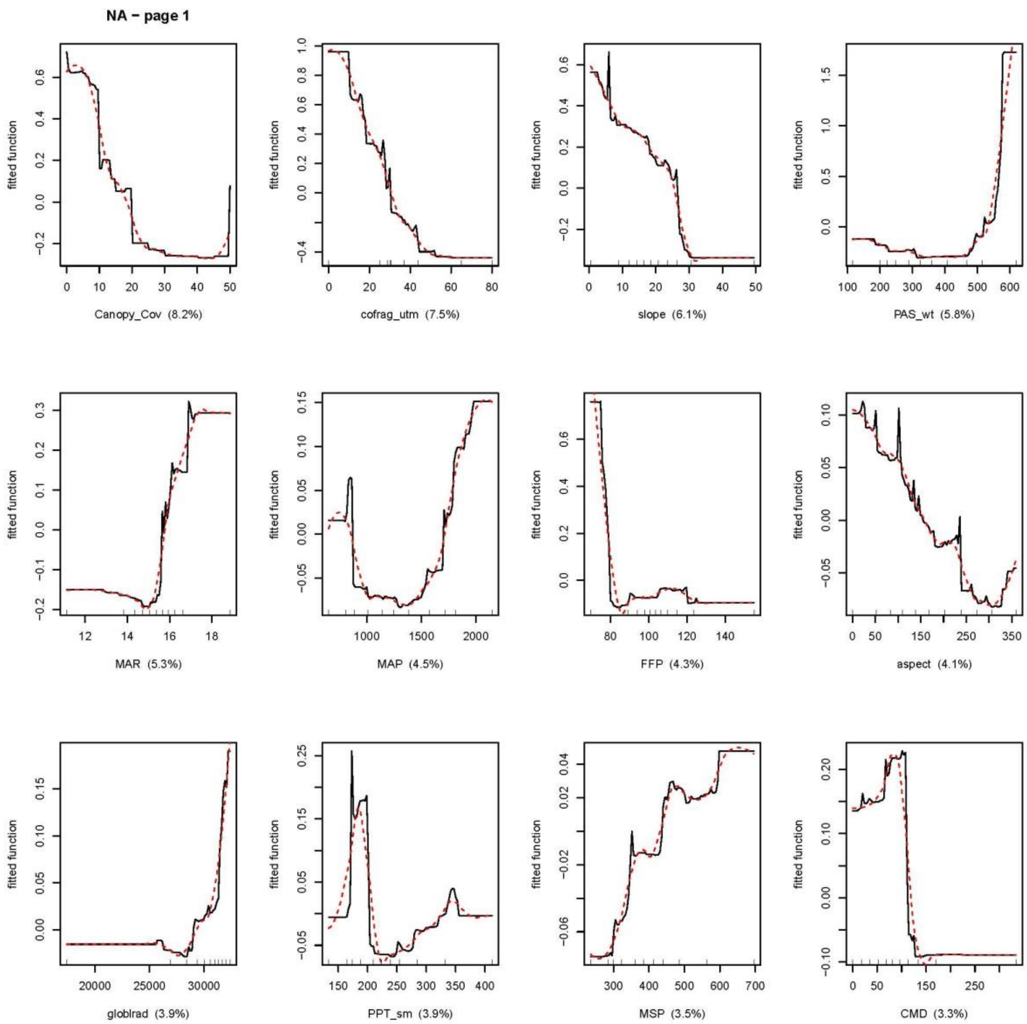


Figure 10. Marginal effects plots for the top twelve predictors in our top huckleberry patch model, depicting the direction, magnitude and shape of the relationship between predictor and response. Black lines are top BRT model predictions while the dotted red line represents a smoothed representation of this relationship fit using a loess smoother.

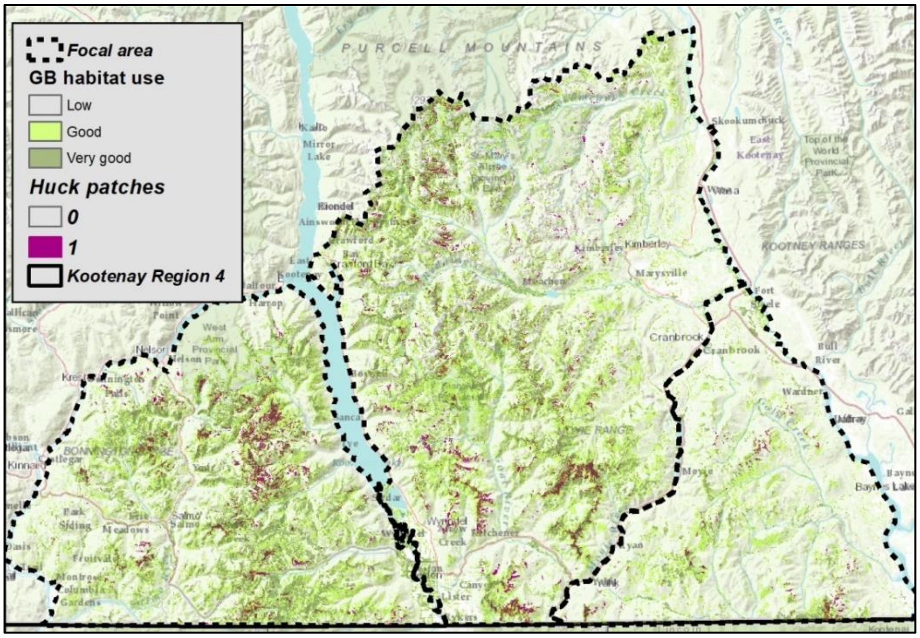


Figure 11. Map of our modelled predictions of huckleberry patches important to grizzly bears overlaid with an all-season both-sex predictive habitat use model from Proctor et al. (2015) in the South Selkirk and Purcell Mts. of southeast BC that was built to help identify linkage areas.

Mortality risk modeling

Our best mortality risk model included positive associations with road density, road presence, highways, and riparian habitats, negative associations included elevation and canopy closure (Table 3). In summary, bears tended to be killed and reported by humans in non-hunt situations in habitats with higher road densities, near highways, in lower elevation riparian and open habitats (Fig 12a). Our best model had a ROC AUC score of 0.74). Most reported mortalities occurred in fall, followed by spring, with the least occurring in summer (Fig. 12b).

Table 3. Most parsimonious model for both sex Reported Mortality Risk model coefficients in the South Selkirk, South Purcell, and Yahk area of southeast BC as select by AIC methods, ROC AUC = -0.74.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Road density	0.134	0.040	0.001	0.056	0.213
Road presence	0.565	0.211	0.007	0.152	0.978
Riparian	0.566	0.212	0.008	0.150	0.981
Highway	0.890	0.204	<0.001	0.490	1.290
elevation	-0.001	0.000	0.001	-0.001	0.000
Canopy cover	-0.005	0.002	0.044	-0.009	0.000
Constant	-2.91	0.35	<0.001	-3.60	-2.22

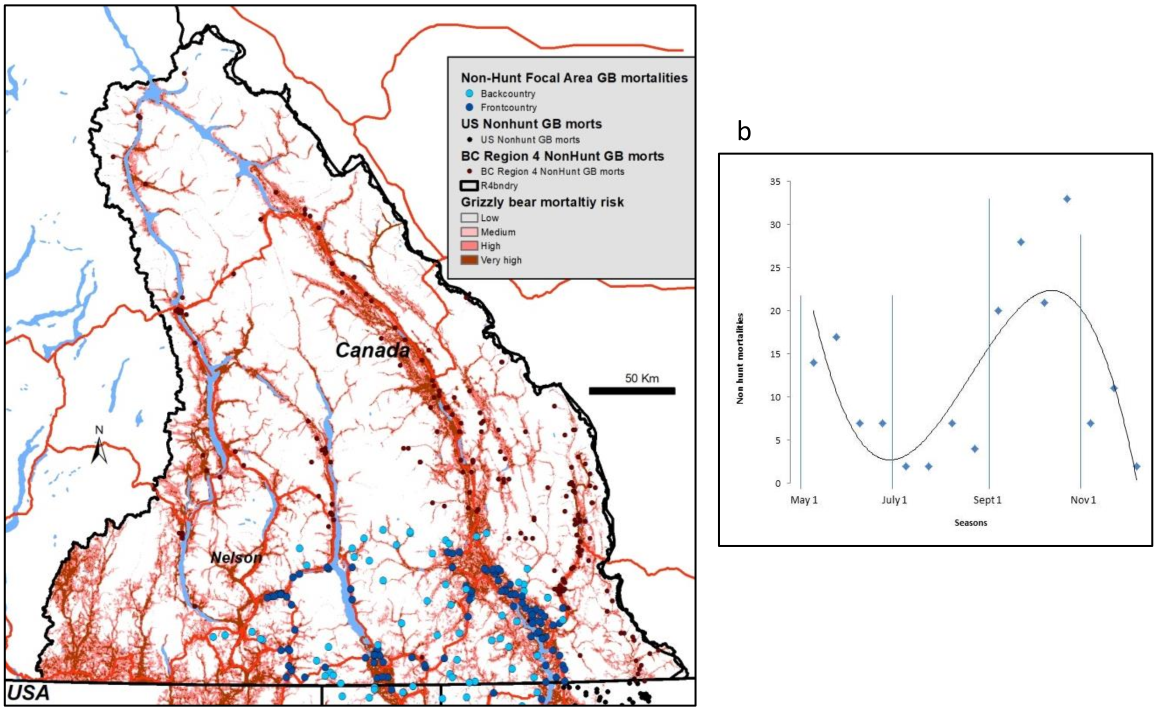
a
b


Figure 12a) Map of the reported non-hunt human-caused grizzly bear mortalities and modeled mortality risk across Kootenay Region 4. Light blue dots are reported front country mortalities in our focal area, where bears were attracted in, dark blue dots are reported and unreported backcountry mortalities (1980-2015) in our focal area, smaller black dots are reported non-hunt mortality records from the BC government (1990-2015) outside of our focal area, and in the US. The reported mortality risk surface was built from reported mortalities, and a portion of unreported mortality (from our telemetry work n = dead bears). Note that the unreported mortality is under-represented in this analysis as it is thought to approximately at least a 1:1 ratio with reported mortalities (McLellan et al. 1999) and likely greater than this estimate (Ciarniello et al. 2009, Mowat and Lamb 2016, McLellan et al. 2016).

Evaluation with female telemetry habitat use modeling and home range selection

HABITAT USE (Female summer)

Our GPS telemetry-based data was also used to predict seasonal habitat use. We developed sex-specific Resource Selection Function (RSF, logistic regression) habitat-use models across our study area. Here we report on the female summer berry season (Tables 4 & 5, Fig. 14a). Our best model evaluated very well. All 5-fold, k = 1-5 Best Models were essentially identical with only slight variation in Log Likelihoods, Pseudo R^2 and coefficients. The model building dataset (80% of GPS locations) predicted very well the model evaluation dataset (20% of GPS locations (Fig. 13). The ROC AUC score of 0.82 is well above the predictive threshold of 0.7. Huckleberry patch patterns dominated female summer habitat use (Table 4. Fig. 14b) with road densities playing a significant but lesser role. Habitat selection for huckleberry patches was strong and bears spent considerable time in or closer than 1 km of huckleberry patches >10ha (Fig, 15c). Also, females mildly selected habitats with road densities < 1.2 km/km^2, but when road densities were lower than 0.6 km/km^2 selection intensified dramatically (Figs. 14a & b).

Table 4. Model ranking using Akaike Information Criteria (AIC) for summer female grizzly bear habitat use in the South Selkirk, South Purcell, and Yahk area of southeast BC. HuckDist10ha is distance to huckleberry patches >10ha, green is greenness, rip is riparian, tri is terrain ruggedness.

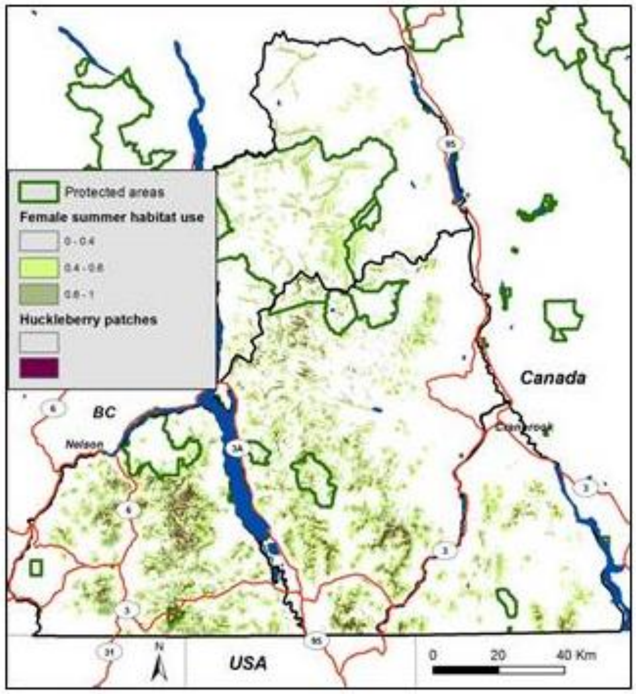
Female Summer Model	Log likelihood	K	AIC	DAIC	AICw
HuckDist10ha green roadden rip alpine tri	-160.613	7	335.23	0.00	0.579
HuckDist10h green roadden alpine tri	-162.775	6	337.55	2.32	0.181
HuckDist10h green roadden rip tri	-163.571	6	339.14	3.92	0.082
HuckDist10h green roadden rip alpine	-163.326	6	338.65	3.43	0.104
HuckDist10h green rip alpine tri	-164.005	6	340.01	4.79	0.053
HuckDist10h roadden rip alpine tri	-167.950	6	347.90	12.67	0.001
green roadden rip alpine tri	-189.311	6	390.62	55.40	0.000

Table 5. Most parsimonious model for summer female grizzly bear habitat use in the South Selkirk, South Purcell, and Yahk area of southeast BC as select by AIC methods (Table 3). The ROC AUC score was 0.82, and the Pseudo R^2 was 0.25.

Variable	Coefficient	Robust standard error	Robust probability	95% CI	
				lower	upper
Dist to hucks >10ha	-0.001	0.001	0.001	-0.001	-0.0004
Greenness	12.246	2.686	<0.001	6.982	17.510
Road density	-0.296	0.092	0.001	-0.477	-0.116
Riparian	1.645	0.614	0.007	0.441	2.848
Alpine	1.165	0.182	<0.001	0.808	1.521
Terrain ruggedness	-0.008	0.002	<0.001	-0.013	-0.004
Constant	-7.256	1.848	<0.001	-10.878	-3.633

Figure 13. Area adjusted evaluation of the RSF scores relative to available habitat of the model building dataset (80% of locations) and model evaluation dataset (20% of locations). Similarity of curves suggests that the model building dataset well predicted the evaluation data.

a



b

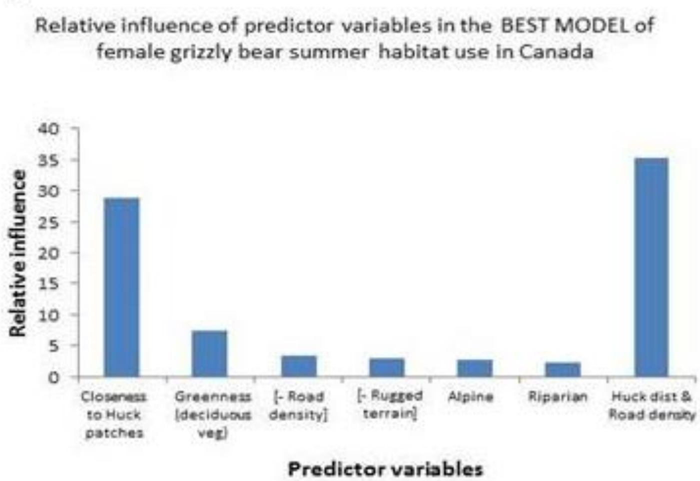


Figure 14a) Female summer grizzly bear habitat use (green) in the south Selkirk and Purcells Mts. as determined through GPS radio telemetry with huckleberry patches important to grizzly bears (purple). This model was very predictive (ROC AUC score = 0.82, Pseudo R^2 = 0.25) and b) relative influence of predictor variables, closeness to huckleberry patches >10ha was the dominant predictor for female summer habtiat use. Huckleberry patches and road density were additive (far right bar).

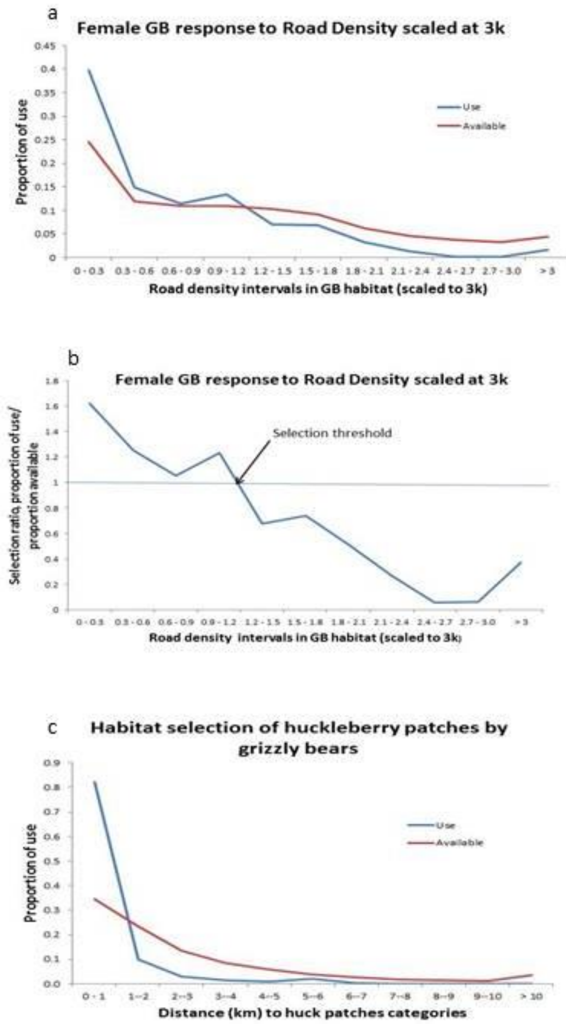


Figure 15a & b) Response curves for female summer habitat use relative to road density in the South Selkirk and Purcells Mts. of souteast BC. These figures show that grizzly bears can tolerate road densities between 0.6 and 1.2 km/km^2, but significanlty prefer habitats (and likely have increased survival) with road density < 0.6 km/km^2 and lower, and c) distance to huckleberry patches which shows that proximity to huckleberry patches >10ha was a big draw for female grizzly bears. The red curve is what is available in the habitat, the blue curve is what the bears use. The graphs show the response of bear habtiat selection relative to what is available.

Female home range selection

Several studies (Nielsen et al, 2004*a*, Schwartz et al 2010, Boulanger and Stenhouse 2014) and ours, link road densities to female survival, suggesting a very strong mechanism that links road densities to population processes that drive viability and conservation status. Our exploration into female home range selection revealed not only a link to survival, but also to habitat displacement. The mean road density in female home ranges across our study area was 0.5 km/km^2 (Fig. 16a). This is in contrast to the ecosystem wide mean road density of 1.04 km/km^2

(Fig. 16a). Further, we found no female home range in habitat with road densities >1.0 km/km^2, suggesting that somewhere above that value, there may be an issue with survival rates being too low to sustain much of a population. This idea is consistent with the conclusions of Boulanger and Stenhouse (2014) who found in habitats with road density > 0.75 km/km^2, female survival was low enough to drive population declines. The Yahk GBPU has the highest average road density of the 3 GBPUs we studied (~1.7 km/km^2). Interestingly, we were challenged to capture and radio collar adult females in the Canadian Yahk in spite of a 3 year effort, yet we were very successful in the Purcell Mts., just north of Hwy 3 and in the S Selkirk Mts. A DNA-based population survey also sampled very few females in the Canadian Yahk (Proctor et al. 2007), while many females were captured north of BC Hwy 3 where average road densities were ~1.0 km/km^2, in the US portion of the Yaak (Kendall et al. 2016) where road densities are <0.6km/km^2 and the South Selkirks (Proctor et al. 2007) where average road densities are ~1.0 km/km^2. We are not suggesting that there are no adult females in the Canadian Yahk, but their density may be a very low. We could not generate a detailed measurement of female habitat-use and survival based on radio collaring data in the Canadian Yahk because we could not collar enough females to get rigorous data. What female activity we have documented in the Canadian Yahk is from females captured and collared in the US. The majority of their home ranges were in the US where a long standing access management program manages road densities below 0.6 km/km^2.

Note also that the Yahk has a relatively low proportion of huckleberry patches and that this was an important predictor of female home range selection. Our results suggest that the combination of a low number of huckleberry patches and higher road densities may be responsible for the low grizzly densities in the Yahk (Proctor et al. 2007, Apps et al. 2016). In the near future we will be extending our huckleberry patch model into the US Yaak. That will allow an interesting comparison of 2 systems, one with an access control system in place, one without to further tease apart the complementary influences on bear density.

Finer scale habitat displacement was evidenced by the fact that we found our collared females continued to avoid habitats with higher road densities within their MCP home ranges (Figs. 17a-c). The clusters of habitat-use depicted by the Kernel Home Ranges (usually a smaller subset of area within the larger MCP where habitat use clusters, see Fig. 17.) showed very clearly that at every road density encountered, all females avoided, or were displaced from, higher road density areas within their MCP home range. We found that on average, females across our study area had significantly lower road densities and more secure habitat in their KHR than their MCP home ranges (RD, $t = 2.75$, $df = 12$, $p = 0.02$; CORE, $t = 4.08$, $df = 12$, $p = <0.001$). We also found that on average, females across our study area had home ranges that contained 78% of habitat >500m from an open road, when the available proportion was 56% (Fig. 16b). The Yahk unit only had 31% of habitat >500m from an open road as available. Habitat with higher proportions of huckleberry patches >10 ha was also strongly selected for, relative to ecosystem averages, and that available within MCP home ranges ($t = 3.47$, $df = 12$, $p = 0.002$, Fig. 16c).

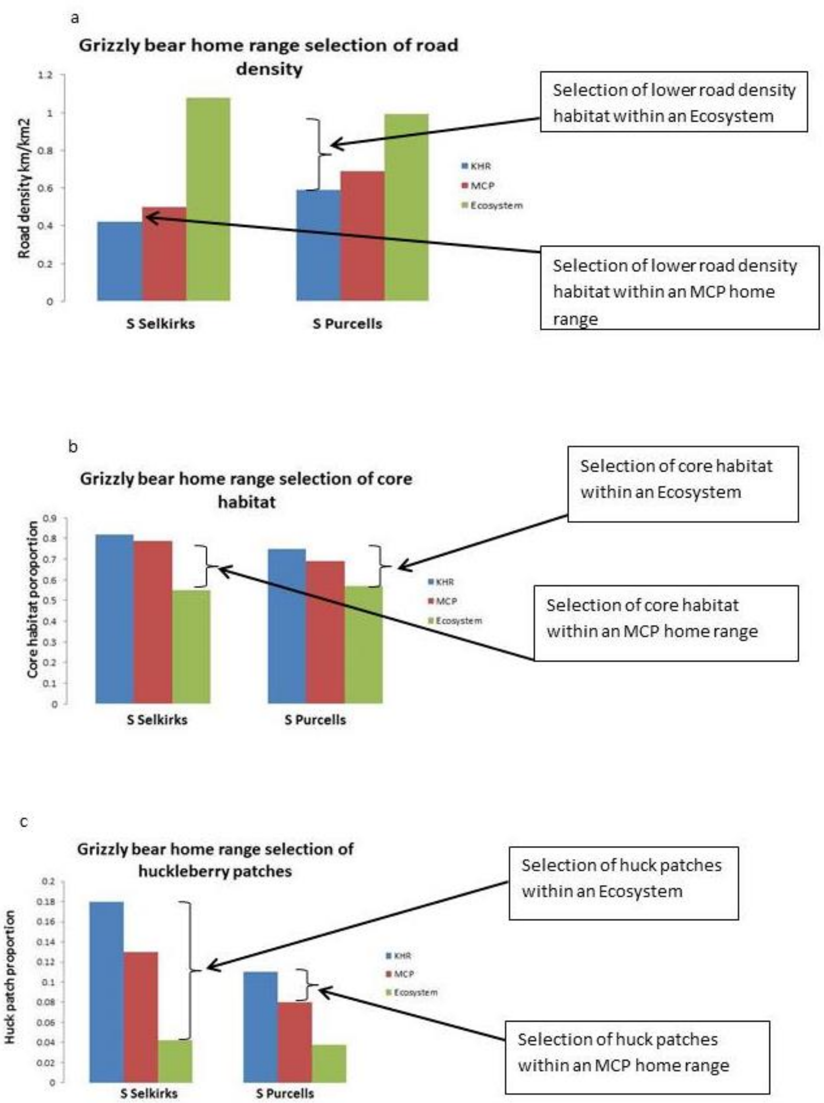


Figure 16a) Female grizzly bear Home Range selection. KHR is Kernel Home Range, a finer representation of actual habitat use (See Fig. 17). MCP is Minimum Convex Polygon, a coarser depiction of a home range. Note all female bears select for lower road densities, high core proportions, and higher huckleberry patch proportion in their KHR than MCP (Fig. 17c). They also are strongly selecting, or surviving within, home ranges with higher proportions of core habitat (habitat > 500m from an open road than is available across their respective ecosystems.

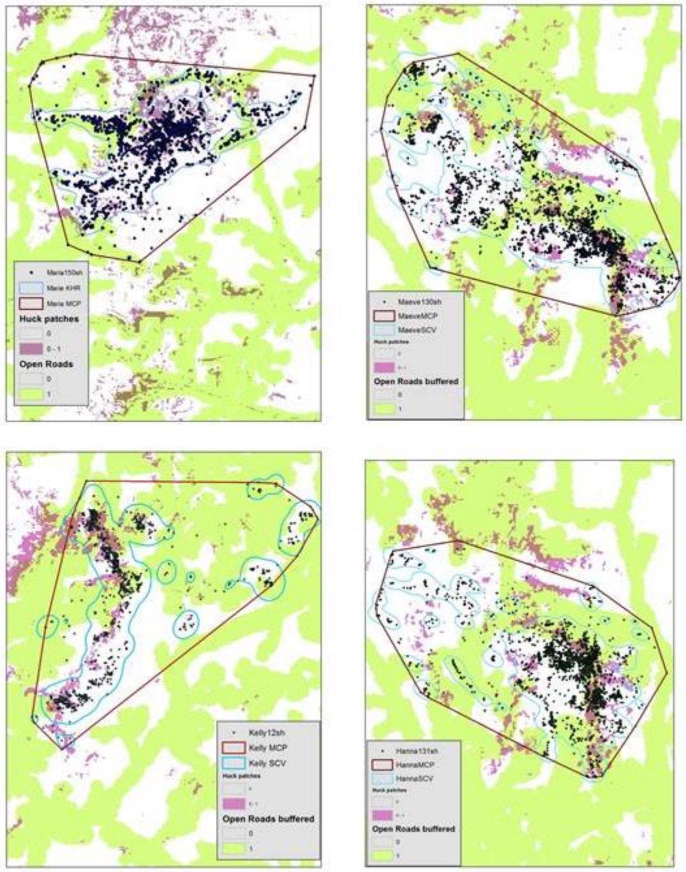


Figure 17. Four representative adult female grizzly bears' home ranges. Minimum Convex Polygon (MCP, brown poly) and 95% Kernel (KHR, blue poly), with buffered roads (500m, green), predicted huckleberry patches (purple), and all season GPS locations (black dots).

Independent model evaluation using DNA data collected on grizzly bears
Density (Both sex and female only)

To further explore the relationship between our huckleberry patch model and road densities we re-analyzed the results of 6 DNA-based abundance survey previously reported in (Proctor et al. 2007). Our goals were to spatialize the results into a density surface (Fig. 18a), but more important was to understand the relative influence of food resources and mortality risk (road density, Fig. 18b, c, & d) on grizzly bear density. The best model ROC AUC score was = 0.82 (AICw = 0.96) when scaled for daily movements (3 km), and 0.82 when scaled for female home range size (AICw = 0.96, Table 5a & b). At both scales, habitat variables, including closeness to huckleberry patch, were contributing variables and there was an additive predictive influence when both huckleberry patches and road density are combined (the bar on the far right in each figures c & d), providing evidence that both have influence.

These results suggest that both huckleberries and road densities contributed significantly to model predictability and therefore both variables were likely additive drivers of bear density. Interestingly, bear densities were ~3 times higher in habitat with road densities < 0.6 km/km2 (Fig. 18b) providing support for the use of this threshold as an access target for grizzly bear conservation effort in neighbouring jurisdictions (Schwartz et a. 2010, Boulanger and Stenhouse 2014, Lamb et al. in review).

When we averaged the coefficients for both scales and converted that to the Odds Ratio, we estimated the effect of changing road densities through potential access controls. We found that for every 0.1 km/km^2 of reduced road density, the grizzly bear density was predicted to increase by ~7%. So hypothetically, reducing the average road density in the South Selkirks from its current 1.0 Km/km^2 to 0.6 km/km^2 would potentially increase the density from 17 to 20 GB/1000km^2 (or the number of bears from 68 to 79).

Table 6a) Most parsimonious model for both sex density when predictor variable data was scaled at 3 km in the South Selkirk, South Purcell, and Yahk area of southeast BC. The ROC AUC score was 0.82, and the Pseudo R^2 was 0.24. The closest model ΔAIC value was 22.1 providing strong support for the best model, and **b)** when predictor variable data was scaled at 8 km. The ROC AUC score was 0.82, and the Pseudo R^2 was 24. The closest model ΔAIC value was 7.1 providing strong support for the best model.

a.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Elevation	0.002	0.000	<0.001	0.001	0.003
Road density	-0.948	0.204	<0.001	-1.349	-0.548
Dist to hucks >10ha	0.000	0.000	<0.001	-0.001	0.000
Greenness	0.946	0.205	<0.001	0.545	1.347
Constant	-2.774	0.754	<0.001	-4.251	-1.297

b.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Dist to hucks >10ha	-0.001	0.000	<0.001	-0.001	-0.0004
Elevation	0.002	0.001	<0.001	0.001	0.004
Road density	-1.514	0.319	<0.001	-2.139	-0.888
Alpine	1.539	0.324	<0.001	0.904	2.174
Terrain ruggedness	-0.027	0.008	0.001	-0.042	-0.012
Constant	1.081	1.082	0.318	-1.040	3.202

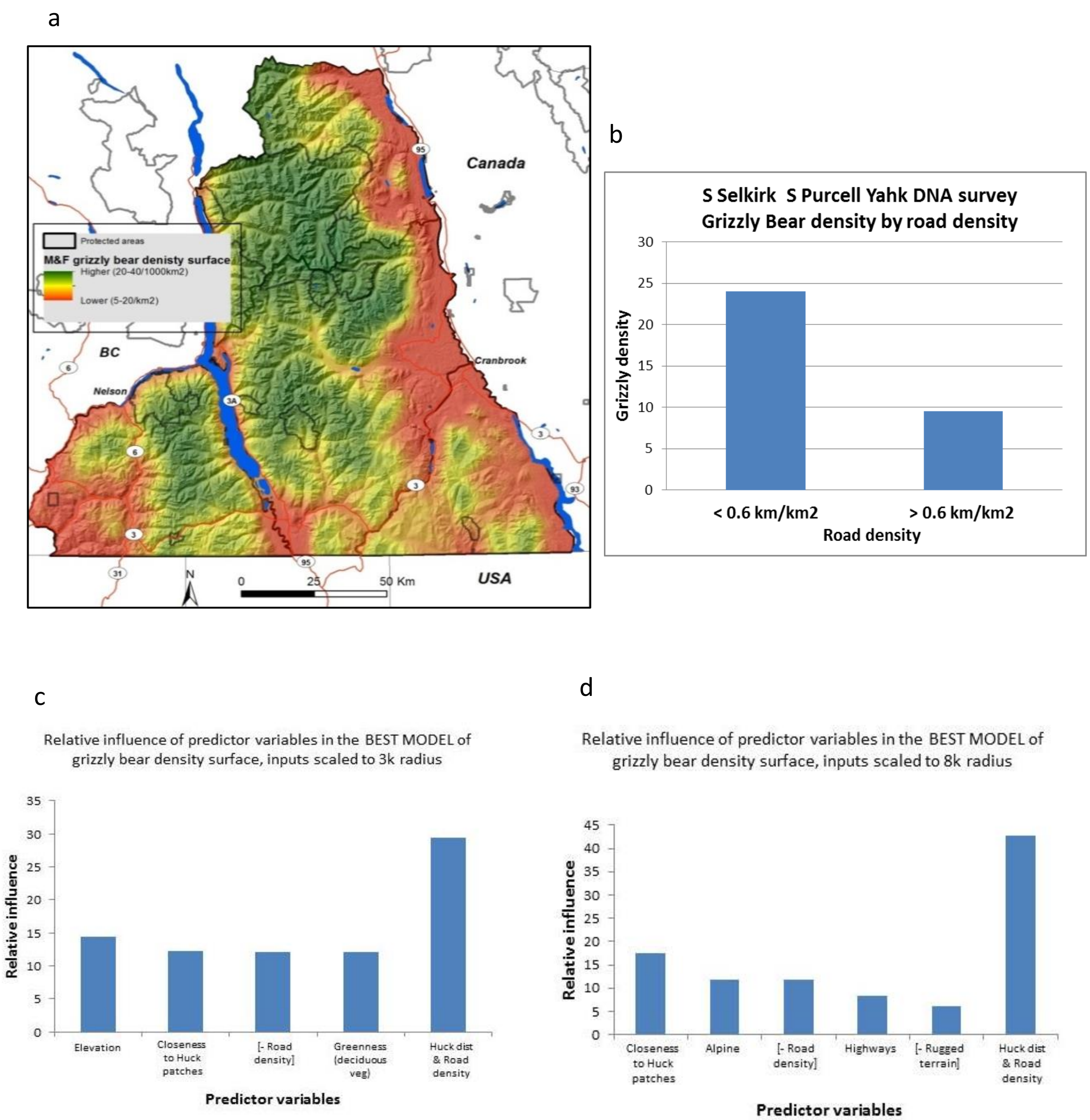


Figure 18a) Grizzly bear (M & F) density surface derived from multiple year DNA surveys carried out between 1998 – 2005 in the South Selkirk and Purcells Mts. and integrated over both home range and daily movement scales. Predictive data was scaled to be relevant for daily movements (3km radius), and female home range (8km radius), b) grizzly bear density in areas of low ($<0.6 km/km^2$) and high ($>0.6 km/km^2$) road density, and c) The relative influence of model predictor variables for the Best Density Model scaled for daily movements (3 km), and d) scaled for female home range size (8 km). At both scales habitat variables including closeness to huckleberry patch are important variables and there is an additive predictive influence when both bottom up huckleberry patches, and top down road density are combined (the bar on the far right in each figure), suggesting that both have influence. From a management perspective these results indicate that to control human access and road densities near huckleberry patches would be most beneficial to grizzly bear density.

We repeated the density surface analysis described above, but with only female detection data (Table 6, Figs. 19a-c). The results were very similar, although the spatial patterns varied from the both sex results. Huckleberry patches and road density were both significant predictor variables that both influenced female density.

Table 7a) Most parsimonious model for female density when predictor variable data was scaled at 3km in the South Selkirk, South Purcell, and Yahk area of southeast BC as select by AIC methods. The ROC AUC score was 0.78, and the Pseudo R^2 was 0.29. The closest ΔAIC value was 9.4 providing strong support for the best model and **b)** when predictor variable data was scaled at 8 m. The ROC AUC score was 0.76, and the Pseudo R^2 was 0.17. The closest ΔAIC value was 9.0 providing strong support for the best model.

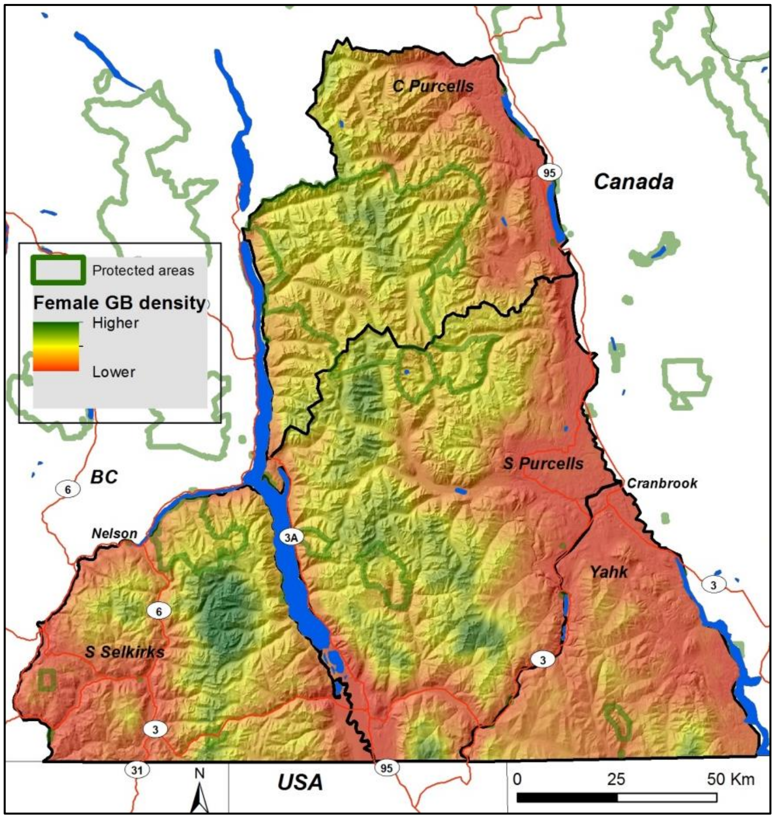
a.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Dist to hucks >10ha	9.771	1.634	<0.001	6.568	12.974
Road density	-1.035	0.214	<0.001	-1.454	-0.617
Highway	-10.719	1.682	<0.001	-14.016	-7.421
High elevation forests	1.984	0.638	<0.002	0.733	3.235
Constant	-0.711	0.198	<0.001	-1.099	-0.323

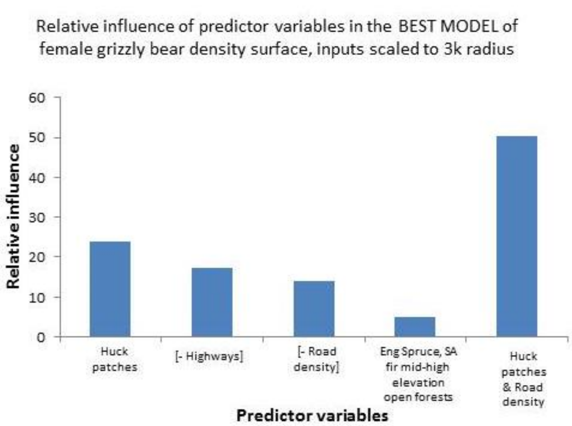
b.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Dist to hucks >10ha	11.570	2.701	<0.001	6.276	16.864
Greenness	9.949	2.956	0.001	4.155	15.743
Road density	-0.870	0.252	0.001	-1.364	-0.376
Riparian	-22.341	3.376	<0.001	-28.957	-15.725
BEI habitat	1.692	0.517	0.001	0.678	2.706
Constant	-7.363	1.872	<0.001	-11.031	-3.694

a



b



c

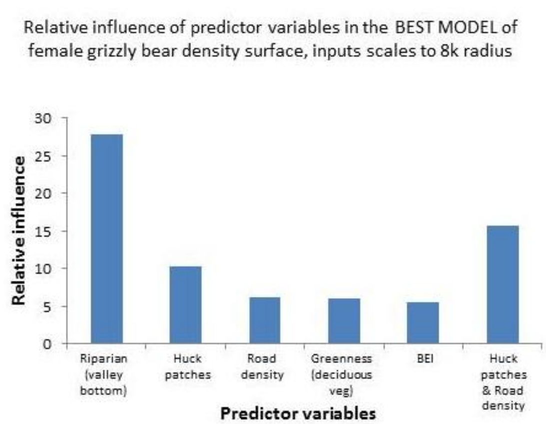


Figure 19a) Female grizzly bear density surface derived from multiple year DNA survey data in the South Selkrik and Purcell Mts. done between 1998 – 2005 and integrated over both home range and daily movement scales. Predictive data was scaled to be relevant for daily movements (3km radius) and female home range (8km radius) and b) relative influence of predictor variables in the Best Female Density Model for the daily movement scale (ROC AUC = 0.76, AICw = 0.97) and c) the female home range scale (ROC AUC = 0.78, AICw =0.99). Huckleberry patches and road density were both important predictor variables. As in the both sex density model, bottom-up huckleberry patches and top-down road density variables were additive, both influencing female density.

Female reproduction (fitness)

We used our family pedigree data and carried out an analysis exploring the variables driving reproductive success, or fitness. Reproductive success is at the heart of population viability, and we wanted to know where and in what types of habitats females had a higher reproductive rate. At both the daily movement (3 km radius) and female home range (8 km radius) scales, huckleberry patches and road densities explained much of the variation (Figs. 20a-c). Competing models that carried a portion of the AIC weights (AICw) and had delta AIC scores >2.0, outside the threshold for considering them as similarly explanatory models, were the same as the best model but with 1 variable removed. As in the density models, bottom-up huckleberry patches and top-down road densities were additive, both influence female reproductive success. Fitness is one of the most powerful drivers in nature and evolution. It is the premier standard to test for significance and influence.

Table 7a) The most parsimonious model for female reproductive success (fitness) when predictor variable data was scaled at 3 km in the South Selkirk, South Purcell, and Yahk area of southeast BC. The ROC AUC score was 0.80, and the Pseudo R^2 was 0.18. The closest model ΔAIC value was 3.8 providing medium support for the best model and **b)** when predictor variable data was scaled at 8 km. The ROC AUC score was 0.79, and the Pseudo R^2 was 0.17. The closest model ΔAIC value was 2.2 providing medium support for the best model.

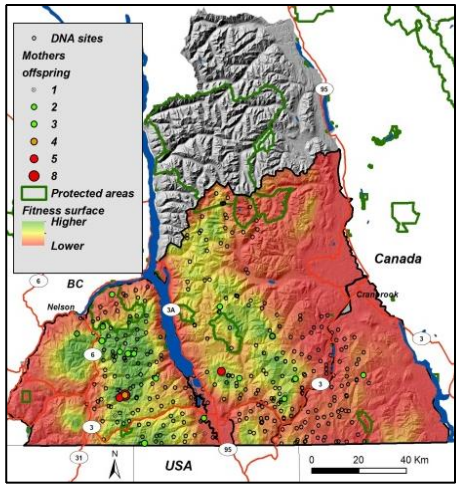
a.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Dist to hucks >10ha	-0.001	0.000	0.034	-0.001	0.000
Road density	-0.852	0.321	0.008	-1.481	-0.223
Greenness	40.227	12.217	0.001	16.283	64.172
Alpine	5.414	2.230	0.015	1.045	9.784
Constant	-28.971	8.738	0.001	-46.097	-11.846

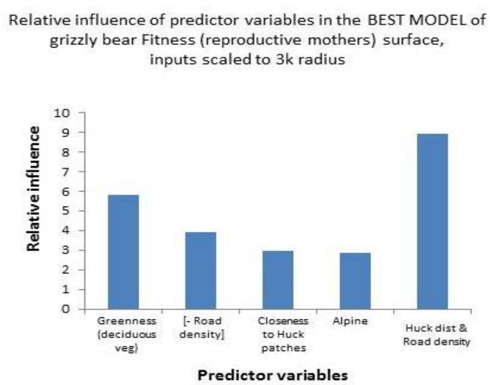
b.

Variable	Coefficient	Standard error	Probability	95% CI	
				upper	lower
Dist to hucks >10ha	-0.001	0.000	0.003	-0.002	0.000
Greenness	35.043	13.440	0.009	8.701	61.384
Mortality risk	-70.195	34.110	0.04	-137.049	-3.341
Constant	-23.513	9.269	0.011	-41.679	-5.347

a



b



c

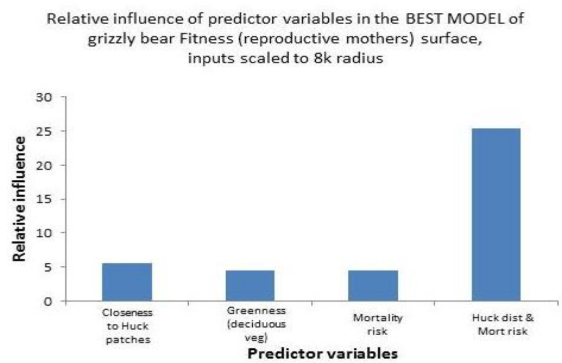
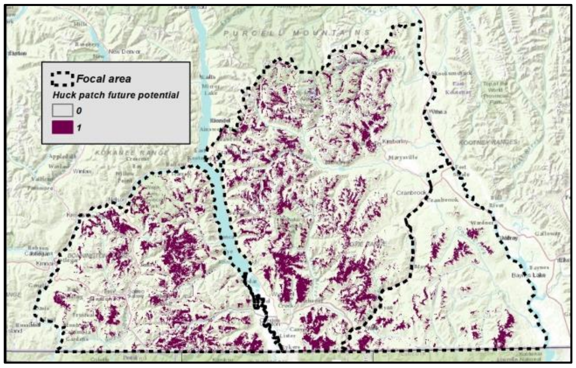


Figure 20a) Female grizzly bear "fitness" surface (mother reproductive events). Predictive data was scaled to be relevant for female daily movements (3km radius) and home range (8km radius) and b) relative influence of predictor variables in the BEST MODEL for the female home range scale (ROC AUC = 0.78, AICw =0.50) for predicting reproductive mothers and c) relative influence of predictor variables in the BEST MODEL for the daily movement scale (ROC AUC = 0.80, AICw =0.61) for predicting reproductive mothers.

Huckleberry patches and forestry

We applied our best model across the entire region and looked for underlying ecological, climate, soil and topographic conditions that were conducive to huckleberry patch development important to grizzly bears and then simulated opening the canopy, through timber harvest or fire, in and outside of the Timber Harvest Land Base (i.e., defined operability zone). This resulted in a predictive huckleberry patch map where underlying site conditions could focus future management activities that opened the canopy (Fig. 21a & b).

a



b

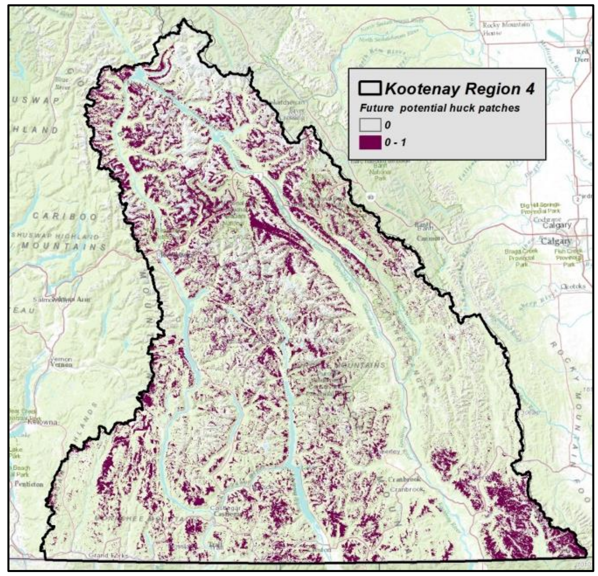


Figure 21a) Future potential black huckleberry patches important for grizzly bears in our focal area of the South Selkirk, South Purcell, and Yahk Grizzly Bear Population Units and b) across Kootenay Region 4.

We then did a statistical comparison of sites with and without huckleberry patches. We also translated the results of our 2014-15 focal area site visit data into the BC Biogeoclimatic Ecological Classification (BEC) system so as to be more understandable to foresters for management planning (MacKillop and Ehman 2016). One component of this comparison was subcontracted to a grizzly bear biologist who also understands and works with the BEC system (see ***APPENDIX I***, MacHutchon 2017).

Our BEC translation results suggested that certain zones, subzones, variants, site series, and structural stages were more likely to have huckleberry patches grizzly bears use. For example, within our 2014-15 focal area, the majority of huckleberry patches documented were within Englemann Spruce-Subalpine Fir (ESSF) variants wm3, wm4, and wmw (Fig. 22) and predominately within site series 103 and to a lesser degree 101 (Fig. 23). Structural stages 3a - shrub dominated, and 6 - mature forest, had the highest probability of being a huckleberry patch (Fig. 24). The overlay of our predicted huckleberry patches was a decent fit for these BEC classifications (Fig 25a & b).

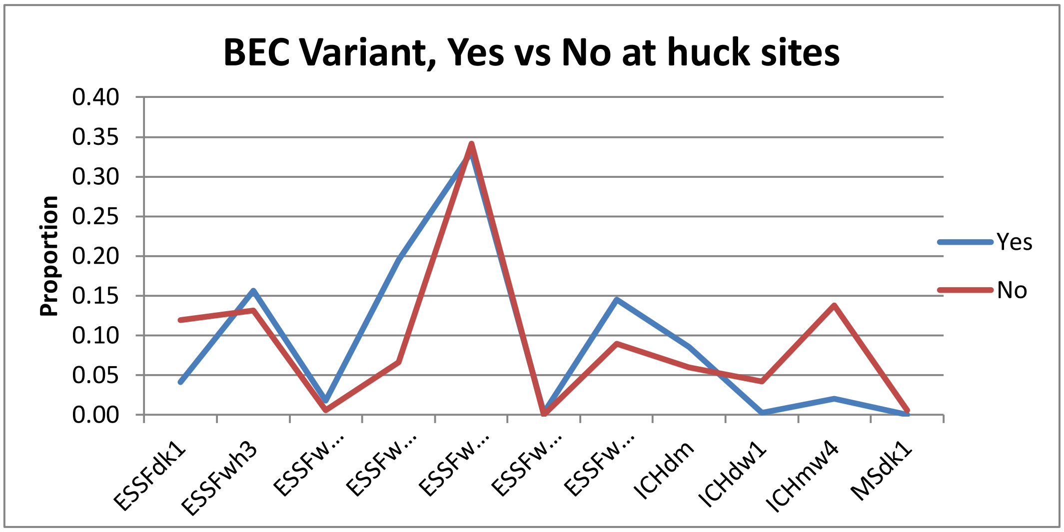


Figure 22. Biogeoclimatic Ecosystem Classification (BEC) variants in our 2014-15 South Selkirk, South Purcell, and Yahk GBPU focal area. ESSF is Englemann Spruce Sub-alpine Fir natural climax forest. The first 2 lower case letters represent the local moisture and temperature regime, i.e., dk is dry cool, wh, is wet hot, wm is wet mild, dm is dry mild, and mw is moist warm. The 3rd lower case digit represents local variants of each moisture temperature regime. Yes are sites of GPS telemetry clusters that we visited over 2 years that were categorized as a huckleberry patch that a grizzly bear used. No are sites that were not a huckleberry patch. ESSFwm3 contained huckleberry patches more than the variant was available and ESSFwm4 contained patches as available, but contained many huckleberry patches. ESSFwmw also contained huckleberry patches more than available.

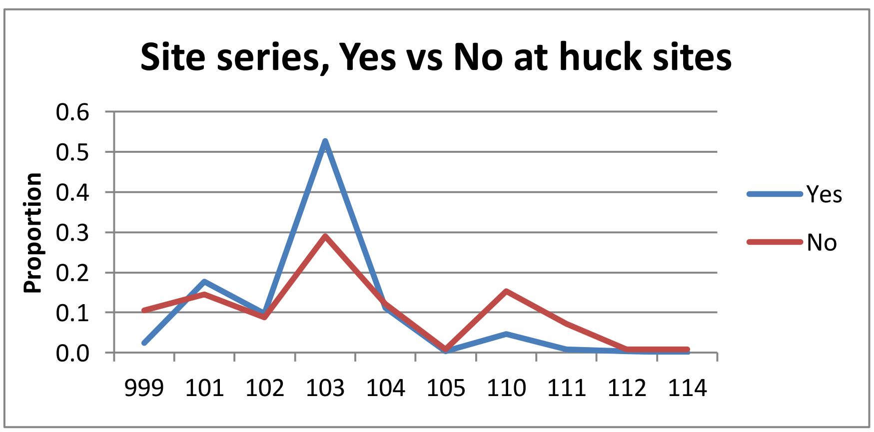


Figure 23. Biogeoclimatic Ecosystem Classification (BEC) site series in our South Selkirk, South Purcell, and Yahk GBPU focal area. Yes are sites of GPS telemetry clusters that we visited over 2 years that were categorized as a huckleberry patch that a grizzly bear used. No are sites that were not a huckleberry patch. Three digit codes represent similar relative soil moisture and nutrient regimes of site series among BEC variants. Site series 103 and to a lesser extend 101 were the dominate site series that contained huckleberry patches used by grizzly bears in the ESSF zone of our focal area in the Kootenays. Site series from 102 to 109 represent sites with drier or poorer nutrients than zonal, which is site series 101, with the 102 being the driest and poorest. Numbers 110 to 114 represent wetter or richer nutrient sites than zonal. 999 are non-forested habitat.

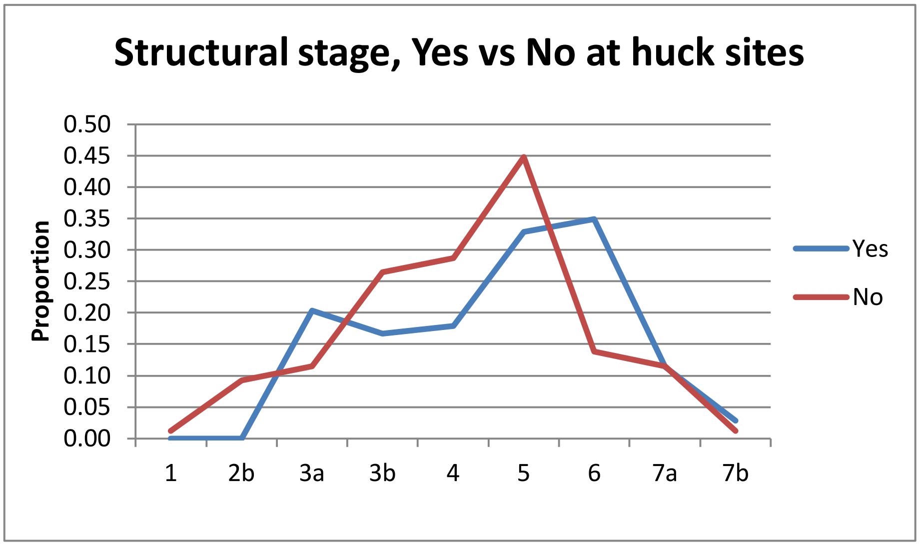


Figure 24. Biogeoclimatic Ecosystem Classification (BEC) structural stages in our South Selkirk, South Purcell, and Yahk GBPU focal area. Yes are sites of GPS telemetry clusters that we visited over 2 years that were categorized as a huckleberry patch that a grizzly bear used. No are sites that were not a huckleberry patch. Structural stage describes the forest structure (herb, shrub, young, old, etc.) throughout a forest succession progression. Structural stages 6 (mature forests) and 3a (short shrub dominated) tended to have more huckleberry patches when in ESSFwm3, wm4, wmw and site series 103 and 101.

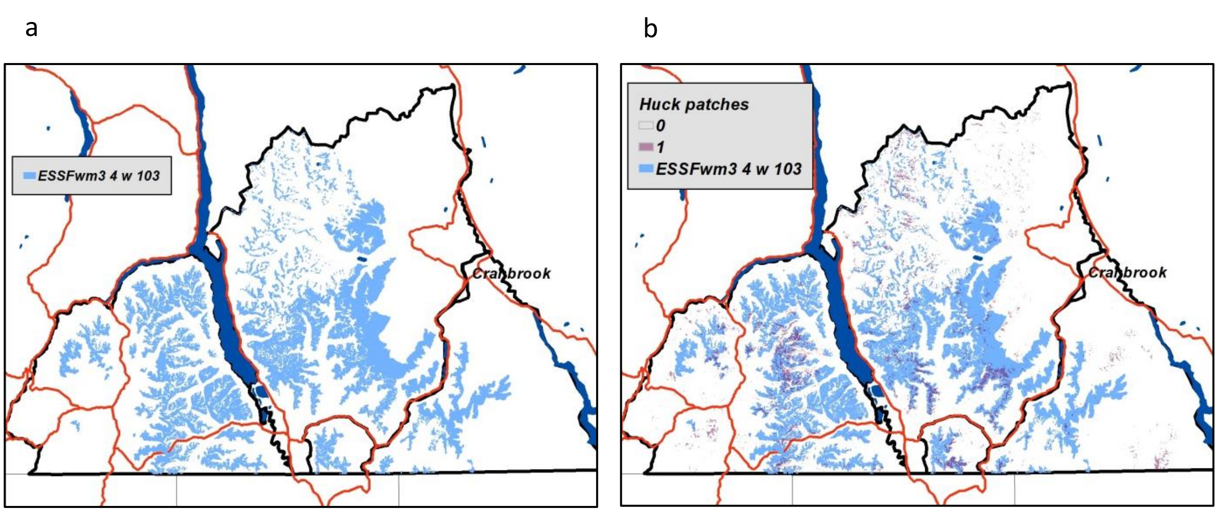


Figure 25a) Biogeoclimatic Ecosystem Classification (BEC) variants (ESSFwm3,4,w) and site series (103) that tended to have the most huckleberry patches in the South Selkirk, South Purcell & Yahk GBPU focal area and b) with predicted huckleberry patches (purple) overlaid.

Our BEC system translation is mainly valid within our 2014-15 focal area. It was informative to find the BEC system somewhat paralleled our modeling results. However, while we identified several BEC zones, variants, site series and structural stages that generally corresponded to our modelled huckleberry patches, there were many areas with these BEC classification combinations that did not have huckleberry patches. One possible reason was because the canopy was not open enough for a productive huckleberry patch to develop.

We also explored timber harvest cut block data from provincial records and more detailed records from the Nature Conservancy of Canada's Darkwoods Conservation property in the South Selkirk's, which has been harvested for many decades and also has many huckleberry patches. Here we looked for patterns in factors that might influence huckleberry patch production, including the type of cutting, (i.e., clear cut, selective cut), planting, slash burning, time since disturbance, fire disturbed (not slash burned), shrub cover, herb cover, and canopy cover.

We found that 74% of all huckleberry patches used by grizzly bears were not in a cut block (Fig. 26). The elevational range where huckleberry patches were more likely was between 1500-2100 m (83%). Many huckleberry patches were above the timber harvest "operability" elevation of approximately 1800 m (see Fig. 27 and caption for explanation). Of those sites we visited not in a cut block, there were 3 times more huckleberry patches in areas that had burned (not slash burns) than those with no discernable fire history. Slope position did not differ much between sites with and without huckleberry patches (Fig. 28).

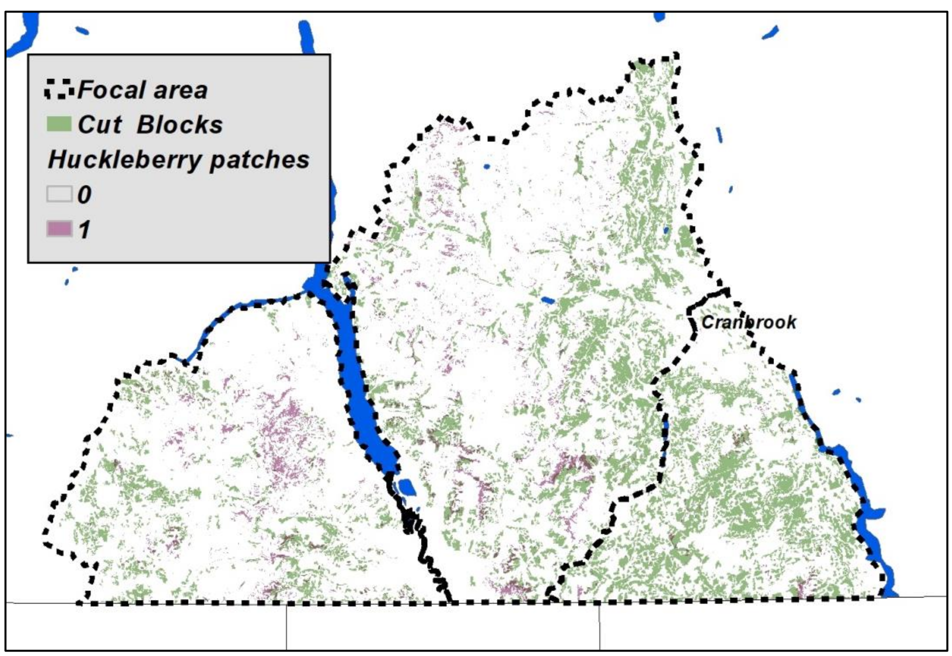


Figure 26. Predicted huckleberry patches overlaid with cut blocks in our South Selkirk, South Purcell, and Yahk focal area. 74% of huckleberry patches are not in cut blocks.

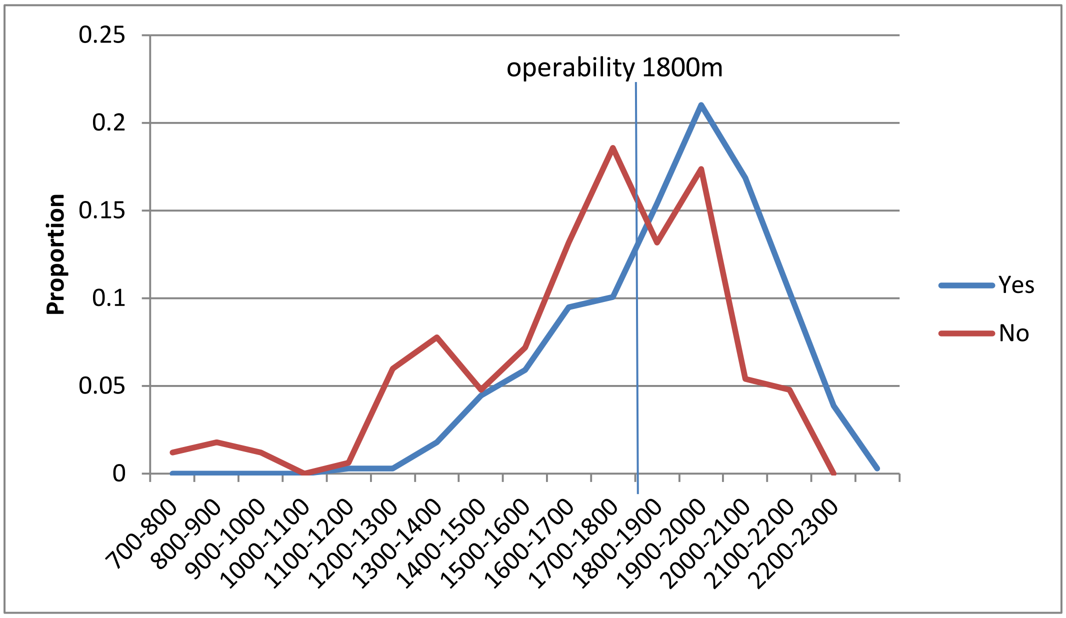


Figure 27. Cut blocks with (Yes) and without (No) huckleberry patches used by grizzly bears in the South Selkirk, South Purcell, and Yahk GBPU focal area of southeast BC as determined through site visits. The Timber Harvest Land Base (THLB) operability line is determined based on economic and ecological conditions, but because a large number of our huckleberry patch site visits included the South Selkirk, Nature Conservancy of Canada Darkwoods Conservation property for which the BC Government does not have a defined operability line, we used 1800 m as an approximation of the THLB line in this area and through the rest of our focal area

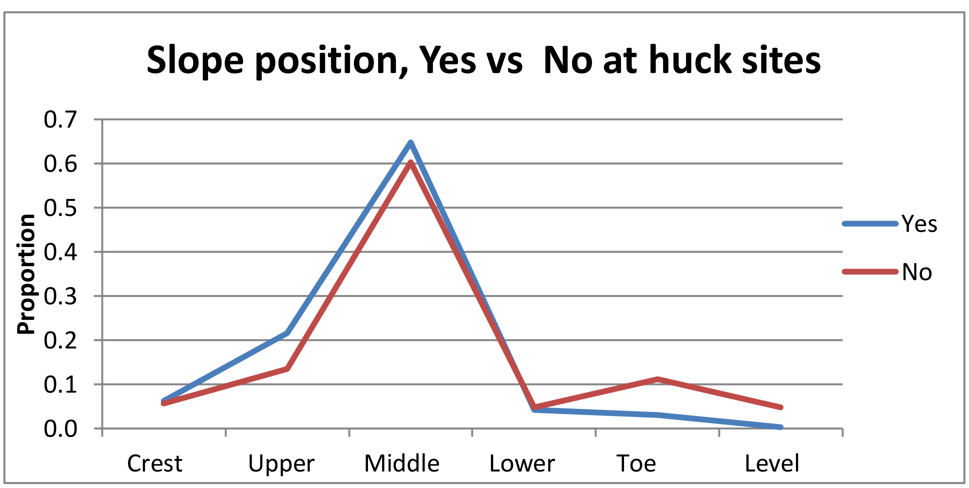


Figure 28. Slope position was very similar for sites with and without huckleberry patches used by grizzly bears in the South Selkirk, South Purcell and Yahk GBPU focal area.

While canopy cover <30% was the most predictive variable in huckleberry patches that grizzly bears use, there was no difference between cut blocks with or without huckleberry patches in mean canopy cover levels ($p = 0.30$). This suggests that while canopy cover is an important predictor of a huckleberry patch that grizzly bears use, opening the canopy does not necessarily result in a huckleberry patch. The cumulative site conditions as revealed through or best model also must be met.

Twenty-six percent of areas predicted to have huckleberry patches important to grizzly bears were in a cut block, suggesting that timber harvest can contribute to the regional availability of huckleberry patches for grizzly bears. Without years of fire suppression, natural fires likely also would have increased the availability of huckleberry patches regionally (McLellan 2015). Within the NCC Darkwoods area, the mean number of years since being logged for blocks with huckleberry patches was 39 years, while the mean age for blocks without patches was 27 years and these were significantly different ($p < 0.001$; Fig. 28). As a proportion of available, logged areas were more likely to not have huckleberry patches than have one. Within the NCC Darkwoods area, cut blocks that were planted post timber harvest were 80% less likely to yield a huckleberry patch. We suspect that planting hastens the return to canopy closure that is not conducive to a productive huckleberry patch. Slash burning post timber harvest did not appear to influence whether or not a cut block contained a huckleberry patch; slash burned cut blocks were slightly less likely to have a patch. There was no difference in % shrub cover between sites with and without huckleberry patches ($p = 0.27$) but herb cover was significantly less in sites with huckleberry patches ($p < 0.001$).

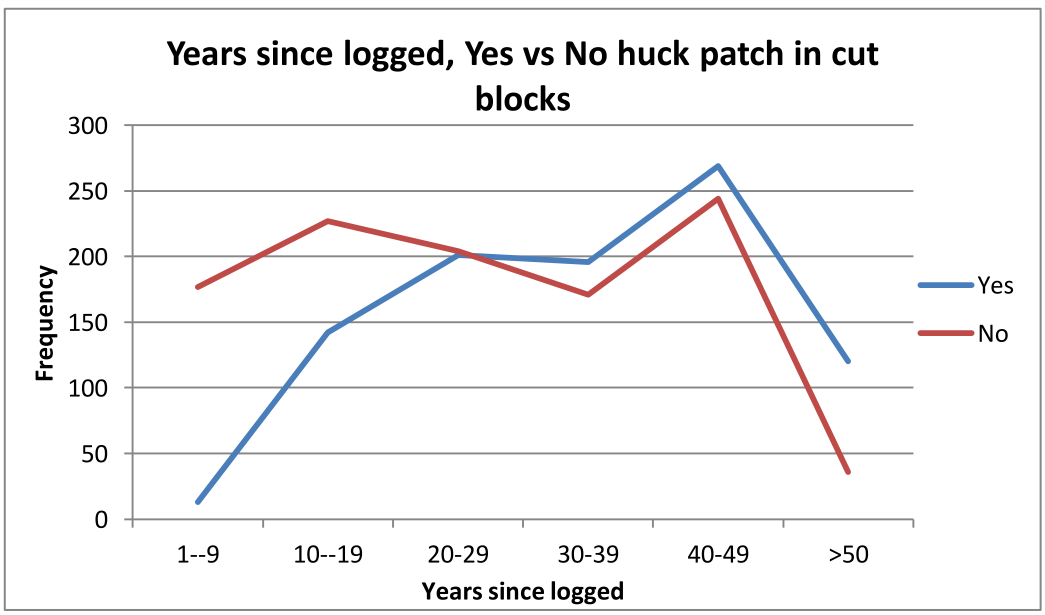


Figure 29. The relationship between years since being logged and the presence of a huckleberry patch grizzly bears use in the Nature Conservancy of Canada's Darkwoods property.

DISCUSSION

Bottom up vs top down forces

We have shown across several population processes that huckleberry patches in our focal area, are the most important driver in female habitat use, home range selection, density, and fitness. Road density was found to be important and additive to the influence of huckleberry patches. We conclude that both bottom up and top down forces influence grizzly bear ecology and conservation in the South Selkirk, South Purcell and Yahk areas within southeast BC and should be integrated to improve management of this sensitive species.

Many investigators have found food resources to heavily influence density of vertebrate populations (Hildebrand et al 1999, Sinclair and Krebs 2002, Garbone and Gittleman 2002, Brasher et al. 2007, McLellan 2011, 2015). There is a wide range of grizzly bear densities across North America that are undoubtedly the result of varying quantities of available food resources (McLellan 1994, Hilderbrand et al. 1999, Mowat and Heard. 2006). Our results support this hypothesis, and further suggest that top down forces likely influence a population's ability to reach the density where they are food regulated. Of course, the dramatic range contraction of North America between 1860 and 1970 (Mattson and Merrill 2002) clearly showed that top down forces can be extreme enough to overcome plentiful food resources, (Mattson and Merrill 2002, Boyce and Waller 2003, NCGBRT 2004). But these extreme mortality rates have essentially halted for the past 40 years, and now food resources primarily determine bear densities and human-caused mortality, while still important in grizzly bear conservation in many areas, is not likely driving density patterns continent wide.

At the scale of our study area, grizzly bears are heavily influenced by the presence of huckleberry patches >10ha. They are also influenced by mortality risk in the form of road density. Huckleberry patches were a positive influence and road density a negative influence. In most top models, besides huckleberry patches, other selected for habitat variables also contributed to higher predictability. This was expected because bears eat many foods other than huckleberries (other less abundant berries, roots, and herbaceous plants, and ants, and more, McLellan and Hovey 1995, Nielsen et al. 2010), even though huckleberries may be the most important energy and fat producing food in our study area (McLellan and Hovey 1995, McLellan 2011, 2015). High energy foods like huckleberries are particularly important for hibernating bears, especially females, as they are known to reabsorb their as yet implanted embryos in the fall if they do not store sufficient fat reserves (>~20-24 % body fat) for hibernation, birth and nurse their young while in the den and for a few months after emergence (Robbins et al. 2012, McLellan 2015). We do not have specific layers predicting these other foods, but they are often found in habitats represented by a decent surrogate variable, greenness (Mace et al. 1996, Nielsen et al. 2002, Stevens 2002. Boyce and Waller 2003, Mowat et al. 2005, Ciarniello et al. 2007, Proctor et al. 2015) and that is represented in most top models complementing the huckleberry patch variable.

With the addition of our huckleberry patch model to our suite of predictor variables, predictability improved greatly over our previous efforts (density – Proctor et al. 2007, and habitat use – Proctor et al. 2015), neither of which had the benefit of the huckleberry patch layer. In Proctor et al.'s (2015) female only habitat use model the ROC AUC score was 0.72 and the Pseudo R^2 was 0.11, while our current female-only habitat use model with the huckleberry patch layer had a ROC AUC score of 0.82 and a Pseudo R^2 of 0. 25. Furthermore, the addition of a highly influential and predictive food layer such as huckleberry patches has the added benefit to allow us to really put to a good test the relative influence of top-down mortality risk. High energy huckleberry patches were certainly the predominant predictive variable, but mortality risk (as represented by open road densities) contributed significantly to all the best models' predictability.

Interestingly, we found that open road density was the best predictive variable representative of overall human access and influence into the backcountry. It consistently out-performed open-road or distance-to-road variables and even the human access variable (a complex interaction between distance from population centres and road networks, Apps et al. 2004, 2016), which was surprising. It was also usually better than our composite modelled mortality risk layer, even though road density was the most influential predictor in that layer. It is logical that the number of humans driving on backcountry roads is an important factor in mediating mortality risk as humans kill bears not roads (Northrup et al. 2012), but the simple measure of open road density was the most predictive. It may be that human population centres are close enough to allow easy enough access to most of our study area and/or that levels of mortality and displacement at further distances from human population centres is similar to those areas closer to towns and main thoroughfares. It has been speculated that human-caused mortality close to backcountry roads may be more likely to not be reported than those closer to population centres because the prospect of being witnessed may decrease. Our mortality risk layer was developed with mortality data skewed toward front country mortalities, so it was not unexpected that road density alone was a better predictor of population processes where the input data was primarily backcountry data. In the nearby Flathead valley, McLellan (2015) found far higher densities of bears in an area with much higher road densities (1.7 km/km^2) than our study area. The Flathead study area, is over an hour drive from the nearest human residence, indicating that at broader scales, distances from human population centres is likely a consideration.

Bottom-up and top-down influential variables vary spatially across our study region. Our results suggest that in areas where there are important huckleberry patches, access controls to reduce open roads in these areas would be a useful to improve habitat security and thus survival, reproductive success, and densities. The huckleberry patches in the South Selkirk area have good overlap with Nature Conservancy Canada (NCC) Darkwoods lands. These private lands have been extensively logged over the past decades (under Pluto Darkwoods timber company ownership) and experienced a degree of public access control over the vast majority of the forest roads on these lands (Wielgus and Vernier 2003). That access control has been continued by the NCC. We found female densities and reproductive success to be relatively high on these private lands. Of the 2 threatened population units in our focal area, the South Selkirks (the other being the Yahk) is approaching recovery at a faster rate, increasing at ~1.8% annually (Kasworm et al 2015, MacHutchon and Proctor 2016). More concerning is the situation on the Canadian Yahk that has a lower huckleberry patch density and higher average road density than the South Selkirks. In fact, the only female telemetry data we have for the Canadian Yahk is from females who were captured and remained most of the time in the US Yaak. The US Yaak has legally mandated access controls that result in road densities < ~0.6 km/km^2. Across our study area we found no females with home ranges with average values > ~1.0 km/km^2 road density. The average road density in the Canadian Yahk was ~1.7 km/km^2.

The often used road density threshold for female grizzly bears of 0.6 km/km^2 was first detected in Montana by Mace et al. (1996) who used VHF collars with a fraction of the number of locations than modern GPS collars. Mace et al.'s (1996) work informed access control protocols across the US grizzly bear recovery zones. Access controls have been a cornerstone (among other policies to reduce human-caused mortality) of the US recovery effort that has been successful (Mace et al, 2012, Schwartz et al, 2006, Bjornlie et al. 2014, Haroldson et al. 2016). Interestingly, our results based on GPS telemetry data also signaled strong bear preference (and or survival) in habitats with road densities < 0.6 km/km^2. As we did, a recent study in southern BC Granby-Kettle GBPU found that grizzly bear densities were ~3 times higher in habitats with road densities <0.6 km/km^2 (Lamb et al. in review). Road density of 0.6 km/km^2 is often used as a threshold target in the US and Alberta in varying proportions of the land base in occupied habitat. Actual standards are complex but the 0.6 km/km^2 target is central to that conservation. Several recent studies show that female mortality increases as road densities increase (Schwartz et al 2010, Boulanger and Stenhouse 2014). In the Flathead, however, bear densities are 3 to 6 times higher than any of these studies but there road densities are 1.7 km/km^2 suggesting that other factors, such as distance from human population centres may be important.

Another important measure of roads in the backcountry is the proportion of an area with habitat >500m from an open road (sometimes called "core" or "secure habitat") and this metric is also used in US recovery management of grizzly bear habitat. We found strong female home range selection (and likely survival) for habitats with higher proportions of core area in female home ranges, corroborating its importance. Schwartz et al. (2010) found a similar result in that road density and the amount of secure habitat (>500m from an open road) were both significant predictors and additive when modeling female grizzly bear survival. They found that as the amount of secure habitat declined, average road densities also needed to decline to maintain female survival. They concluded that appropriate conservation management required the amount of secure habitat needed to be balanced with road density targets to alleviate isolated patches of secure habitat being surrounded by a matrix of high road densities where mortality risk was elevated. It should be noted that there are no open roads in any of the large and numerous huckleberry fields in the Flathead which also may help explain the high density of bears in an area with high road densities.

An insight in our results relative to managing road density, is that we show clearly the primary importance of food resources and how they are additive with road densities in influencing and predicting population processes. Our results suggests that any access controls that include information of the most important food resource, in our case huckleberry patches, should confer greater benefit to bear conservation and recovery than a broadly applied access control strategy that does not take into account the location of important food resources. This also highlights another improvement in our analysis, the spatialization of important food resources, road densities, and mortality risk that simultaneously inform where landscape habitat management would be the most effective.

Huckleberry patch modeling

Most previous efforts to predict huckleberry species have focused on plant occurrence (Nielsen et al 2004*b*, Roberts et al 2014, Braid and Nielsen 2015). Here we focused on huckleberry patches important to grizzly bears. It was our use of extensive and wide spread (across 2 mountain ranges) grizzly bear GPS telemetry data with relatively short location intervals that allowed us to locate many patches that bears used. Our occurrence map demonstrated that huckleberry plant occurrence is relatively widespread in our region. But our telemetry data and our predictive patch model demonstrated that only a portion of that occurrence distribution was being used by our sample of grizzly bears.

There were several striking differences between our occurrence and patch models, as were expected, as our patch model was modeled to locate patches within the distribution of occurrence (Fig. 9b). Notable was the dominance of precipitation as snow as a predictor of occurrence, suggesting that deep snow is likely a beneficial for huckleberry occurrence. Even more snow was beneficial for patches. Deep snow is an important insulator to conserve moisture in harsh winter conditions (Stark and Baker 1992). Canopy cover was also important predictor of occurrence, but even more so for patches as it was the most influential. Interestingly, coarse fragments in soil (as a negative relationship) was minimally important in huckleberry occurrence, but very important for patch formation. Huckleberry occurrence is thought to be an indicator of soils low in nitrogen (Klinka et al. 1989).

Our results suggest that certain combinations of soil conditions, ecological and topographic features, climate conditions, and position in this mountainous habitat when combined with lower canopy cover yield huckleberry patches with enough fat building berries to make it worth a grizzly bear's investment. Almost all of these variables cannot be manipulated to improve huckleberry production or patch creation with the exception of canopy cover, the most influential variable. This variable will undoubtedly play a significant role in understanding the relationship between forestry and huckleberry patches. It also may provide an avenue for management with an eye to huckleberry patch maintenance and/or creation. Nielsen et al. (2004*a*) found canopy cover to be the only significant predictive variable for fruit (*V. membranaceum*) production in clear cuts in Alberta, but sample sizes limited their spectrum of predictor variables when comparing huckleberry production between clear cuts and upland forests. They were not modeling food patches known to be used by grizzly bears as we did, but fruit production that may be a good surrogate for patches that tend to be used by bears. They also found that 3 *Vaccinium sp.* were more prevalent in upland forests than clear cuts. This is consistent with our finding that 74% of huckleberry patches used by grizzly bears were not in a cut block and tended to higher elevation open habitats. They suggested that areas with forests with minimal natural openings might benefit from cut blocks that open the canopy. Our results suggest that canopy opening activities (logging or burns) may be more effective at yielding huckleberry patches in areas where the underlying soil, topography and climate conditions are conducive to huckleberry patch occurrence, as per our model results. They also highly recommend that huckleberry patches be accompanied by access controls for habitat security reasons consistent with our findings as well. McLellan and Hovey (2001) and McLellan (2015) found that grizzly bears foraged almost exclusively in old burns when eating huckleberries in the Flathead. On the coastal mountains, however, bears feed on huckleberries in many cut-blocks, as well as burns and in subalpine parkland (McLellan unpublished data).

Many of the best predictor variables were related to micro- and macro-climate conditions (precipitation as snow, annual average precipitation, precipitation in summer, frost free period, inter minimum temperature). Climate change, of course, may alter the long term patterns of some of these variables that affect temperature and timing and supply of moisture. We are currently working with climate modellers to explore how climate change modeling predictions may influence our regional huckleberry crop. Roberts et al. (2014) modelled several critical bear food items in Alberta and concluded that the important huckleberry species (*V. membranaceum*) may likely maintain and even increase its current distribution with climate change. Because huckleberry is a major food across such a large area from wetter coastal forests to the relatively dry areas of the East Kootenay, increase in wildfires at higher elevations will likely increase berry production at least in some areas.

We focused on huckleberry patches important to grizzly bears, rather than annual variability in production. In our view, we have very little control over annual variation in berry productivity, but there is some possibility of control over conditions that allow a patch to generate and persist. Our partners in the US Fish & Wildlife Service working in the US portions of the ecosystems of our focal area, have been involved in tracking and understanding annual variation in productivity. Holden et al. (2014) found that huckleberry production was highest during cool springs with high July daily temperature ranges. Growing-degree days across April to June and July temperature range explained 70% of the inter-annual variability in huckleberry productivity they measured. We have plans to integrate our respective research questions and field methods to provide improved insights into spatial and temporal patterns in huckleberry production.

Female habitat use

Our huckleberry patch model was highly predictive in the suite of population processes we measured. In female summer habitat use, it was the most dominant (Fig. 14). This was expected as from mid-July through mid-September grizzly bears focus on storing fat reserves for reproduction and hibernation (McLellan and Hovey 1995). Greenness was the 2nd most influential variable and is a surrogate for other foods that grizzly bears feed on during this time. Greenness has been shown to be predictive of grizzly bear habitat use by many researchers, (Mace et al. 1996, Nielsen et al. 2002, Proctor et al. 2015), but surrogate-driven models can be improved on when they use direct food resources (Nielsen et al. 2010) as we found in this study. Road density was a significant contributing predictor in our female summer habitat use model but this was likely its least relative influence across our models. This was likely the case for 2 reasons. First, most detected mortality occurs in the spring and fall, generally outside of the main berry season (but our mortalities were skewed toward front country events) and 74% of the important huckleberry patches were not in cut blocks, but in higher elevations, suggesting that they were less associated with roads, and many weren't. The road avoidance we did detect was corroborated by our home range selection results that demonstrated evidence of displacement from open roads, no matter what the density.

McLellan (2015) suggested in a relatively high density grizzly bear population where huckleberries were a big influence of inter-decade population trends, that the huckleberry fields grizzles used were all in higher elevation open forested areas and separated from all forestry roads. That separation, he concluded was likely one reason for the high densities of bears as a result of having high habitat security in the highest quality habitats. To some degree, we have a similar situation in portions of our focal area. In the South Selkirk Mt. portion of our area, where there were plentiful cut blocks with huckleberry patches, access management has been a policy for 3 decades providing high habitat security in the highest quality habitats.

Female home range selection

Huckleberry patches were the most influential predictor in female home range selection. The ratio of selection (use/availability) for huckleberry patches were ~3:1, while the ratio for selecting habitats with low road densities was ~2:1. Mace et al. (1996) also found home range selection was influenced by avoiding areas with higher road densities. They found female bears lived on average, in home ranges with 0.6 km/km^2. Our females lived on average in home ranges with 0.5 km/km^2. This 0.5 km/km^2 value was also found to be optimal by recent work in the Granby-Kettle area of south central BC (Lamb et al. (in review). There are likely several mechanisms related to human disturbance that influences home range selection. Several researchers have shown that female survival is lower in areas with higher road densities and lower amounts of secure habitats (>500m from an open road, Schwartz et al, 2010, Boulanger and Stenhouse 2014). This supports the idea that home range selection may reflect "home range survival".

Our results also found evidence of displacement in our comparison of the larger Minimum Convex Polygon (MCP) to the smaller more refined Kernel Home Range (KHR). It was very clear that all females were selecting their KHR to avoid roads even within their larger MCP home ranges, no matter how low a road density they had in their MCP home range.

The dynamic between bears being displaced by roads and bears being killed by humans on roads is sometimes difficult to tease apart. Mechanisms influencing grizzly bear displacement from roads is complex (Roever et al. 2010). Bears can also be attracted to roads for the food resources on roadsides (often planted, Roever et al. 2010). Traffic on roads can also cause shifts in temporal use of roadside habitats (Northrup et al. 2012). Most studies recognize the link between roads and the increased risk of mortality that accompanies their sometimes attractive qualities. In the end, the precise relationship between habitat, displacement, selection, and survival likely varies spatially and temporally.

Density

Density is the cumulative outcome of several population processes, habitat quality, use, and effectiveness, survival, and reproduction. The most striking result of our density model was the additive influence of attraction to huckleberry patches and avoidance of/survival in areas with higher road densities (Fig. 18). Other researchers have queued in on this additive relationship (Nielsen et al 2009, Roberts et al. 2014). As mentioned above, like Lamb et al. (in review) we also found grizzly densities to be several times higher in areas with road densities < 0.6 km/km^2.

Abundance and density estimates are becoming common in bear research (Proctor et al. 2010, Mowat et al. 2005, 2013, Apps et al. 2004, 2016) and the use of recently developed statistical methods has greatly improved our ability to overcome past hurdles such as closure violation, but it is the addition of environmental predictors that increase our inference with these otherwise basic ecological investigations. (Royle et al 2013, Proffitt et al 2015, Morehouse and Boyce 2016, Lamb et al. in review). While covariates are more often being incorporated into density estimates, particularly within the recently developed Spatially Explicit Capture Recapture (SECR) methods, we know of none that incorporate bottom up food models at this time. However, top down mortality risk represented by road density, has been used to improve spatially explicit density predictions (Lamb et al. in review). Here, our focus was less the actual bear densities (they are >10 years old), but more the environmental covariates used to tease apart bottom up from top down predictors, so we used logistic regression techniques as per Apps et al. (2004, 2016). In the upcoming year, we are rerunning this density analysis with our improved suite of predictor variables with the Spatially Explicit Capture Recapture methods.

The home range-scaled (8km) model for female density (Fig 18c) had an anomaly in the strongly negative coefficient (Table 7) of the riparian variable. Riparian habitats are typically a positive variable (McLellan and Hovey 2001, Proctor et al. 2015), however the DNA surveys are typically done in June and July, as were the 6 in this analysis, and riparian habitats are often associated with valley bottoms and roads. Our only explanation for this result is that female grizzly bears as sampled during DNA surveys were avoiding riparian habitats that were associated with roads. Closeness to huckleberries and avoidance of habitats with higher road densities were also additive.

Fitness

Our top fitness model included both huckleberry patch and road density variables. Therefore it may be our best representative for identification of “safe harbour” habitat as introduced by Nielsen et al. (2009) where higher quality habitats are accompanied by high levels of habitat security. Our female summer habitat use model (see above) also identified the best habitats including our huckleberry patch and other positive habitat variables and road avoidance/survival during the season when mortalities were the lowest (Fig. 12b). That model may also be a representation of “safe harbour” habitats.

The use of a thorough pedigree from extensive genetic sampling to explore reproductive success has been around for many years (Blouin 2003, Boudry et al. 2003, Pemberton 2008, Lemay and Boulding 2009, Ford et al. 2011), although the explosion in genetic sampling and the use of many genetic markers has made it affordable and more accurate. Our use of fitness derived from a genetic pedigree in a top down – bottom up analysis may be unique. We did not sample these populations with this analysis in mind but realized its potential for integrating one of the most powerful forces in nature – reproductive success – to understand ecology and conservation of grizzly bears. Here we Integrated a pedigree to infer differential reproductive success and used these data to examine patterns in land use for the benefit of a species conservation. Past ecological studies of many wildlife populations have relied on surrogates for important processes mainly due to technological and logistic limitations often associated with wildlife studies. But our long term project could take advantage of a thorough genetic sampling that took many years to accumulate. This also had the advantage of allowing offspring to survive and disperse away from their natal home range. This approach has some differences from studies that estimate reproductive success by counting offspring the year, or year after, they are born. Many of those offspring may not survive to adulthood, although this can be measured. Our sample was likely a combination of young and older offspring, some still with their mother, but many long since dispersed. In that regard, our measure may be closer to a real fitness measure.

However, while useful and creative, our method has limitations that are usually based on the inability to tell age from a genetic sample. It is sometimes challenging to tell in a family group, which female is the mother or daughter. This is why we limited our pedigree assignments to only groups where we had perfect genetic matches within triads - mother, father and offspring. Another issue is that some females may be young and have not been alive long enough to accumulate surviving offspring. Furthermore, the sampling, even if done over a short period, may reflect conditions over many years. What was very dangerous habitat a two decades ago, may be now be safe. We think that the longer-term sampling effort would allow for that limitation to be diminished by a larger sample size, that is, any particular area would have a mix of young and older successful females and our chances of sampling them would be equalized across our study area and this still represents the spatial patterns we identified.

The significance of this population metric is that fitness, or reproductive success, is the ultimate measuring stick for whether or not a variable is important to population viability, management, and conservation. The additive influence of bottom up and top down forces in our fitness modeling results speaks to the importance of including both realms in conservation management of this species. Furthermore, the fact that our huckleberry patch model was such a good predictor variable across all the population characteristics and processes we modelled, suggests that the relationships we found were real and not an anomaly of sampling bias or chance.

Huckleberry patches and forestry

Black huckleberries are widely distributed in Coastal and Interior Northwest montane and higher elevation forests, and subalpine habitats and are reportedly the tastiest of wild berry crops and preferred by peoples for millennia (Kerns et al. 2004). They are an important fruiting shrub for humans and wildlife (Hobby and Keefer 2010). They are bee pollinated, animal dispersing, mostly rhizome spreading (Stark and Baker 1992), intermediately shade, fire, and low nutrient tolerant (Klinka et al. 1989, Hobby and Keefer 2010) with a mycorrhizae symbiotic nutrient uptake system (Gorzalek et al. 2012). While fire has been shown to precede huckleberry plants and patches used by grizzly bears (McLellan 2015), the production and timing of a patch post-fire appears to be dependent on the severity of the fire (Miller 1997, Hobby and Keefer 2010).

Annual fruit production is undulant and many researchers have attempted to unlock the appropriate conditions that will result in a good huckleberry year. (Nielsen et al 2004*a*, Hobby and Keefer 2010, Holden et al. 2014). It appears that the appropriate conditions for a good annual crop vary spatially and temporally. Here we did not track annual production, but instead let the bears take us to patches that they used over the course of a decade of radio tracking. Our results are based on the assumption that bears will frequent patches that are worth their time investment to fuel their required weight gain and fat deposition for hibernation and reproduction (McLellan 2011, 2015, Robbins et al. 2012), at least during the years the patches were productive. The goal of this project was to locate, understand, and predict geophysical, ecological, soil, climate and topographical conditions that conspired to yield a huckleberry patch that grizzly bears used, not understand or predict their undulant annual fruit productivity.

We were surprised that only 26% of our predicted huckleberry patches were within timber harvest cut blocks. However, 18%, on average, of our focal area was a cut block at any one time suggesting that cut blocks have yielded huckleberry patches more than a simple area assessment would suggest. Our results also show that just because the canopy has been opened by logging it does not necessarily result in a huckleberry patch. The cumulative site conditions as revealed through our top model must also be present.

The Yahk GBPU area has approximately 34% of its area in cut blocks, yet only 1.1% of that GBPU is a predicted huckleberry patch. This suggests that the underlying climate, geophysical, soil, and topographic conditions important for huckleberry patch production do not exist in much of the Yahk. Where site conditions are more favorable to huckleberry patch development in the South Selkirk Mountains, 3.9% of that area is a predicted huckleberry patch, yet only 11% of it has been logged. In a separate effort, we are attempting to translate these patterns into the ability to estimate grizzly bear carrying capacity for these different ecosystems (at least relative carrying capacity). We need to improve our understanding of the potential use of other fruits in the Yahk area (e.g., buffalo berry (*Shepherdia canadenesis*), grouseberry (*Vaccinium scoparium*), or low bilberry (*Vaccinium myrtillus*).

We found that post-harvest tree planting was a detriment to huckleberry patch production likely because planting hastens the return to canopy closure. Fire outside of post-harvest slash burning was found to have a higher proportion of huckleberry patches. This is consistent with conventional wisdom that fires often precede huckleberry patch development (Minore 1975, Minore et al. 1979, Azinger 2002, Hobby and Keefer 2010, McLellan 2015) including reports that first nations people used fire to stimulate huckleberry within in the pacific northwest (French 1999). Hamer and Herrero (1987) documented fire inducing succession stages that resulted in increased grizzly bear forage, although the berry crop in their area was buffalo berry. The relationship of huckleberries to fire is complex, and we will not review the literature here. The US Forest Service has an extensive website devoted to huckleberry ecology: www.fs.fed.us/database/feis/plants/shrub/vacmem/all.html#FIRE%20ECOLOGY%20OR%20ADAPTATIONS.

The relationship between timber harvest, fire suppression, wild fire ecology and huckleberries is complex (Minore 1972. 1975, Minore et al.1979, Hobby and Keefer 2010). Slash burning post timber harvest did not appear to influence whether or not a cut block contained a huckleberry patch, and slash burned cut blocks were slightly less likely to have a patch.

We were surprised that our predictor variable "time-since-last-fire" was so low in our ranking of influential variables (Fig. 9). We suspect that while fire has been noted by many to precede good huckleberry patches, our evidence suggests that it is the combination of underlying soil, climate, and topographical conditions coupled with the canopy opening that contributes to the huckleberry patch genesis. We did not explore details of the relationship between fire and huckleberries, although many good huckleberry fields are a result of fires many decades ago (McLellan 2015). We suspect that conditions of those fires, including intensity and location, contributed to decades of canopy openness post fire. The average age of our huckleberry patches was ~40 years post disturbance, and a large proportion were in higher elevations (83% >1500 & <2000 meters), which may contribute to slower times to canopy cover post disturbance to some degree.

Can timber harvest mimic natural disturbance regimes and yield a spectrum of forest succession across a broad land base that provides for the natural spectrum of flora and fauna and ecosystems and also yields a profitable timber industry? We suspect yes to some degree, but it will take some experimentation and allowing for some portion of the working forest to take several decades to reach canopy cover >30% to allow useful huckleberry patches to develop. While we are not tracking annual production, it would be beneficial to understand long-term patterns in huckleberry patch supply. Forest fire suppression over the past decades has been indicated to potentially have reduced large productive huckleberry patches (Minore 1975, Minore et al.1979, Hamer and Herrero 1987, Hobby and Keefer 2010) such as that exist in the Flathead valley of southeast BC that support a high density of grizzly bears (McLellan 2015). We are continuing and expanding this project across the entire Kootenay Region 4 with field visits to identify important huckleberry patches grizzly bears use. With that larger regional data, we may be able to further identify patterns with fire suppression and huckleberry patch prevalence.

In that regard, our results suggest that canopy openness is one of the driving characteristics in huckleberry patch development, in areas where the combinations of climate, soil, and topographic conditions are right. Nielsen et al (2004*a*) found canopy cover to be the only significant variable influencing huckleberry production in clear cuts in Alberta. We found that canopy cover <30% was conducive to huckleberry patch development in areas with appropriate site conditions, and that huckleberry production was best over a 40-50 year window. Timber harvest management that plans on maintaining canopy cover <30% for 4-5 decades may challenge timber companies where quick conifer regrowth resulting in canopy closure and wood fiber production are the goals.

In spite of the fact that good huckleberry patches required canopy cover <30% for several decades and that this may be counter-productive for timber companies, we envision that BC's forests are being managed for overall ecosystem health that includes the full spectrum of wildlife including large carnivores such as grizzly bears. Of course, a vibrant timber industry is important for BC, but timber is one of many values our forests deliver. A main tenant of the Association of BC Forest Professional's (ABCFP) principles of forest stewardship (ABCFP 2012) is to maintain function, structure, and composition of key ecosystem components over both temporal and spatial scales. The ABCFP (2012) suggest that maintaining ecological integrity requires strategic management of valued ecosystem components (such as grizzly bears) at both the landscape and site levels. Therefore we hope that some portion of the timber harvest land base might be managed for long-term grizzly bear forage in the form of huckleberry patches, within a well-balanced multi-value management plan, and that our results may help stimulate and inform such management.

Huckleberry patches and the BEC system

Our effort to translate our huckleberry patch model results into the BEC system was challenging. The BEC system sub-divides ecosystems into many complex units that are difficult to use as predictors in a modeling exercise. However, we did a post modeling analysis to look for patterns between our modeling results and the BEC system. What we found was encouraging, but not perfect. For example, within the ESSF wet mild subzone of our focal study area, site series 103 and to a lesser degree 101, contained many of our predicted huckleberry patches. However, it does not appear to be a simple as opening the canopy in these BEC subzones and site series to yield a huckleberry patch. Fig 30a shows a map of our huckleberry patches intersect with the ESSFwm3, 4, w subzones and site series 103 where canopy cover is <30%. The overlap is encouraging but imperfect. Figure 30b is a map of future huckleberry patch potential in areas with the appropriate underlying site conditions where we simulated opening up the canopy to less than 30% cover. The overlap with the ESSFwm3, 4,w subzones and site series 103 is again encouraging but not perfect. We suggest these BEC subzone and site series combinations favour huckleberry patch production but the match is not tight.

We recommend that foresters who use the BEC system for harvest and silviculture management use our future predictive map (Figs 21 & 30) ***and*** our BEC recommendations (see Appendix I) to experiment with production of black huckleberry patches important to grizzly bears. We speculate that the difference between our model predictions and the BEC system is that we are predicting patches that grow to a size and productivity that it is worth it for a grizzly bear to use, rather than just growing huckleberry plants at some lower level of overall patch productivity. The BEC system was decent at predicting huckleberry plant occurrence, we were better at predicting huckleberry patch occurrence, 2 very different things. There are likely other differences and complexities that we are not aware of.

a b

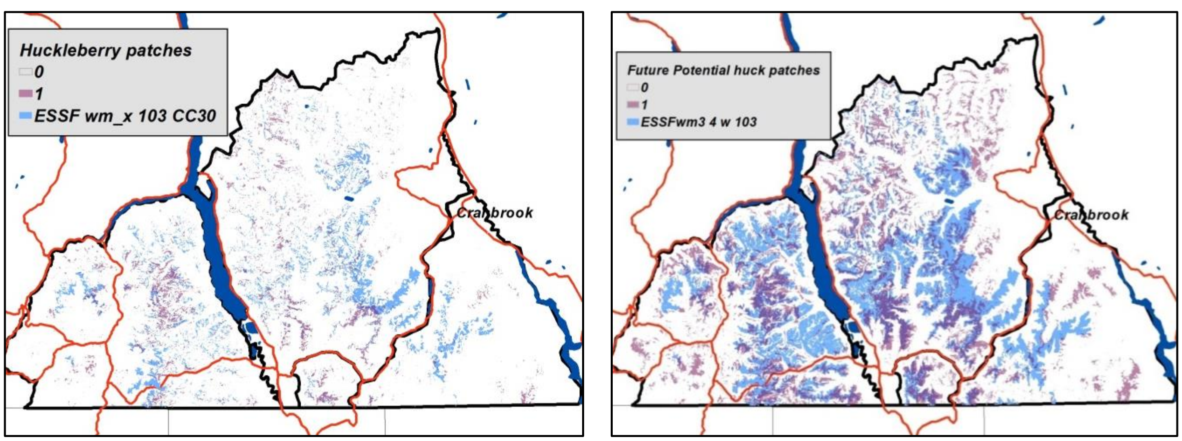


Figure 30a. Map of Biogeoclimatic Ecosystem Classification (BEC) units that favours huckleberry patches (ESSFwm3, 4, w subzones and site Series 103 where the canopy cover is < 30%)., and b) future potential huckleberry patches that grizzly bears might use relative to BEC units that are conducive to developing into huckleberry patches in our focal area of the South Selkirk, South Purcell, and Yahk GBPU areas.

MANAGEMENT IMPLICATIONS

The management implications of our results are significant, particularly in southern Canada. Some areas of British Columbia and Alberta are struggling with their grizzly bear management. As Proctor et al. (2012) demonstrated, the grizzly bears of southern Canada are beleaguered by extensive population level fragmentation, and beyond the importance for their own conservation status, they are an important link to long term survival of grizzly bears in the northwestern lower 48 states that are at the southern tip of occupied peninsulas. It is critical for long-term conservation of grizzly bears across their southern North American distribution that BC and Alberta understand and manage not only for inter-population connectivity and mortality reduction, but also for quality and security of core backcountry habitats. We recently published a paper detailing connectivity mapping (Proctor et al. 2015) as a follow up companion paper to Proctor et al. (2012) that detailed the regional population level fragmentation. The connectivity mapping paper is stimulating and informing connectivity management in our larger trans-border study region. However, within Canada, the backcountry habitats that we are working to reconnect are generally being ignored from a management perspective. Currently, these jurisdictions do a minimal job of managing backcountry top-down forces (human-caused mortality) in the backcountry, and bottom-up management is generally non-existent, either in providing for enhancing the quality of habitat through understanding their primary food resources spatially and managing for them, or in terms of providing habitat security in and around the most important food resources (AB, M. Boyce, G. Stenhouse, pers. comm. BC, Boyce et al. 2016, M. Proctor unpub. data).

There are several proximate reasons for this management shortfall, but the ultimate cause may be the lack of a consensus among scientists about the influence and relationship between bottom-up and top-down influences on grizzly bear population viability and conservation status. This work helps clarify that relationship and provides direction for management priorities within our region. As one might expect, in our study area, the answer is ***BOTH*** bottom-up and top-down influences drive grizzly bear viability and are at work in our populations. What this work brings to the management arena is the relative contribution of both, and how management efforts using both are likely necessary for effective long-term management of grizzly bears in our region. As sometimes is the case, there are two perspectives arguing the importance of bottom-up ***or*** top-down. This work will provide insight into that false dichotomy, and hopefully push through it to foster more comprehensive management.

CONCLUSIONS

Bottom up vs Top down influences on grizzly bears

- Both bottom up and top down forces are important to grizzly bear population process, ecology and conservation.
- Huckleberry patches, representing bottom up food resources were most influential in female habitat selection, home range selections, density, and fitness.
- Road density was the most predictive of human disturbance variables in predicting female habitat selection, home range selection, density, and fitness.
- Road density was in all multi-variate best models and was additive to the influence of huckleberry patches.
- Grizzly bear densities were 2-3 times higher in habitats with road densities <0.6 km/km^2.
- The fact that our huckleberry patch model was such a good predictor variable across all the population characteristics and processes we modelled, suggests that the relationships we found were real and not an anomaly of sampling bias or chance.

Forestry and huckleberry patches

- The right combination of topographic, soil, ecological, and climate conditions when coupled with canopy cover <30% has the highest probability of yielding a black huckleberry patch that grizzly bears might use.
- Within the South Selkirk, South Purcell, and Yahk GBPUs, black huckleberry patches that grizzly bears use frequently occur in BEC variants ESSFwm3, wm4, or wmw and site series 103, and to a lesser extent 101.

- Three-quarters of the huckleberry patches we identified were not in cut blocks, although 1/4 were, suggesting timber harvest has a role to play in grizzly bear forage management and as a replacement to natural forest fires as an agent for opening the forest canopy.
- Post-harvest slash burning appeared to make no difference to huckleberry patch production, whereas selective cuts and planting seemed to have an inhibitory role.
- Cut blocks in the right combination of site conditions that have <30% canopy cover for several decades would be beneficial to long-term grizzly bear forage supply, although may be counter to forest regeneration focused on maximizing future timber harvest potential.
- However, we hope that BC's forests are being managed for overall ecosystem health that includes the full spectrum of wildlife including large carnivores such as grizzly bears. Timber is one of many values our forests deliver.

RECOMMENDATIONS

Access controls around good huckleberry patches

We recommend that the landscape not be managed so that there is an even road density spatially, but in a mosaic of human access that includes several human access targets based on habitat quality and the presence of hyperphagic foods. For instance, we suggest that approximately 25% of the landscape, particularly portions with important huckleberry fields have no roads.

Huckleberries are ***the*** major food resource for grizzly bears in at least most of the Kootenay Region (McLellan and Hovey 1995, McLellan 2011) driving population productivity (McLellan 2015). Furthermore, it has been suggested that huckleberry patches in areas with minimal road densities, and therefore human disturbance, may be beneficial to female grizzly bear reproductive rates (McLellan 2015) and this study supports that suggestion.

We recommend that managers in the southern portion of the Purcell and Selkirk mountains within the Kootenay Region where huckleberries are known to be important to grizzly bears, apply access controls around important huckleberry patches we have identified. This can take several avenues, one being the establishment of Wildlife Habitat Areas, the other is road closures, of which some could be seasonal during the huckleberry season (late July – late September). Access management usually is not a popular management activity, so we recommend that the results of this project be discussed with stakeholder groups so they can see the benefits to our natural systems. Our experience is that when the public and industry see the facts, they usually support good habitat management. This does not mean that people will be shut out of the backcountry, just that some areas with excessively high road densities may be reduced to levels compatible with grizzly bear survival, reproduction, and habitat use.

There are several specific patches that would benefit from some form of protection (access management potentially), to insure less human disturbance for female grizzly bears. An example of two patches are the Iron Range and Grizzly Meadows patches just north of Hwy 3 in the South Purcell Mountains depicted in Fig. 31.

Access controls target 60% of landscape be >500m from open roads and 25% be any road density

We recommend that approximately 60% of the landscape be beyond 500m of an open road in patches >5-10 km^2, and that approximately 25% of the landscape have any level of road density to support resource extraction and recreation.

Access controls target of 0.6 km/km^2

We recommend that the landscape not be managed so that there is an even road density spatially, but that higher quality habitats such as many identified in Proctor et al. (2015) be managed to have <0.6 km/km^2. This is in addition to the above recommendation where areas around important hyperphagic food patches be managed for no roads

Huckleberry patch development be integrated into forest planning

We recommend that the timber industry test for huckleberry patch genesis in the areas we have identified as good future potential for huckleberry patches when the canopy is opened up (Figs. 21 & 30).

We recommend that forest and ecosystem planners plan for ecosystem-wide (or GBPU-wide) grizzly bear forage where feasible and practical. This would entail managing for a reasonable huckleberry supply where ecological and climate conditions allow at the stand, landscape, GBPU and ecosystem scales and can be facilitated through the use of our huckleberry patch future potential map (Figs. 21 & 30) and through protecting existing patches (Fig. 7). This does not mean that forestry should be prioritized around producing huckleberry patches by any means, but that during the forest cycle, a paradigm that mimics natural disturbance regimes be applied. This recommendation includes a portion of the landscape below and above the Timber Harvest Land Base operability line be managed for slower regrowth time to canopy closure.

Of particular importance for forest management to support huckleberry patch creation or maintenance would be focus on grizzly bear units in the region with a conservation concern such as the South Purcell and Yahk GBPUs and the west portion of the South Selkirk GBPU.

Our map of important huckleberry patches should be incorporated into current logging planning cycles (or other land uses in the backcountry) to insure that road building and harvest plans be designed to not destroy or provide permanent access to important patches. For example, we have been notified that BC Timber Sales (BCTS) is currently doing a 5-year planning exercise, consequently, we have made arrangements to make our huckleberry patch maps available for that planning effort.

Nature Conservancy Canada Darkwoods property be managed for some portion of canopy openness to retain good huckleberry patch density

A large portion of the extensive huckleberry field in the South Selkirk's GBPU (Fig. 10) is owned by the Nature Conservancy of Canada. We have been in contact with their planning staff and are providing our huckleberry maps so they can incorporate them into their land use plans. One option being discussed is to keep the canopy open through selective logging in several locations to maintain already existing huckleberry patches.

Manage wildfire in a let burn policy where human development is not at risk

We also recommend that some portion of forest fires be let burn when structures and other human settlements are not at risk.

Manage huckleberry patches and access controls for landscape connectivity

Huckleberry patches are important habitat for female reproduction and low road densities are important to reduce mortality risk and increase female survival. The southern portion of the Central Purcell GBPU, while not listed as threatened, has fewer bears than government estimates predicted (Proctor et al. 2007) and has recently experienced elevated mortality levels. Grizzly bear hunting has been closed in MU 405 and 406 (just north of Hwy 3 and east of Kootenay Lake in the South Purcell's) to foster connectivity between the South Purcell grizzly bear population and the threatened South Selkirk population across Hwy 3A and the threatened Yahk across Hwy 3 (MacHutchon and Proctor 2016, McLellan et al. 2016). It would be beneficial to provide habitat security for grizzly bears to these important huckleberry patches to ensure maximum reproductive output of females in this local area (Fig. 31).

There currently is a well-organized effort to manage aspects of the landscape to enhance inter-area connectivity of grizzly bears including private land and conservation easement purchases of strategic linkage lands, non-lethal grizzly bear management methods, electric fence and bear resistant garbage bin programs, and more (Proctor et al. 2008, 2017, MacHutchon and Proctor 2016).

Ultimately, the results from this project could be used to improve the quality of important backcountry habitats. These habitats are an important component of the core habitats identified in Proctor et al. (2015) and are thus integral to the system of core and linkage areas that make up the regional grizzly bear meta-population (Proctor et al. 2012, 2015).

Continue huckleberry research effort across Region 4

As mentioned above, we will be carrying out field site visits across the rest of the Kootenay Region 4 in 2017 and 2018 in an effort to improve the regional huckleberry patch model outside our focal area. We will then be able to provide better analyses of current huckleberry patches beyond our focal area, and also make an improved link with the BEC system across the region as well.

Model buffalo berry patches especially in the East Kootenay

It would be useful if a similar project were carried out for buffalo berry (*Shepherdia canadensis*) within Region 4. We found very little evidence of grizzly bear habitat use clusters being centered on buffalo berry patches, although we used GPS clusters after July 15, so if buffalo berry were used significantly in our focal area, it might have been before July 15. Also a larger area within the East Kootenay is known to have a well-used buffalo berry crop and it is one of the key fruits eaten by grizzly bears on the east slope of the Rocky Mountains in Alberta.

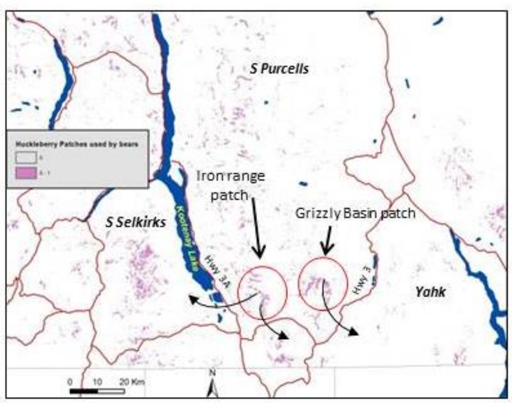


Figure 31. Map depicting 2 huckleberry patches that are situated to potentially foster inter subpopulation connectivity by migrant offspring from females using the Iron range and Grizzly Meadows huckleberry patches. These patches are prime candidates for access controls to provide habitat security to enhance female survival and reproduction. The spatialization of these surfaces makes a direct link to wildlife and landuse managers – here we show where the fitness is good and where the huckleberry patches are that could benefit from protection to enhace connectivity.

ACKNOWLEDGEMENTS

We acknowledge and appreciate financial support from the BC Habitat Conservation Trust Foundation and Fish and Wildlife Compensation Program (on behalf of its program partners BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations and the public) for support doing the huckleberry and other work. Further financial support was obtained from the Liz Claiborne Art Ortenberg Foundation, and Wilburforce Foundation, the Nature Conservancy Canada, The Great Northern Landscape Conservation Cooperative, National Fish and Wildlife Foundation. US Fish & Wildlife Service, Yellowstone to Yukon Conservation Initiative, Parks Canada. We also thank Wildlife Genetics for their fine laboratory work developing genotypes. We also appreciate the huckleberry field team of Grant MacHutchon and Stephan Himmer. We also received invaluable huckleberry modeling work of Clayton Lamb, assistance trapping and collaring grizzly bears from Parks Canada Wardens, particularly Blair Fyten and Tom Radandt from the USFWS, and advice from Wayne Kasworm and Chris Servheen of the USFWS.

REFERENCES

Association of BC Forest Professionals. 2012. Principles of forest stewardship. Association of BC Forest Professionals, Vancouver, British Columbia. 9 pp.

Anzinger, D. L. 2002. Big huckleberry (*Vaccinion membranaceum* Dougl.) Ecology and Forest Succession, Mt Hood National Forest and Warm Springs Indian Reservation, Oregon. MSc. Thesis. Oregon State University.

Apps, C.D., B.N. McLellan, J.G. Woods, and M. Proctor. 2004. Estimating grizzly bear distribution and abundance relative to habitat and human influence. Journal of Wildlife Management. **68**:138-152.

Apps, C. D., B. N.McLellan, M. F. Proctor, G. B. Stenhouse, and C. Servheen. 2016. Predicting spatial variation in grizzly bear abundance to inform conservation. Journal of Wildlife Management. **80**:396-413.

Barney, D. 1999. Growing Western Huckleberries. University of Idaho, Sandpoint Research and Extension Center, Moscow, Idaho.

Barney, D.L., P. McDaniel, and A. Falen. 2006. Soil characteristics associated with wild huckleberry and bilberry colonies in the northwestern United States: Implications for managed production and cultivation. Proc. North Am. Blueberry Res. Ext. Work. Conf. Tifton, Georgia., pp 1–12

Bjornlie, D. D., D. J. Thompson, M. A. Haroldson, C. C. Schwartz, K. A. Gunther, S. L. Cain, D. Tyers, K. L. Frey, and B. Aber. 2014. Methods for estimating distribution and range extent of grizzly bears in the Greater Yellowstone Ecosystem. Wildlife Society Bulletin 38:182–187.

Blouin, M. S. 2003. DNA-based methods for pedigree reconstruction and kinship analysis on natural populations. Trend in Ecology and Evolution 18:503-511.

Boudry, P., B. Collet, F. Cornette, V. Hervouet, and F. Bonhomme. 2002. High variance in reproduction success of the Pacific oyster (*Crassostrea gigas*) revealed by microsatellite-based parentage analysis of multifactorial crosses. Aquaculture 204: 283-296.

Boulanger, J., and G. B. Stenhouse. 2014. The impact of roads on the demography of grizzly bears in Alberta. PlosOne 9(12): e115535. Doi:10.137/journal.pone.0115535

Boyce, M. S., and L. L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology and Evolution 14:268–272.

Boyce, M. S., P. B. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

Boyce, M. S., A. E. Derocher, and D. L. Garshelis. 2016. Scientific review of Grizzly Bear Harvest Management System in British Columbia. BC Ministry of Forests, Lands and Natural Resources. Victoria, BC.

Brasher, M.G., Steckel, J.D., Gates, R.J., 2007. Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. Journal of Wildlife Management 71, 2532–2541.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information- theoretic approach. Springer-Verlag, New York, New York, USA.

Bursac, Z., C. H. Gauss, D. K. Williams, and D. W. Hosmer. 2008. Purposeful selection of variables in logistic regression. Source Code for Biology and Medicine 3:1–8.

Carbone, C., Gittleman, J.L., 2002. A common rule for the scaling of carnivore density. Science 295, 2273–2276. Cattet, M., Boulanger, J., Stenhouse, G., Powell, R., Reynolds-Hogland, M., 2008.

Chatterjee, S., A. S. Hadi, and B. Price. 2000. Regression analysis by example, third edition. John Wiley and Sons, New York, New York, USA.

Ciarniello, L. M., M. S. Boyce, D. C. Heard and D. R. Seip. 2007. Components of grizzly bear habitat selection: density, habitat, roads, and mortality risk. Journal of Wildlife Management 71:1446–1457.

Ciarniello, L. M, M. S. Boyce, D. R. Seip, and D. C. Heard. 2009. Comparison of grizzly bear *Ursus arctos* demographics in wilderness mountains versus a plateau with resource development. Wildlife Biology 15:247-265.

Crist, E. P., and R. C. Ciccone. 1984. Application of the tasseled cap concept to simulated thematic mapper data. Photogrammetric Engineering and Remote Sensing 50:343–352.

Elith, J., J. R. Leathwick, and T. Hastie. 2008. A working guide to boosted regression trees. Journal of Animal Ecology **77**:802-813.

Evans, J. 2004. Topographic Ruggedness Index. <http://arcscripts.esri.com/details.asp?dbid=12435> Accessed 15 Nov. 2007.

Ford, M. J., M. B. Hansen, J. A. Hempelmann, K. L. Ayers, C. K. Emmons, G. S. Schorr, R. W. Baird, K. C. Balcomb, S. K Wasser, K. M. Parsons, and K. Balcomb-Bartok. 2011. Inferred paternity and male reproductive success in a killer whale (*Orcinus orca*) population. Journal of Heredity 102:537-553.

Frair, J. L., S. E. Nielsen, E. H. Merrill, S. R. Lele, M. S. Boyce, R. H. M. Munro, G. B. Stenhouse, and H. L. Beyer. 2004. Removing GPS-collar bias in habitat-selection studies. Journal of Applied Ecology 41:201–212.

French, D. 1999. Aboriginal control of huckleberry yield in the Northwest. Paper presented at the American Anthropological Association conference. Chicago.IL. First published in 1957. In Indians, Fire and the Land in the Pacific Northwest, Ed., R. Boyd. Oregon State University Press. Corvallis. OR.

Garshelis, D. L., M. L. Gibeau, and S. Herrero. 2005. Grizzly bear demographics in and around Banff National Park and Kananaskis Country, Alberta. Journal of Wildlife Management 69:277-297.

Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75:887–898.

Gorzalek, M. A., S. Hambleton, and H. B. Massicotte. 2012. Community structure of ericoid mycorhizas and root-associated fungi of *Vaccinium membrenaceum* across an elevation gradient in the Canadian Rocky Mountains. Fungal Biology 5:36-45.

Habitat Management Branch Province of BC (2000) Huckleberry (Vaccinium membranaceum).

Hamer, D., and S. Herrero. 1987. Wildfire's influence on grizzly bear feeding ecology in Banff National Park, Alberta. International Conference on Bear Research and Management 7:179-186.

Hamilton, A. N., and M. A. Austin 2004. Grizzly Bear Harvest Management in British Columbia: Background Report. BC Ministry of Environment. Victoria BC.

Haroldson, M. A., D. D. Bjornlie, and F. T. van Manen. 2016. Estimating number of females with cubs. Pages 13–23 *in* F. T. van Manen, M. A. Haroldson, and B. E. Karabensh, editors. Yellowstone grizzly bear investigations: annual report of the Interagency Grizzly Bear Study Team. 2015. US Geological Survey. Bozeman. MT.

Hilderbrand, G. V., C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. A. Hanley, S. M. Arthur, and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. Canadian Journal of Zoology 77:132–138.

Hobby. T. and M.E. Keefer. 2010. A black huckleberry case study in the Kootenay region of British Columbia. BC Journal of Ecosystems and Management 11:52-61.

Holden, Z. A., W. F. Kasworm, C. Servheen, B. Hahn, and S. Dobrowski. 2012. Sensitivity of berry productivity to climate variation it he Cabinet-Yaak grizzly bear recovery zone, Northwest United States 199-2010. Wildlife Society Bulletin 36: 226-231.

Hosmer, D. W., Jr., and S. Lemeshow. 1989. Applied logistic regression. John Wiley and Sons, New York, New York, USA.

Kasworm, W. F., T. G. Radandt, J. E. Teisberg, M. Proctor, and C. Servheen. 2013. Cabinet-Yaak grizzly bear recovery area 2012 research and monitoring progress report. U.S. Fish and Wildlife Service, Missoula, Montana. 97 pp.

Kendall, K. C., A. C. MacLeod, K. L. Boyd, J. Boulanger, J. A. Boyle, W. K. Kasworm, D. Paetkau, M. F. Proctor, K. Annis, and T. A. Graves. 2016, Density, distribution and genetic structure of grizzly bears in the Cabinet-Yaak Ecosystem. Journal of Wildlife Management 80:314-331.

Kerns, B. K., S. J. Alexander, and J. D. Bailey. 2004. Huckleberry conditions, stand conditions, and use in western Oregon" evaluating the role for forest management. Economic Botany 58:668-678.

Klinka, K., V.J. Krajina, and A. Ceska. 1989. Indicator plants of coastal British Columbia. University of British Columbia Press, Vancouver, B.C.

Kumar, L., A. K. Skidmore, and E. Knowles. 1997. Modelling topographic variation in solar radiation in a GIS environment. International Journal for Geographical Information Science 11:475–497.

Lamb C. T., G. Mowat, B. N. McLellan, S. E. Nielsen, and S. Boutin. 2017. Forbidden fruit: human settlement and abundant fruit create an ecological trap for an apex predator. Journal of Applied Ecology 86:55-65

Lamb C. T., G. Mowat, A. Reid, L. Smit, M. Proctor, B. N. McLellan, S. E. Nielsen, and S. Boutin. In review. Improved security stimulates an increase and expansion of a threatened grizzly bear population. Journal of Applied Ecology.

Lemay, M. A., E. G. Boulding. 2009, Microsatellit pedigree analysis reveals high variance in reproductive success in reduced genetic diversity in hatchery-spawned northern abalone. Aquaculture 295:22-29.

Lewis, J. S. J. L. Rachlow, E. O. Garton, and L. E. Vierling. 2006. Effects of habitat on PGS collar performance: using data screening to reduce location error.

Mace, R. D., J. S. Waller, T. L. Manley, L. J. Lyon, and H. Zuring. 1996. Relationships among grizzly bears, roads, and habitat use in the Swan Mountains, Montana. Journal of Applied Ecology **33**:1395-1404.

Mace, R. D., J. S. Waller, T. L. Manley, K. Ake, and W. T. Wittinger. 1999. Landscape evaluation of grizzly bear habitat in Western Montana. Conservation Biology 13:367–377.

Mace, R. D., D. W, Carney, T. Chilton-Radandt, S. A. Courville, M. A. Haroldson, R. B. Harris, J. Jonkel, B. McLellan, M. Madel, T. L Manley, C. C. Schwartz, C. Servheen, G. Stenhouse, J. S. Waller, and E. Wenum. 2012. Grizzly bear population vital rates and trend in the Northern Continental Divide Ecosystem, Montana. Journal of Wildlife Management 76:119-128.

MacHutchon, A.G., and M.F. Proctor. 2016. Management Plan for the Yahk and South Selkirk Grizzly Bear (*Ursus arctos*) Sub-Populations, British Columbia. Trans-Border Grizzly Bear Project, Kaslo, B.C. 84 pp.

MacKillop, D. J. and A. J. Ehman. 2016. A field guide to site classification and identification for southeast British Columbia: the south-central Columbia Mountains. Province of B.C., Victoria, B.C., Land Management Handbook 70. 478 pp.

Manley, T. L., K. Ake, and R. D. Mace. 1992. Mapping grizzly bear habitat using Landsat TM satellite imagery. Pages 231–240 *in* J. D. Greer, editor*.* Remote sensing and natural resource management. American Society of Photogrammetry and Remote Sensing, Bethesda, Maryland, USA.

Manly, B. F. J., L. L. McDonald, D. L. Thomas. T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies, second edition. Kluwer Academic Publishers, Dordrecht, Netherlands.

Mattson, D. J., and T. Merrill. 2002. Extirpations of grizzly bears in the contiguous United States, 1850-2000. Conservation Biology 16:1123-1136.

McLellan, B.N. 1989. Population dynamics of grizzly bears during a period of resource extraction development. III. Natality and rate of change. Canadian Journal of Zoology 67:1865-1868.

McLellan, B.N. 1994. Density dependent population regulation of brown bears. Pages 15-24 *in* M. Taylor (ed). Density dependent population regulation in black, brown, and polar Int. Conf. Bear Res. and Manage. Monogr. Series No. 3

McLellan, B. N. 1998. Maintaining viability of brown bears along the southern fringe of their distribution. Ursus 10:607–611.

McLellan, B.N. and F.W. Hovey. 1995. The diet of grizzly bears in the Flathead River drainage of southeastern British Columbia. Canadian Journal of Zoology **73**:704-712.

McLellan, B. N., F. W. Hovey, R. D. Mace, J. G. Woods, D. W. Carney, M. L. Gibeau, W. L. Wakkinen, and W. F. Kasworm. 1999. Rates and causes of grizzly bear mortality in the interior mountains of British Columbia, Alberta, Montana, Washington, and Idaho. Journal of Wildlife Management **63**:911-920.

McLellan, B. N., and F. W. Hovey. 2001. Habitats selected by grizzly bears in multiple use landscapes. Journal of Wildlife Management 65:92–99.

McLellan, B.N. 2011. Implications of a high-energy and low-protein diet on the body composition, fitness, and competitive anilities of black (*Ursus americanus*) and grizzly (*Ursus* arctos) bears. Canadian Journal of Zoology **89**:546-558.

McLellan, B.N. 2015. Some mechanisms underlying variation on vital rates on grizzly bear in an industrial landscape. Journal of Wildlife Management **79**:749-765.

McLellan, B. N., Proctor, M. F., Huber, D. and Stefan Michel. (IUCN SSC Bear Specialist Group). 2016*a*. *Ursus arctos*. The IUCN Red List of Threatened Species 2016. IUCN website.

McLellan, B. N., G. Mowat and A. N. Hamilton. 2016*b* Sustainability of the grizzly bear hunt in British Columbia, Canada. Journal of Wildlife Management 81:218-229.

Meidinger, D. V., and J. Pojar. 1991. Ecosystems of British Columbia. British Columbia Ministry of Forests Special Report Series 6, Victoria, British Columbia, Canada.

Miller, M. 1977. Response of blue huckleberry to prescribed fires in a western Montana larch-fir forest. U.S. Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station, Missoula, Mont. Research Note INT-188, p. 33.

Minore, D. 1972. The wild huckleberries of Oregon and Washington—a dwindling resource. USDA Forest Service, Pacific Northwest Research Station, RP-322, Portland, OR.

Minore, D. 1975. Observations on the rhizomes and roots of Vaccinium membranaceum. U.S. Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon Research Note PNW-261. p. 5.

Minore, D. 1984. Vaccinium membranaceum berry production seven years after treatment to reduce overstory tree canopies. Northwest Sci 3–7.

Minore, D., A. W. Smart, and M. E. Dubraisch. 1979. Huckleberry ecology and management research in the Pacific Northwest. U.S. Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg. General Technical Report PNW-093.

Ministry of Forests and Range and Ministry of Environment. 2010. Field manual for describing ecosystems, 2nd edition. Land Management Handbook 25, B.C. Ministry of Forests and Range and B.C. Ministry of Environment, Victoria, B.C.

Morehouse, A. and M. Boyce 2016. Grizzly Bear without borders: spatially explicit capture-recapture in southwest Alberta. Journal of Wildlife Management 80: 1152-1166.

Mowat, G., and D. C. Heard. 2006. Major components of grizzly bear diet across North America. Journal of Canadian Zoology 84:473-489.

Mowat, G., D. C. Heard, D. R. Seip, K. G. Poole, G. Stenhouse and D. W. Paetkau. 2005. Grizzly and black bear densities in the interior mountains of North America. Wildlife Biology 11:41-58.

Mowat, G. and C. Lamb. 2016 Population status of the South Rockies and Flathead grizzly bear populations in British Columbia, 2006-2014. BC Ministry of Forests, Lands, and Natural Resource Operations, Nelson BC.

Mowat, G., D. C. Heard and C. J. Schwarz. 2013. Predicting grizzly bear density in western North America. PLoS One. 8(12): e82757.

Nielsen, S. E., M. S. Boyce, G. B. Stenhouse, and R. H. M. Munro. 2002. Modeling grizzly bear habitats in the Yellowhead ecosystem of Alberta: taking autocorrelation seriously. Ursus 13:45–56.

Nielsen, S. E., R. H. M. Munro, E. Bainbridge, G. B. Stenhouse, and M. S. Boyce. 2004a. Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Alberta, Canada. Forest Ecology and Management 199:67–82.

Nielsen, S. E., M. S. Boyce, and G. B. Stenhouse. 2004*b*. Grizzly bears and forestry I. Selection of clearcuts by grizzly bears in west-central Alberta. Forest Ecology and Management 199:51–65.

Nielsen, S. E., S. Herrero, M. S. Boyce, R. D. Mace, B. Benn, M. L. Gibeau, and S. Jevons. 2004*b*. Modeling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies Ecosystem of Canada. Biological Conservation 120:101–113.

Nielsen, S. E., M. S. Boyce, and G. B. Stenhouse. 2004*c*. Grizzly bears and forestry I. Selection of clearcuts by grizzly bears in west-central Alberta. Forest Ecology and Management 199:51–65.

Nielsen, S. E., J. Cranston, and G. B. Stenhouse. 2009. Identification of priority areas for grizzly bear conservation and recovery in Alberta, Canada. Journal of Conservation Planning 5:38–60.

Nielsen. S., and Nielsen, C. 2010. A landscape analysis of huckleberry in southeast British Columbia , spatial-temporal patterns of forest fires , and protocols for long-term monitoring of inter-annual variation in fruit production for huckleberry and buffaloberry. Prepared for Province of British Columbia.

Nielsen, S. E., G. McDermid, G. B. Stenhouse, and M. S. Boyce. 2010. Dynamic wildlife habitat models: seasonal foods and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. Biological Conservation 143:1623-1634.

North Cascades Grizzly Bear Recovery Team. 2004, Recovery plan for grizzly bear in the North Cascades of British Columbia. B.C. Ministry of Environment, Victoria, BC. Canada.

Northrup, J. M, J. Pitt, T. B. Muhly, G. B. Stenhouse, M. Musiano, and M. S, Boyce. 2012. Vehicle traffic shapes grizzly bear behaviour on a multiple-use landscape. Journal of Applied Ecology 49:1159-1167.

Oriol-Cotterll, A., M. Valeix, L. G. Frank, C. Riginos, and D. W. Macdonald. 2015. Landscapes of coexistence for terrestrial carnivores: the ecological consequences of being downgraded from the ultimate to penultimate predator by humans. Oikos 124:1263-1273.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modeling 133:225-245.

Pemberton, J. M. 2008. Wild pedigrees: the way forward. Proceedings of the Royal Society B. 275: 613-621.

Proctor, M. F. 2017 . Trans-border grizzly Bear Project progress report. Birchdale Ecological, Kaslo, BC. Canada. 69pp.

Proctor, M., J. Boulanger, S. Nielsen, C. Servheen, W. Kasworm, T. Radandt and D. Paetkau. 2007. Abundance and density of Central Purcell, South Purcell, Yaak, and south Selkirk grizzly bear population units in southeast British Columbia. British Columbia Ministry of Environment, Nelson, British Columbia, Canada.

Proctor, M., C. Servheen, W. Kasworm, and T. Radandt. 2008. Habitat security for grizzly bears in the Yahk Grizzly Bear Population Unit of the south Purcell Mts. of southeast British Columbia. Trans-border Grizzly Bear Project report. Tembec Enterprises. Cranbrook BC.

Proctor, M.F, B.N. McLellan, J. Boulanger, C. Apps, G, Mowat, D, Paetkau, and G. Stenhouse. 2010. Ecological investigations of Canadian grizzly bears using hair-snagged DNA, 1995-2005. Ursus. 21:169-188.

Proctor, M. F., D. Paetkau, B. N. McLellan, G. B. Stenhouse, K. C. Kendall, R. D. Mace, W. F. Kasworm, C. Servheen, C. L. Lausen, M. L. Gibeau, W. L. Wakkinen, M. A. Haroldson, G. Mowat, C. D. Apps, L. M. Ciarniello, R. M. R. Barclay, M. S. Boyce, C. C. Schwartz, and C. Strobeck. 2012a. Population Fragmentation and Inter-Ecosystem Movements of Grizzly Bears in Western Canada and the Northern United States. Wildlife Monographs **180**:1-46.

Proctor, M. F., S. E. Nielsen, W. F. Kasworm, C. Servheen, T. G. Radandt, A. G. MacHutchon, and M. S. Boyce. 2015. Grizzly bear connectivity mapping in the Canada-US trans-border region. Journal of Wildlife Management 79:554-55.

Proffitt, K. M., J. F. Goldberg, M. Hebblewhite, R. Russell, B. S. Jimenez, H. S. Robinson, K. Pilgrim, and M. K. Schwartz. 2015. Integrating resource selection into spatial capture-recapture models for large carnivores. Ecosphere 6:1-15.

Power, M. 1992. Top down and bottom up forces in food webs: do plants have primacy. Ecology 73:733-746.

R Core Team. 2016. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/

Rho, P. 2002. Wetness, an avenue script for Arcview 3.2. http://arcscripts.esri.com/details.asp?dbid¼12223. Accessed 5 May 2005.

Riley, S. J., S. DeGloria, and R. A. Elliot. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. Intermountain Journal of Sciences 5:1–4.

Ridgeway, G. 2015. Generalized boosted regression models: package "gbm". *CRAN,* https://cran.r-project.org/web/packages/gbm/index.html.

Roberts. D., Nielsen, S., Stenhouse, G.B. 2014. Idiosyncratic responses of grizzly bear habitat to climate change based on projected food resource changes. Ecol Appl 14:1144–1154.

Robbins, C. T., M. Ben-David, J. K. Fortin, and O. L. Nelson. 2012. Maternal condition determines birth date and growth of newborn bear cubs. Journal of Mammalogy 93:540–546.

Roever, C. L., M. S. Boyce, and G. B. Stenhouse. 2010. Grizzly bear movements relative to roads: application of step functions. Ecography 33: 1113-1122.

Royle, J. A., R. B. Chandler, C. C. Sun, and A. K. Fuller. 2013. Integrating resource selection information with spatial capture–recapture. Methods in Ecology and Evolution 4:520-530.

Schwartz, C. C., M. A. Haroldson, G. C. White, R. B. Harris, S. Cherry, K. A. Keating, D. Moody, and C. Servheen. 2006. Temporal, spatial, and environmental influences on the demographics of the Yellowstone grizzly bear. Wildlife Monographs 161:1–68.

Schwartz, C. C., M. A. Haroldson, and G. C. White. 2010. Hazards affecting grizzly bear survival in the greater Yellowstone ecosystem. Journal of Wildlife Management 74:654–667.

Serrouya, R., B.N. McLellan, G. Pavan, and C.D. Apps. 2011. Grizzly bear selection of avalanche chutes: testing the effectiveness of forest buffer retention. Journal of Wildlife Management. 75:1597-1608.

Shirley, S. M., Z. Yang, R. A. Hutchinson, J. D. Alexander, K. McGarigal, and M. G. Betts. 2013. Species distribution modeling for the people: unclassified landsat TM imagery preficts bird occurrence at fine resolutions. Diversity and Distributions: 1-12.

Stark, N. and S. Baker. 1992. The ecology and culture of Montana huckleberries: A guide for growers and researchers. University of Montana, School of Forestry, Missoula, MT. Miscellaneous Publication No. 52, p. 87.

Stenhouse, G.B., J. Boulanger, J., M. Efford, S. Rovang, T. McKay, A. Sorensen, and K. Graham. 2015. Estimates of Grizzly Bear Population Size and Density for the 2014 Alberta Yellowhead Population Unit (BMA 3) and South Jasper National Park Inventory Project. Report prepared for Weyerhaeuser Ltd., West Fraser Mills Ltd, Alberta Environment and Parks, and Jasper National Park. 73 pages. https://friresearch.ca/sites/default/files/GBP_2015_10_Report_PopulationSize.pdf

Stevens, S. 2002. Landsat TM-based Greenness as a surrogate for grizzly bear habitat quality in the Central Rockies Ecosystem. Thesis, University of Calgary, Calgary, Alberta, Canada.

Waller, J. S., and R. D. Mace. 1997. Grizzly bear habitat selection in the Swan Mountains, Montana. Journal of Wildlife Management 61:1032–1039.

Wakkinen, W. L., and W. F. Kasworm. 2004. Demographic and population trends of grizzly bears in the Cabinet–Yaak and Selkirk ecosystems of British Columbia, Idaho, Montana, and Washington. Ursus 15 (Workshop Supplement):65–75.

White, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 48:817–838.

Wielgus, R. B. and P. R. Vernier. 2003. Grizzly bear selection of managed and unmanaged forests in the Selkirk Mountains. Canadian Journal of Forest Research 33:822–829.

Woods, J.G., D. Paetkau, D. Lewis, B.N. McLellan, M. Proctor, and C. Strobeck. 1999. Genetic tagging free-ranging black and brown bears. Wildlife Society Bulletin. 27(3):616-627.

Zager, P., Jonkel, C., and J. Habeck. 1983. Logging and wildfire influence grizzly bear habitat in northwestern Montana. International Conference on Bear Research and Management 5:124–132.

Appendix I

Relationship between Huckleberry Patches used by Grizzly Bears and Kootenay BEC Ecosystem Units

Trans-Border Grizzly Bear Project

c/o Birchdale Ecological

Box 606

Kaslo, BC V0G 1M0

Prepared by:

A. Grant MacHutchon

Wildlife Biologist, M.Sc., R.P.Bio. 484

Nelson, BC

Telephone: 250-505-5083

Email: machutchon@uniserve.com

May 11, 2017

Table of Contents

List of Figures

List of Tables

1 Introduction

The overall huckleberry patch model project was undertaken to map, predict, and inform management for one of the most important regional grizzly bear foods, black huckleberry (*Vaccinium membranaceum*). Details of the overall project can be found in Proctor et al. (2016).

My sub-project, reported here, was an attempt to elucidate the relationship between the huckleberry patch model of Proctor et al. (2016) to the Biogeoclimatic Ecosystem Classification (BEC) ecosystem units identified within Kootenay Region 4 (MacKillop and Ehman 2016, MacKillop et al. 2016). My project goal was to identify the suite of BEC ecosystem units within a defined range of ecological conditions that appeared to be most likely to be or to be able to generate a black huckleberry patch important for grizzly bear foraging.

The resulting range of BEC ecosystem units and ecological conditions would aid foresters, biologists, and land managers in:

1. Identifying ecosystem units in the field that likely are important for grizzly bear foraging on black huckleberry, even if the huckleberry model did not map them or huckleberry fruit production is not high in the current year.
2. Identifying ecosystem units that likely could be important for grizzly bear foraging on black huckleberry if the canopy were opened up with logging, other silviculture treatments, or prescribed burning.

1.1 BEC Ecosystem Units

Biogeoclimatic Ecosystem Classification (BEC) is a hierarchical classification system that groups similar ecosystems at three levels of integration: regional, local, and chronological. At the regional or biogeoclimatic (BGC) mapping scale, landscapes are divided into zones, subzones, and variants based on climate. At the local or BEC site series scale, stand-level ecosystems within a biogeoclimatic unit are classified and differentiated on the basis of site, soil, and vegetation characteristics. The stand and regional scales are linked together through the distribution of vegetation on zonal sites with similar climate conditions. Zonal sites support the plant community that best reflects the regional climate of that subzone/ variant (MacKillop and Ehman 2016).

Within the BEC system, each biogeoclimatic subzone/ variant reflects a “bioclimate envelope”—a set of climatic conditions that supports relatively homogeneous patterns of vegetation communities on similar sites. Although there is considerable variation in climate, both across the geographic range of a subzone/ variant and across wet/ dry or hot/ cool years, similarity in climate conditions within a given biogeoclimatic unit has been demonstrated in several studies (MacKillop and Ehman 2016). Subzone designations within the BEC system use two letter, lower case codes where the first letter represents the subzone’s relative climate wetness and the second the subzone’s relative climate temperature (Table 1).

Table 1. Biogeoclimatic Ecosystem Classification (BEC) subzone codes within Kootenay Region 4.

BGC Subzone	Subzone Description
xx	Very Dry Very Cold
xk	Very Dry Cool
xw	Very Dry Warm
dc	Dry Cold
dk	Dry Cool
dm	Dry Mild
dw	Dry Warm
dh	Dry Hot
mk	Moist Cool
mm	Moist Mild
mw	Moist Warm
mh	Moist Hot
wc	Wet Cold
wk	Wet Cool
wm	Wet Mild
wh	Wet Hot
vc	Very Wet Cold
vk	Very Wet Cool

There is a new standard coding system for BEC site series that were introduced or revised after March 31, 2010 that uses a three-digit rather than a two-digit code (MacKenzie 2011). The first digit refers to the classification version number, so all recent changes begin with “1”. This includes most BEC subzones and variants within southeast B.C. classified by MacKillop and Ehman (2016) and MacKillop et al. (2016). The new convention for site series number retains “#01” as the designation for the zonal ecosystem (preceded by the revision number 1, i.e., 101). New site series numbered from 102 to 109 are reserved for units drier or poorer than zonal, with the 102 being the driest and poorest and the numbering proceeding left to right, top to bottom on the edatopic grid for each BEC variant. Numbers 110 to 119 are reserved for forested units wetter or richer than zonal, the numbering also proceeding left to right, top to bottom. In this way, regardless of BEC variant, the soil moisture and nutrient regimes will be similar among similarly numbered site series, whereas in the past this was not always the case. This makes it much easier to understand the general ecological conditions that each site series has regardless of which BEC zone, subzone, or variant it is in.

Provincial and regional BEC mapping has evolved over time as the zones, subzones, and variants have been classified and reclassified. The most recent BEC mapping for Kootenay Region 4 is version 11, which is based on regional units classified by MacKillop and Ehman (2016) and MacKillop et al. (2016), as well as unpublished data. Region 4 BEC mapping version 11 was used for this project.

When classifying and mapping ecosystem units In B.C. (MoFR and MoE 2010), structural stage is used to describe the appearance of a stand or community using the characteristic life form and certain physical attributes. Stages depict stand development features along a trajectory that is characteristic for the vegetation, e.g., refer to a certain type of vegetation, such as, herb community or mature forest. In contrast, successional status describes a temporal stage in a pathway of plant community development that is characteristic for a particular environment. The proportion of 'seral' species compared to 'climax' species, the vegetation layers in which these species occur, and the relative age and vigour of each species differentiates the stages. Structural stage is most often used in ecosystem mapping to describe the developmental state of an ecosystem at the time of mapping. Following are the major structural stages:

1. **Sparse** – Either the initial stages of primary succession or a very early stage of cohort establishment following a stand-destroying disturbance.
2. **Herb** – Early successional stage or a herb community maintained by environmental conditions (e.g., very wet, warm & dry, or late snow site) or disturbance (e.g., avalanche track, flooding, intensive grazing, animal burrowing).
3. **Shrub/Herb** – Early successional stage or a shrub community maintained by environmental conditions (e.g., wet soils, cold air accumulation) or disturbance (e.g., avalanche track); tree cover sparse but tree seedlings and advance regeneration may be abundant.
4. **Pole/ Sapling** – Trees > 10 m tall, typically densely stocked, and have overtopped shrub and herb layers; younger stands are vigorous (usually > 15–20 years old); older stagnated stands (up to 100 years old) are also included; self-thinning and vertical structure are not yet evident in the canopy.
5. **Young Forest** – Self-thinning has become evident and the forest canopy has begun to differentiate into distinct layers (dominant, main canopy, and overtopped); vigorous growth and a more open stand than in the Pole/Sapling stage.
6. **Mature Forest** – Trees established after the last stand-replacing disturbance have matured; a second cycle of shade-tolerant trees may have become established; shrub and herb understories become well developed as the canopy opens up.

7. **Old Forest** – Stands of old age with complex structure; patchy shrub and herb understories are typical; regeneration is usually of shade-tolerant species with composition similar to the overstorey; long-lived seral species may be present in some ecosystem types or on edaphic sites.

2 Study Area

Field site visits in 2014 and 2015 occurred in an area encompassing three Grizzly Bear Population Units (GBPUs), the South Selkirk, Yahk, and Central Purcell GBPUs, which covered the southern extent of the Selkirk and Purcell Mountain ranges in B.C. (Figure 1). Model building of huckleberry patches important to grizzly bears, which was based on field site visit data, initially occurred within the sampling area but was subsequently expanded to all of Kootenay Region 4 in an effort to inform a region wide field validation effort. The Kootenay region is mountainous and predominately covered by conifer forests with patches of deciduous forest throughout. It consists of mountain valleys, upland forests, and alpine habitats. The region is relatively wet with much of the annual precipitation received as snow in winter, especially at higher elevations. Summers can be somewhat dry and hot. The predominant ecosystems in the region from valley bottom to mountain top are Biogeoclimatic (BGC) zones, Interior Cedar Hemlock (ICH; 28.7%) at lower elevations, Englemann Spruce Sub-alpine Fir (ESSF; 48.3%) at mid to higher elevations, and Interior Mountain-heather Alpine (IMA; 3.3%). Drier areas occur on the eastern and western sides of the Kootenay region in the Interior Douglas-fir (IDF; 10.2%) and Montane Spruce (MS; 9.5%) zones.

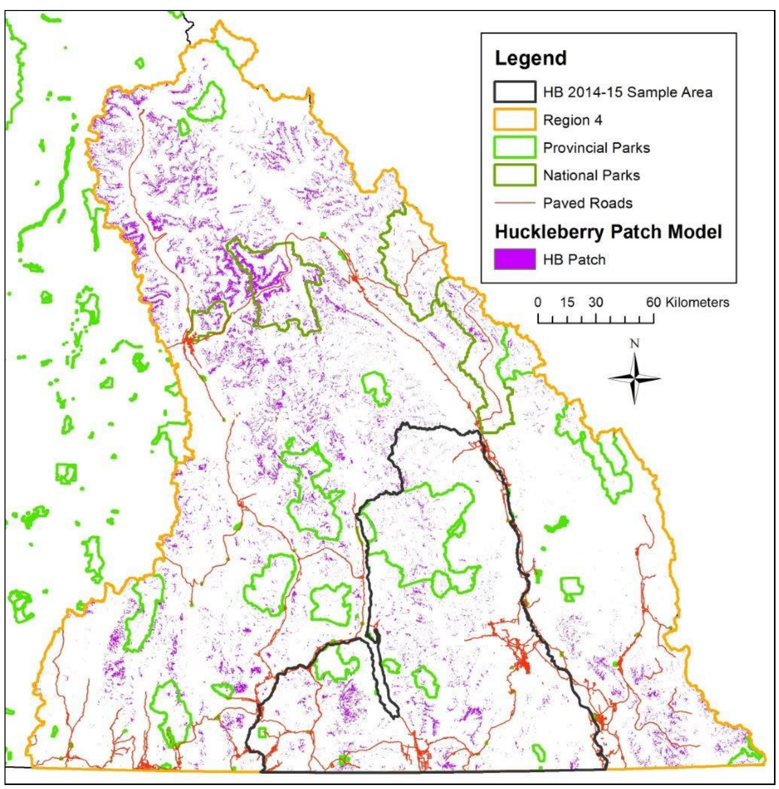


Figure 1. The 2014-15 field sampling area within the South Selkirk, Yahk, and Central Purcell Grizzly Bear Population Units and the predictive modelling area for huckleberry patches important to grizzly bears within Kootenay Region 4.

3 Methods

An extensive 10-year GPS telemetry dataset (60 grizzly bears, ~100,000 locations) was used to identify clusters of mid-July to mid-September locations that were suspected to be huckleberry patches.

3.1 Field Sampling

In 2014, visits were made to sites within clusters of grizzly bear GPS locations to determine if the site was a huckleberry patch or not during August and September. For all locations sampled, the B.C. Government standard 20 m x 20 m plot size (MoFR and MoE 2010) was used to describe site characteristics. Plot centres were picked to be in the middle of the best local huckleberry patch or, if it was not a huckleberry patch, where there was evident grizzly bear sign (e.g., root digs, bear bed), at GPS locations, or in a distinct ecosystem unit (e.g., forested BEC site series or other ecosystem unit).

The following characteristics were recorded at all sites visited:

- **Yes/No** – Was it a huckleberry patch or not?
- **Description** – A general description of the vegetation community, major indicator plants, major bear foods, and why a bear likely used area, if it did.
- **Biogeoclimatic Ecosystem Classification (BEC) zone, subzone, variant, and site series** – Zone, subzone, and variant were based on regional BEC mapping. Site series was based on vegetation composition and site characteristics, full ecosystem plots for some sites, and regional BEC field guides.
- **Elevation** – At the centre of the plot and read from a hand-held GPS in metres.
- **Slope** – Percent slope gradient of the plot measured with a clinometer.
- **Aspect** – Orientation of slope in degrees; "999" was recorded for level ground. Aspect was a fixed point measurement from the centre of the plot.
- **Mesoslope position** – As per MoFR and MoE (2010), Site Description section, page 25.
- **Structural stage** – As per MoFR and MoE (2010), Site Description section, page 21.
- **Site disturbance** – As per MoFR and MoE (2010), Site Description section, page 27.
- **Canopy cover** – Estimate of the percent tree canopy cover.
- **Huckleberry fruit abundance** – As per MoFR and MoE (2010), Vegetation, page 17.
- **Huckleberry patch quality** – A subjective assessment value between 1 and 10, where 1 was lowest quality and 10 was highest quality.
- **Huckleberry modal height** – Height in centimetres based on a mental average of multiple measurements.
- **Huckleberry cover** – Estimated percent cover of black huckleberry.
- **Huckleberry fruit phenology** – Recorded as “green”, “reddish hue, not quite ripe”, “generally ripe”, “overripe”, or “finished”.

- **Bear sign** - Old or recent bear sign within or in the vicinity of the plot.

In addition to the site characteristics above, full B.C. Government ecosystem plots (MoFR and MoE 2010), including soil pits, were done at a subset of grizzly bear huckleberry feeding sites.

In 2015, a preliminary model of huckleberry patches important to grizzly bears (generation 1) was available based on the 2014 field data. Consequently, in 2015 sites visited and described were selected for one of three reasons:

1. It was an area with grizzly bear GPS-collar locations and it also was within the area identified as a black huckleberry patch in the generation 1 model developed based on the 2014 field data,
2. It was an area with grizzly bear GPS-collar locations, but was not identified in the generation 1 huckleberry patch model,
3. It was an area with no grizzly bear GPS-collar locations, but it was within the area identified as a huckleberry patch in the generation 1 model.

Full BC Government ecosystem plots (MoFR and MoE 2010) were not done in 2015 in favour of the quicker site description technique above. In this way, the number of sites visited in 2015 was almost double that in 2014 despite more challenging access issues.

3.2 Huckleberry Patch Modelling

Environmental variables hypothesized to limit the occurrence of huckleberry based on the research literature included, soil pH, soil texture, climate, forest fire, canopy cover, and topography. Consequently, a suite of ecological variables were assembled in ArcGIS to be used to predict huckleberry patches important to grizzly bears across Kootenay Region 4 (Table 2; Proctor et al. 2016).

Records of black huckleberry presence or absence in Kootenay Region 4 were acquired from vegetation plots conducted through the BEC research program. Within the study area, 10,129 vegetation plots were conducted between 1980 and 2013, of which, black huckleberry was detected at 4,297 plots (~42% of plots). Proctor et al. (2016) used boosted logistic regression trees and the functional environmental response variables in Table 2 to discriminate between black huckleberry patches used by grizzly bears and the availability of black huckleberry across the study area.

3.3 Predictive Ecosystem Mapping (PEM)

Various Predictive Ecosystem Mapping (PEM) projects have been done in Kootenay Region 4 and within these projects individual 25 x 25 m pixels have been classified into one to three different ecosystem units (forested BEC site series and non-forested units). Four of the most recent PEM projects that overlapped the 2014-15 sampling area were used to assess the relative amount of different forested ecosystem units within the study area versus modelled huckleberry patches, particularly in the ESSF zone. These four PEM projects included Cranbrook TSA, Invermere TSA, Kootenay Lake, and Arrow TSA 2.0.

Table 2. Environmental variables used to predict huckleberry patches used by grizzly bears in Kootenay Region 4 (Proctor et al. 2016).

Abbreviation	Name
aspect	Aspect
Canopy_cov	Canopy cover
CMD	Hargreaves climatic moisture deficit (mm)
cofrag_utm	Coarse Fragments in soils
cti	Compound Topographic Index
DD5	Degree-days below 5°C
FFP	Frost Free Period
fire_cnt	Number of fires in a region since 1900
globlrad	Global radiation
Last fire binned	Time since last fire binned into 5 categories
MAP	Mean Annual Precipitation
MAR	Mean annual solar radiation (MJ m-2 d-1)
MAT	Mean Annual Temp
MCMT	Mean coldest month temperature (°C),
MSP	Mean annual summer (May to Sept.) precipitation (mm),
MWMT	Mean warmest month temperature (°C),
NFFD	Number of frost-free days
orgcarp	Organic carbon % in soils
PAS	Precipitation as snow
PAS_wt	Precipitation as snow (Winter)
ph2	Soil ph, dissolved using water
phca_utm	Soil ph
PPT_sm	Precipiation in Summer
SHM	Summer heat-moisture index
slope	Slope

Abbreviation	Name
Tave_wt	Average Temperature- winter
tcaly_utm	% clay in soils?
tclay	Clay % in soils
Tmax_sm	Maximum Temperature - summer
Tmin_sp	Minimum Temp - spring
Tmin_wt	Temperature Minimum
tsand	Sand % in soil

4 Results and Discussion

4.1 Field Sampling

In 2014, 193 sites within grizzly bear GPS location clusters were described and of these, 126 (65.3%) were huckleberry patches. The other 67 (34.7%) sites visited were feeding sites on other foods or appeared to be from other grizzly bear activity (e.g., bedding). Full ecosystem field plots were done at 48 (38%) of the 126 huckleberry feeding sites identified in 2014. In 2015, 319 sites were described of which 214 (67%) were huckleberry patches for a combined 2014-15 sample of 340 huckleberry patches.

4.2 Huckleberry Patch Modelling

The top six environmental variables found to be important for predicting huckleberry patches used by grizzly bears were, in decreasing importance: (1) canopy cover, (2) coarse fragments in soil, (3) slope, (4) precipitation as snow in winter, (5) mean annual solar radiation, and (6) mean annual precipitation (Figure 2, Proctor et al. 2016). Overall, areas with low canopy cover, few coarse fragments in the soil, low angle slope, and high winter snow load, mean annual solar radiation, and mean annual precipitation were most likely to produce huckleberry patches important to grizzly bears (Figure 3).

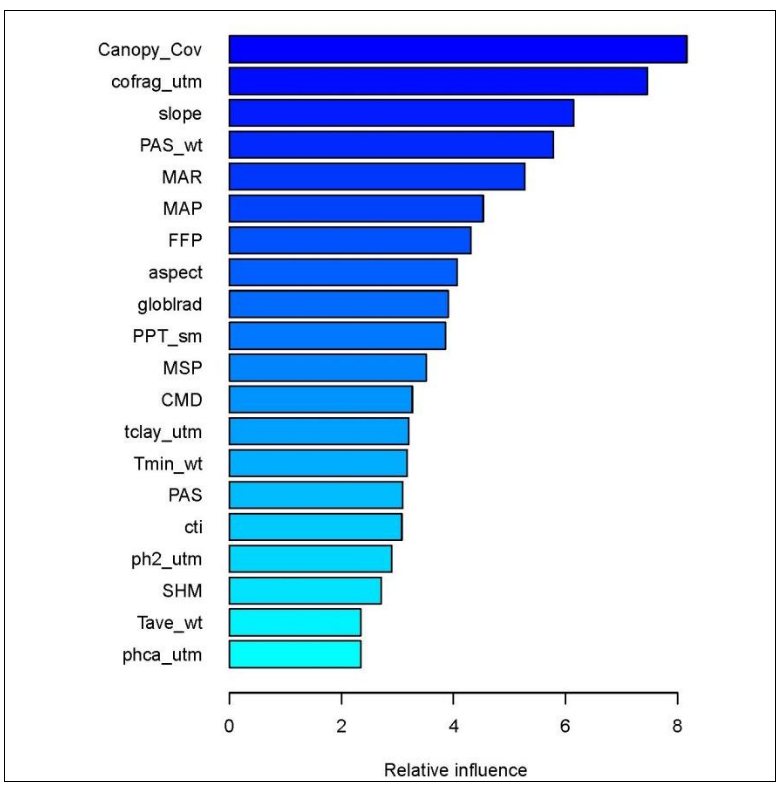


Figure 2. Relative influence of the top 20 environmental variable predictors in a model of huckleberry patches important to grizzly bears (from Proctor et al. 2016).

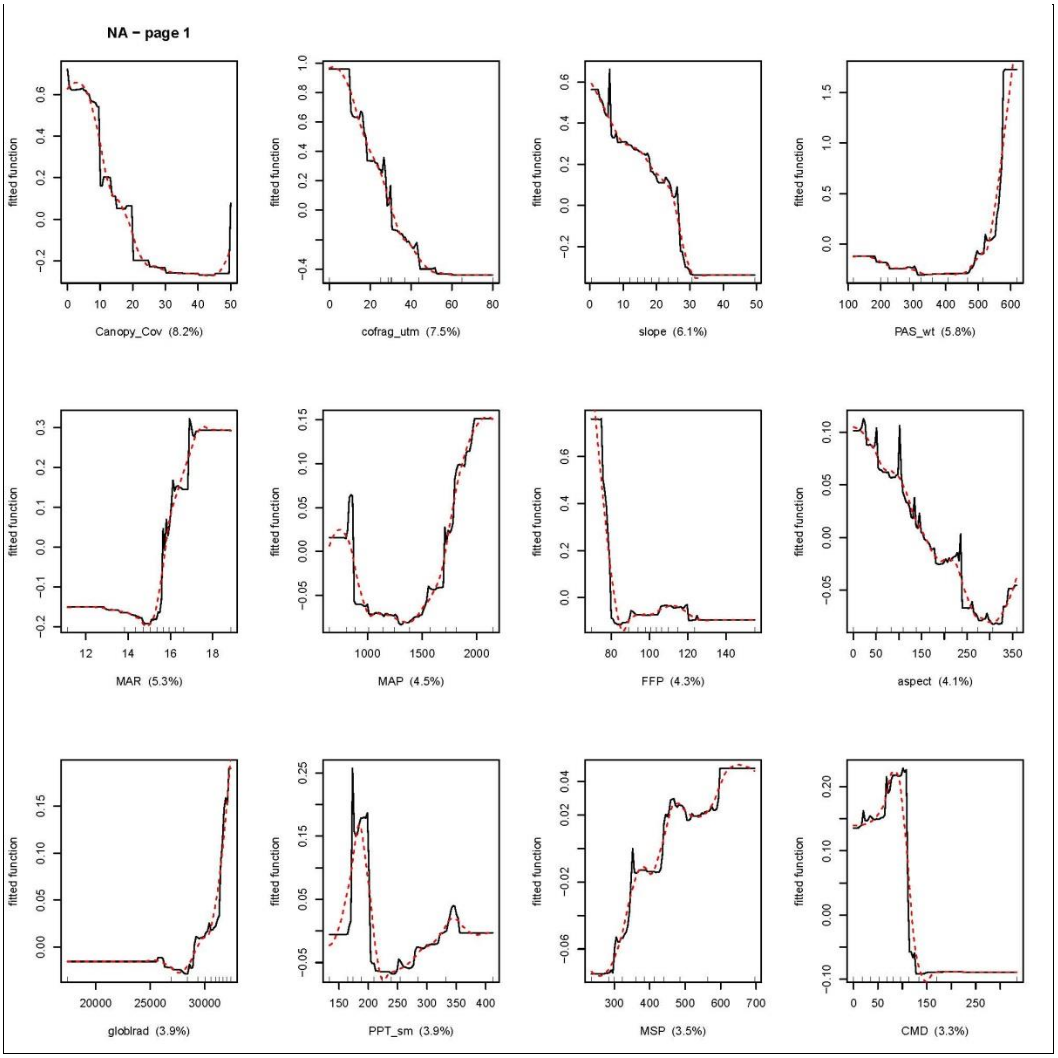


Figure 3. Marginal effects plots for the top twelve environmental variable predictors in a model of huckleberry patches important to grizzly bears showing the direction, magnitude, and shape of the relationship between predictor and response (from Proctor et al. 2016).

4.3 Relation between Huckleberry Patches and BEC Units

4.3.1 Field Sample Sites

Almost 90% (89.1%) of the 340 huckleberry patch sites in the 2014-15 field sample were in the ESSF zone while the remainder were in the ICH zone (Table 3). Over 91% (310) of sites were within the 101 to 105 forested sites series in both the ESSF and ICH zones and of this, 52.4% were in the 103 forested site series. Less than 9% of sites were in wetter forested site series (i.e., 110 to 112) or non-forested ecosystem units (i.e., 999).

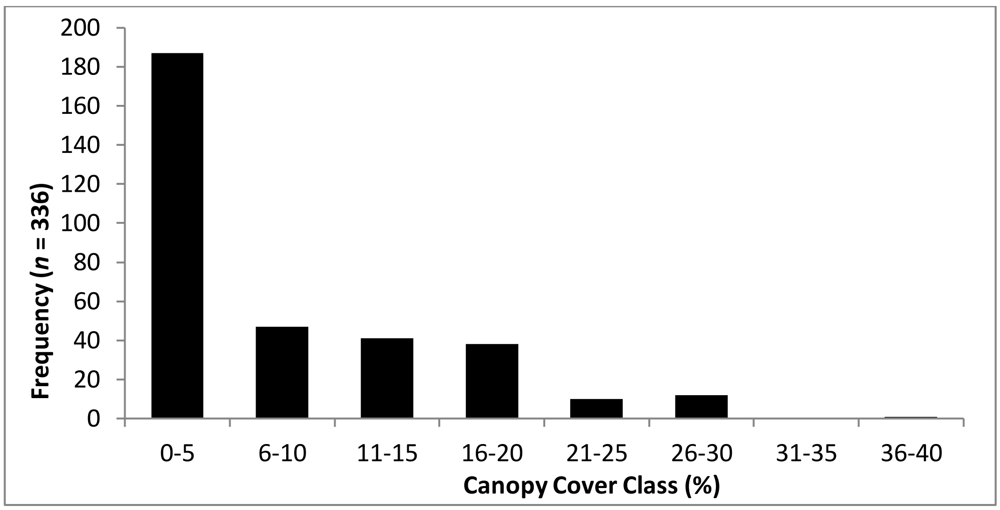
Table 3. Field sites with grizzly bear huckleberry use in 2014 and 2015 within various Biogeoclimatic Ecosystem Classification (BEC) variants and forested site series (101 to 112) or non-forested ecosystem units (999).

BEC Variant	102	103	104	105	101	110	111	112	999	Total	Percent
ESSFdk1		3	11							14	4.1
ESSFwh3	1	19	12		12	9			1	54	15.9
ESSFwm2		2			4					6	1.8
ESSFwm3	6	28	11	1	7	7		1	6	67	19.7
ESSFwm4	7	74			28	1	2			112	32.9
ESSFwmp		1								1	0.3
ESSFwmw	19	23			5				2	49	14.4
ICHdm		25			4					29	8.5
ICHdw1			1							1	0.3
ICHmw4		3	3				1			7	2.1
Total	33	178	38	1	60	17	3	1	9	340	100.0
Percent	9.7	52.4	11.2	0.3	17.6	5.0	0.9	0.3	2.6		

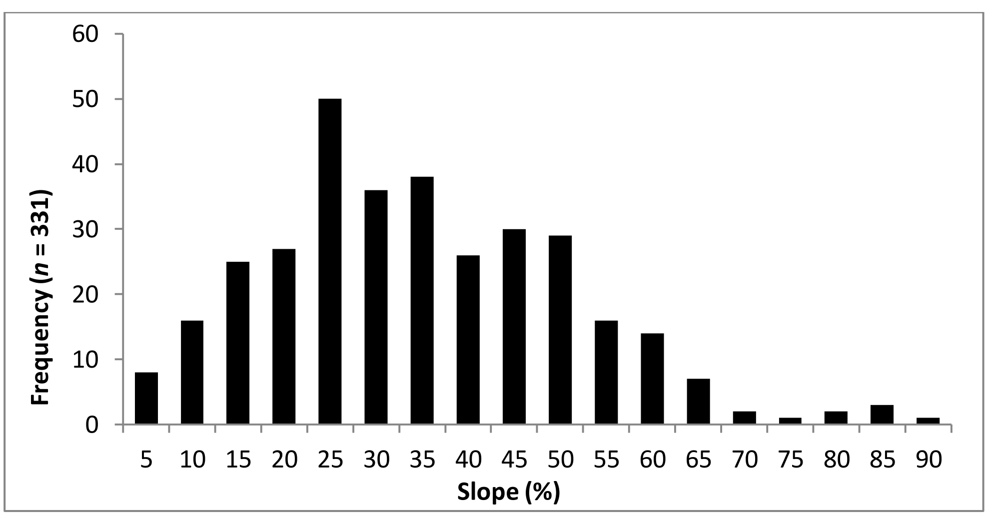
The 101 to 105 forested sites series have a range of soil moisture from moderately dry (site series 102) to fresh (site series 101), which is roughly equivalent to subxeric to mesic relative soil moisture. The relative soil nutrient regime of the 101 to 105 forested sites series ranges from very poor to rich. The 110 to 112 forested site series, in contrast, have soil moisture from moist to wet, which is roughly equivalent to subhygric to subhydric relative soil moisture. Soil nutrient regime of the 110 to 112 forested site series ranges from medium to very rich. The 110 to 112 site series are found on lower slope to toe slope to level moisture receiving sites that are wet. Black huckleberry can be relatively prominent in these wetter site series, especially the 110 and 111, but they were much more infrequently sampled during field visits, presumably because the availability of fruit was generally less, but also likely because the wetter site series were much less common on the study area (see section 4.3.2 below).

Canopy cover and slope and, to a lesser extent, aspect were among the most important environmental variables for predicting huckleberry patches used by grizzly bears in Proctor et al. (2016; see section 4.2 above). These are also the most easily measured variables in the field of the suite of huckleberry model predictive variables.

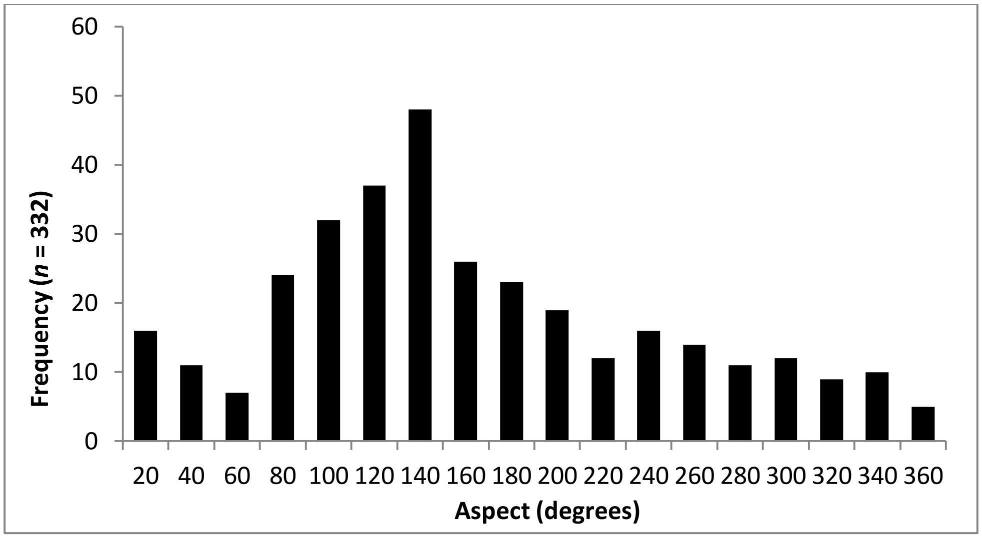
For all huckleberry patches sampled in 2014 and 2015, 93.2% had 20% or less canopy cover and 99.7% had 30% or less (Figure 4). The huckleberry patch model most often selected sites with between 0 and 20% canopy cover from what was available (Figure 3).



(a)



(b)



(c)

Figure 4. The frequency of huckleberry patches sampled in 2014 and 2015 within various categories of (a) canopy cover, (b) slope, and (c) aspect.

Level sites are considered those <5% slope, gentle slopes are >5 to <25%, moderate slopes are >25 to <50%, moderately steep slopes are 50 to <70%, steep slopes are >70%, and very steep slopes are >100% slope gradient (MoFR and MoE 2010). Most sample sites were on gentle (35.6%) to moderate (48.0%) slope gradient. The huckleberry patch model most often selected sites with slopes between 0 and 30% from what was available (Figure 3).

Huckleberry patch sample sites were on a wide range of aspects, but they were most often on aspects between 60 to 200 degrees. For ecosystem description within B.C., cool aspects are considered those northerly or easterly (285°-135°) on moderate to steep slopes (25-100% slope) whereas warm aspects are considered southerly or westerly (135°-285°) on moderate to steep slopes (RISC 1998). In this regard, field sampled huckleberry patches bridged between cool and warm aspects. The huckleberry patch model most often selected aspects between about 20 to 180 degrees from what was available (Figure 3)

As canopy openness is the most important factor associated with huckleberry patches important to grizzly bears, it was expected that most huckleberry patches would be in structural stages that typically are more open, that is structural stage 3, which is shrub dominated or structural stage 6 and 7, which are mature to old forest that typically has more open canopy then pole/ sapling (4) and young forest (5). As expected, the majority of sample sites were in structural stage 3, 6, and 7 (63%), however there also were a considerable number of sites in structural stage 4 and 5 (37%; Figure 5). In this context, it appears that with the right site conditions it does not matter as much what structural stage the forest is in as long as the canopy is sufficiently open. That said, as expected, forests in structural stage 4 were more likely to have a denser canopy, therefore less likely to produce huckleberries and be sampled. The results also suggest that is not essential to have stand disturbance, such as fire or logging, to produce huckleberry patches important to bears as huckleberry patches sampled were more frequently in mature and old forest structural stage (36%) than in shrub dominated sites (27%). Again, the most important factors for important huckleberry patches appeared to be canopy openness and site condition.

The term "site condition" in the above discussion and subsequent discussion below refers to the suite of environmental variables, other than canopy openness, found to be important for predicting huckleberry patches used by grizzly bears, i.e., coarse fragments in soil, slope, precipitation as snow in winter, mean annual solar radiation, mean annual precipitation, and, to a lesser extent, aspect. Canopy openness, slope, and aspect are the site condition variables that are easiest to measure in the field.

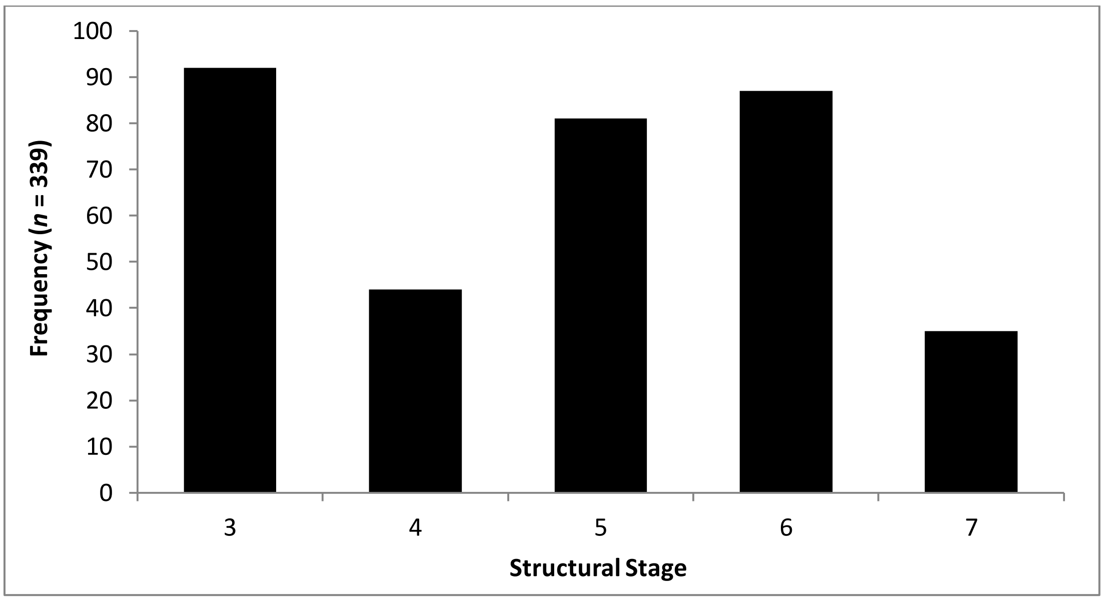


Figure 5. The frequency of huckleberry patch sites in 2014-15 within various structural stages. Structural stages are: 3 = shrub, 4 = pole/sapling, 5 = young forest, 6 = mature forest, 7 = old forest (see section 1.1 or MoFR and MoE 2010 for more detail).

4.3.2 PEM ESSF Forested Site Series, 2014-15 Sampling Area

Four PEM map projects covering the 2014-15 study area were clipped by the BEC version 11 ESSF zone as this zone contained the majority of modelled huckleberry patches. The four PEM projects did not necessarily have the version 11 BEC zone, subzone, and variant line-work available during their mapping, so in some cases clipping by this ESSF zone included other PEM BEC zones. Nevertheless, these areas were assumed to now be classified within the ESSF zone.

The percentage of forested site series within the study area versus modelled huckleberry patches was used to assess relative differences as the distribution among forested site series was most relevant to this project (Table 4). Three of the four PEM projects that overlapped the 2014-15 study area used the newest BEC forested site series codes (3 digit), whereas the Invermere TSA project used older 2 digit codes. Only forested site series with a 3 digit code were used in the

Table 4 summary as the older two digit codes can reflect greater variability in relative soil moisture or nutrient regime (section 1.1).

Overall, there were not large differences in the percentage of forested site series within modelled huckleberry patches versus the sample area in the ESSF zone. There was, however, a greater percentage of the drier 101, 102, and 103 sites series in huckleberry modelled patches (72.4%) versus in the sample area (67.4%). There also was a somewhat higher percentage of the wetter 110 and 111 sites series in huckleberry modelled patches (15.7%) versus in the sample area (14.8%). Interestingly, there was considerably less huckleberry modelled for the 104 (11.4%) site series than was in the study area (17.4%), which was not expected given the site series distribution of field sample sites above. However, what was available for site conditions conducive to huckleberry patches good for bears overall in the sample area may have been quite different than for the 104 site series visited in the field.

Table 4. The percentage of each Biogeoclimatic forested site series within the Engelmann-Spruce – Subalpine Fir (ESSF) zone within the 2014-15 sampling area (SA) versus the huckleberry modelled portion of the sampling area (HB). Total area results as well as a break down by structural stage is given. Structural stage is one indicator of potential canopy openness among site series. Structural stages are: 1 = sparse, 2 = herb, 3 = shrub, 4 = pole/sapling, 5 = young forest, 6 = mature forest, 7 = old forest (see section 1.1 or MoFR and MoE 2010 for more detail).

	Structural Stage													
Site Series	SA 1-2	HB 1-2	SA 3	HB 3	SA 4	HB 4	SA 5	HB 5	SA 6-7	HB 6-7	SA None	HB None	SA All	HB All
101	1.8	3.8	2.5	8.8	1.3	1.8	4.3	4.4	15.4	12.6	17.7	15.5	43.1	46.8
102	0.6	0.9	0.3	0.5	0.1	0.0	0.2	0.1	0.8	0.3	2.0	2.3	3.9	4.1
103	1.2	2.3	1.4	4.2	0.4	0.4	2.2	2.4	4.0	4.4	11.1	7.8	20.4	21.4
104	0.6	1.0	0.9	1.4	0.6	0.2	1.3	0.4	5.2	1.9	8.9	6.5	17.4	11.4
105	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.4	0.4
110	0.7	1.3	1.2	3.1	0.5	0.6	1.3	1.2	6.5	5.0	3.9	3.5	14.0	14.8
111	0.0	0.1	0.1	0.2	0.0	0.0	0.1	0.1	0.5	0.6	0.0	0.0	0.8	1.0
11112											0.1	0.0	0.1	0.0
112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
113			0.0				0.0		0.0	0.0	0.0		0.0	0.0
114							0.0		0.0				0.0	
Total	4.9	9.4	6.5	18.3	2.9	3.1	9.4	8.7	32.6	25.0	43.7	35.6	100.0	100.0

Only 56.3% of the 101 to 114 forested site series in the ESSF zone of the 2014-15 sampling area were assigned a structural stage during PEM mapping. The percentages in Table 4 for various structural stage are the proportion of the whole sample area or huckleberry mapped area rather than a proportion of the 56.3% of the study area that was assigned structural stage. For all forested site series that were assigned structural stage, considerably more modelled huckleberry was in early seral structural stages 1 to 3 (27.7%) than in the sample area (11.4%). In contrast, there was less percentage modelled huckleberry in older seral structural stages 6 and 7 (25.0%) than was in the sample area (32.6%). The amount of mid-seral structural stage 4 and 5 was not too different (11.8% modelled versus 12.3% in the sample area).

This general pattern among early, mid, and old-seral structural stages was also evident among two drier site series (101, 103) and two wetter sites series (110, 111), although the percentage huckleberry modelled and within the sample area varied considerably among the two groups. For site series 101 and 103, there was 19.1% HB versus 7.0% SA in structural stage 1-3, 8.9% HB versus 8.2% SA in structural stage 4-5, and 17.0% HB versus 19.4% SA in structural stage 6-7. For site series 110 and 111, there was 4.6% HB versus 2.0% SA in structural stage 1-3, 2.0% HB versus 1.9% SA in structural stage 4-5, and 5.6% HB versus 7.0% SA in structural stage 6-7.

These results suggest that any forested site series that has huckleberry growing within it is capable of producing a huckleberry patch good for grizzly bears as long as the canopy is open and the site conditions are appropriate. This was the same general conclusion suggested by the field sample sites above. Given that drier forested site series 101 and 103 are much more common within the sample area (63.5%) than wetter 110 and 111 site series (14.8%), they were much more likely to be available for the huckleberry model. Because older forests (structural stage 6-7) are treed, in contrast to structural stage 1 to 3, a smaller percentage of that available are likely to have canopy openness and site conditions conducive to producing huckleberry patches good for grizzly bears.

4.3.3 2014-15 Sampling Area versus Region 4

Results for the 2014-15 sampling area were contrasted against those for Kootenay Region 4 because huckleberry patch model building was largely based on the 2014-15 field sampling area (plus some additional results from the Flathead River valley) whereas model results for Kootenay Region 4 were extrapolated from the sample areas and have not yet been fully tested. In addition, the climate of Kootenay Region 4 is much wetter in the northern half then in the southern half and much drier on the eastern and western sides than within the 2014-15 sampling area (MacKillop and Ehman 2016; pages 46-47). Consequently, the composition of various Biogeoclimatic zones, subzones, and variants is different between the two areas. Region 4 rather than Ecoregional boundaries was used for huckleberry modelling as that was the area for which GIS layers had previously been compiled. Nevertheless, the results by Biogeoclimatic zone, subzone, and variant within Region 4 are expected to apply where those same variants extend outside Region 4.

The vast majority of predicted huckleberry patches were in the ESSF zone for both the 2014-15 sample area (89.9%) and region 4 (91.5%; Table 5) yet the ESSF zone makes up a little less than 50% of each area. Less than 10% of the predicted huckleberry patches were in the ICH zone, but it makes up 27 to 29% of each area. A small percentage of predicted huckleberry patches in the 2014-15 sample area (0.6%) and region 4 (1.0%) were in the IMA, MS, and IDF zones even though they make up about 23% of each area. For the ESSF zone in region 4, 8.4% is predicted to be huckleberry patches good for grizzly bears, whereas 1.2% of the ICH zone, and 0.6% of the IMA, MS, and IDF zones combined are.

Table 5. The percentage of each Biogeoclimatic zone within the 2014-15 sampling area (SA), the huckleberry modelled portion of the sampling area (SA HB), region 4 (R4), and the huckleberry modelled portion of region 4 (R4 HB). Also listed is the amount of huckleberry modelled area as a percentage of each zone total for the sampling area (HB%SA) and region 4 (HB%R4).

BEC Zone	BEC Zone Name	SA (%)	SA HB (%)	Diff	HB % SA	R4 (%)	R4 HB (%)	Diff	HB % R4
ESSF	Engelmann Spruce – Subalpine Fir	48.3	89.9	41.6	5.2	49.9	91.5	41.6	8.4
ICH	Interior Cedar – Hemlock	28.7	9.5	-19.2	0.9	27.4	7.4	-20.0	1.2
MS	Montane Spruce	9.5	0.6	-8.8	0.2	8.9	0.7	-8.2	0.4
IMA	Interior Mountain-heather Alpine	3.3	0.0	-3.3	0.0	7.0	0.4	-6.6	0.2
IDF	Interior Douglas Fir	10.2	0.0	-10.2	0.0	6.8	0.0	-6.8	0.0

Precipitation as snow in winter was one of the top six environmental variables in the huckleberry patch prediction model (see section 4.2) and the marginal effect of winter snow on huckleberry patches increased substantially after about 475 mm, which corresponds to MacKillop and Ehman's (2016) categories of wet through extremely wet winter precipitation (Table 6).

Table 6. Categories of winter precipitation in the Kootenay Region (from MacKillop and Ehman 2016).

Category	Snowfall
Very dry	< 150 mm
Dry	150–300 mm
Moist	300–450 mm
Wet	450–600 mm
Very Wet	600–900 mm
Extremely wet	> 900 mm

When broken down by relative wetness among Biogeoclimatic subzones, huckleberry patches predicted within the wet and very wet ESSH subzones were 77.5% of the 2014-15 sampling area and 73% of region 4 whereas they make up between 31 to 33% of each area (Table 7). A greater proportion of the 73% of huckleberry patches predicted within the wet and very wet ESSH subzones of region 4 are in more sparsely treed higher elevation woodland and parkland areas (41.4%) compared to more densely treed areas below (31.7%). Most of the predicted huckleberry patches in ICH subzones are in the moist to very wet, but these are still only 6.6% of all patches within region 4.

Table 7. The percentage of each Biogeoclimatic subzone relative wetness class within the 2014-15 sampling area (SA), the huckleberry modelled portion of the sampling area (SA HB), region 4 (R4), and the huckleberry modelled portion of region 4 (R4 HB). Also listed is the amount of huckleberry modelled area as a percentage of each subzone total in the sampling area (HB%SA) and region 4 (HB%R4).

BEC Subzone Relative Wetness	SA (%)	SA HB (%)	Diff	HB % SA	R4 (%)	R4 HB (%)	Diff	HB % R4
ESSF Dry	15.3	12.3	-3.0	2.2	17.0	15.9	-1.1	4.3
ESSF Moist					1.6	2.6	1.0	7.7
ESSF Wet	33.0	77.5	44.6	6.6	25.7	46.6	20.9	8.4
ESSF Very Wet					5.7	26.4	20.8	21.5
ICH Very Dry	3.9	0.0	-3.8	0.0	1.8	0.0	-1.8	0.0
ICH Dry	17.8	4.7	-13.1	0.7	6.8	0.8	-6.0	0.5
ICH Moist	7.0	4.7	-2.3	1.9	13.1	3.7	-9.4	1.3

ICH Wet	0.1	0.1	0.0	5.0	3.8	1.6	-2.2	1.9
ICH Very Wet					1.8	1.3	-0.5	3.3
IMA	3.3	0.0	-3.3	0.0	7.0	0.4	-6.6	0.2
MS Dry	9.5	0.6	-8.8	0.2	8.9	0.7	-8.2	0.4
IDF Very Dry	3.5	0.0	-3.5	0.0	1.7	0.0	-1.7	0.0
IDF Dry	6.7	0.0	-6.7	0.0	5.1	0.0	-5.1	0.0

5 Determining BEC Ecosystem Importance to Grizzly Bears for Black Huckleberry Fruit

Using the results above, the following is a step-wise process to help determine whether a BEC forested site series is: (a) a black huckleberry patch likely important for grizzly bears, or (b) could be a black huckleberry patch important for grizzly bears if the canopy were opened up with logging, other silviculture treatments, or prescribed burning. The relative importance classes used in the tables following were as in Table 8.

Table 8. Six-class relative importance scale used in the step-wise process to evaluate the potential for a BEC forested site series to be a black huckleberry patch important for grizzly bears (based on RISC 1999, BC MoFR and MoE 2010).

Relative Importance Rating	Class Code
High	1
Moderately High	2
Moderate	3
Low	4
Very Low	5
Nil	6

5.1 Step 1 – BEC Zone

Determine what BEC zone you are in and its relative importance for potentially producing huckleberry patches important for grizzly bears (Table 9).

Table 9. The relative importance of each Biogeoclimatic zone within Kootenay Region 4 for black huckleberry patches important to grizzly bears.

BEC Zone	BEC Zone Name	Relative Importance
ESSF	Engelmann Spruce – Subalpine Fir	High
ICH	Interior Cedar – Hemlock	Moderate
MS	Montane Spruce	Low
IMA	Interior Mountain-heather Alpine	Very Low
IDF	Interior Douglas Fir	Nil

5.2 Step 2 – BEC Subzone

Within the high to moderate ESSF or ICH zones of Table 8, determine what BEC subzone and variant you are in and its relative wetness, therefore its relative importance for potentially producing huckleberry patches important for grizzly bears (Table 10).

Table 10. The relative importance of Biogeoclimatic subzones and variants within the ESSF or ICH zones within Kootenay Region 4 for black huckleberry patches important to grizzly bears.

BEC Subzone, Relative Wetness	BEC Subzones and Variants	Relative Importance
ESSF Moist (1 dry)	dc1, mm1, mm2, mmw, mmp, mh	High
ESSF Wet	wc2, wc4, wcw, wcp, wm, wm1, wm2, wm3, wm4, wmw, wmp, wh1, 1h2, wh3	High
ESSF Very Wet	vc, vcw, vcp	High
ESSF Dry	dc2, dcw, dcp, dk1, dk2, dkw, dkp	Moderately High
ICH Wet	wk1	Moderately High
ICH Very Wet	vk1	Moderately High
ICH Moist	mk1, mk4, mk5, mw1, mw2, mw3, mw4, mw5	Moderate
ICH Dry	dm, dw1	Low
ICH Very Dry	xw, xwa	Very Low

5.3 Step 3 – Forested BEC Site Series

Within the high to moderately high ESSF or ICH subzones of Table 10, determine what BEC site series you are in, therefore the relative prominence (Table 11) of huckleberry (Table 12).

Table 11. Prominence categories based on the frequency and mean cover of plants within BEC ecosystem plots within each BEC site series (from MacKillop and Ehman 2016).

Freq. (% of plots)		Mean Cover (%)				
>1->25	*	<1	1-3	3-10	10-25	>25
50-70		●	●●	●●●	●●●●	●●●●●
>70		●	●●	●●●	●●●●	●●●●●

5.4 Step 4 – Forest Canopy Openness

Within the BEC site series of Table 12 with a high prominence of black huckleberry, determine the openness of the forest canopy, therefore its relative importance for producing huckleberry patches important for grizzly bears (Table 13):

Table 13. The relative importance of BEC site series with a high prominence of huckleberry in Table 12 for patches important to grizzly bears based on forest canopy openness.

Canopy Cover (%)	Relative Importance
0-10	High
11-20	High
21-30	Moderately High
31-40	Moderate
41-50	Low
>50	Very Low

Table 12. The relative prominence of black huckleberry within BEC forested site series of the high to moderately high ESSF or ICH subzones and variants of Table 10 above. X indicates the site series is not available in that BEC variant. Blank means the data is not currently available. The percentage of each BEC variant within region 4 (R4) and the huckleberry modelled portion of region 4 (R4 HB) are provided as is the amount of huckleberry modelled area as a percentage of each variant total for region 4 (HB%R4).

	Site Series													
BEC Label	102	103	104	105	101	110	111	112	113	114	R4 (%)	R4 HB (%)	Diff	HB % R4
High Relative Importance BEC Subzones and Variants														
ESSFdc 1	●●●●●	●●●●	●●●●	X	●●●●	●●●●●	●●●●	●●	X	X	1.4	4.8	3.5	16.4
ESSFmm 1											0.0	0.1	0.1	16.3
ESSFmm 2											0.1	0.0	-0.1	0.0
ESSFmmw											0.0	0.0	0.0	5.1
ESSFmmp											0.1	0.1	0.0	4.4
ESSFmh	●●●	●●●	●●●	●●●●	●●●●	●●●	●●●	●●	X	X	1.4	2.4	1.0	8.1
ESSFwc 2											1.6	3.6	2.0	10.3
ESSFwc 4	●●●●	●●●●	X	X	●●●●	●●●●	●●●	●●●	X	X	3.5	5.0	1.5	6.7
ESSFwcw	●●●●	●●●●	●●●●	X	●●●●	●●●	X	X	X	X	3.4	9.2	5.8	12.5
ESSFwcp											3.0	7.8	4.8	11.9
ESSFwm											1.4	2.2	0.8	7.2
ESSFwm 1	●●	●●●	●●●●	X	●●●●	●●●	●●●	●●●	X	X	0.8	1.4	0.5	7.5
ESSFwm 2	●●●●	●●●●	●●●●●	X	●●●●	●●●●	●●	●●	X	X	1.2	2.0	0.7	7.4
ESSFwm 3	●●●●	●●●●	●●●●●	●●●●	●●●●	●●●●	●●●●	●●●	X	X	0.9	1.6	0.7	8.3

	Site Series													
BEC Label	102	103	104	105	101	110	111	112	113	114	R4 (%)	R4 HB (%)	Diff	HB % R4
ESSFwm 4	●●●	●●●●	X	X	●●●●	●●●	●●	X	X	X	2.0	3.4	1.5	8.0
ESSFwmw	●●●	●●●●	X	X	●●●●	●●●	X	X	X	X	2.6	4.7	2.1	8.4
ESSFwmp											1.7	1.1	-0.5	3.2
ESSFwh 1	●●●●	●●●●	●●●●	X	●●●●	●●●	●●●	X	X	X	2.0	2.7	0.7	6.1
ESSFwh 2	●●●	●●●●	●●●●	X	●●●●	●●●	●●	●●	X	X	0.6	0.5	-0.1	3.7
ESSFwh 3	●●●●	●●●●	●●●●	X	●●●●	●●●●	●●●	●●	X	X	1.1	1.5	0.4	6.5
ESSFvc	●●●	●●●●	●●●●	X	●●●●	●●●	●	X	X	X	2.6	7.9	5.3	14.1
ESSFvcw	●●●●	●●●●	●●●●	X	●●●●	●●●	X	X	X	X	1.5	9.6	8.1	29.6
ESSFvcp											1.6	9.0	7.4	25.9

Moderately High Relative Importance BEC Subzones and Variants

BEC Label	102	103	104	105	101	110	111	112	113	114	R4 (%)	R4 HB (%)	Diff	HB % R4
ESSFdc 2		●●●	●●●	●●●	●●●	●●●	●●	X	X	X	0.2	0.2	0.0	4.6
ESSFdcw	●●	●●●	X	X			X	X	X	X	0.4	0.4	0.0	4.4
ESSFdcp											0.0	0.0	0.0	0.4
ESSFdk 1		●●	●●	X	●●	●●●	●●●●	X	X	X	3.8	4.4	0.6	5.3
ESSFdk 2			*	X	●●	●●●	●●		X	X	5.2	2.6	-2.6	2.3
ESSFdkw											3.7	3.3	-0.5	4.0
ESSFdkp											2.3	0.2	-2.1	0.5

	Site Series													
BEC Label	102	103	104	105	101	110	111	112	113	114	R4 (%)	R4 HB (%)	Diff	HB % R4
ICH wk 1	●●●	●●●	●●	X	●●	*	●●●	●●	●	X	3.8	1.6	-2.2	1.9
ICH vk 1	●●●	●●●	●●●	X	*	*	●●●	*	X	X	1.8	1.3	-0.5	3.3

5.5 Step 5 – Site Slope

Within the high to moderately high canopy openness of Table 13, determine what site slope category you are in, therefore its relative importance for producing huckleberry patches important for grizzly bears (Table 14).

Table 14. The relative importance of site slope angle (in percent) within the high to moderately high canopy openness of Table 12 for black huckleberry patches important to grizzly bears. Slope angle categories are from MoFR and MoE (2010).

Slope (%)	Description	Relative Importance
<5%	Level	Moderately High
>5 to <25	Gentle	High
>25 to <50	Moderate	High
50 to <70	Moderately Steep	Moderate
>70 to <100	Steep	Low
>100	Very steep	Very Low

5.6 Step 6 – Site Aspect

Within the high to moderately high slopes of Table 14, sites with an aspect between 20 to 200 degrees (northerly, easterly, or southerly) have the highest probability of being a huckleberry patch important to grizzly bears.

6 Management Application

One of the main tenants of the Association of BC Forest Professional's (ABCFP) principles of forest stewardship (ABCFP 2012) is to maintain function, structure, and composition of key ecosystem components over both temporal and spatial scales. The ABCFP (2012) suggest that maintaining ecological integrity requires strategic management of valued ecosystem components (such as grizzly bears) at both the landscape and site levels.

The broader ecological investigations and predictive modelling of black huckleberry patches important to grizzly bears outlined in Proctor et al. (2016) and summarized in this report should be of use to foresters, biologists, or other land managers in landscape level forest harvest planning, silviculture prescriptions, and/ or wildlife habitat management compatible with maintaining or improving habitat (i.e., black huckleberry patches) important for grizzly bear foraging.

The exercise outlined in this report was done so that the predictive modelling of Proctor et al. (2016) could be translated into those BEC zones, subzones, variants, and site series and range of site conditions most important for producing black huckleberry patches important to grizzly bears. Report results and the step-wise approach outlined for determining the relative importance of a site as a huckleberry patch useful to grizzly bears should be of use to to foresters, biologists, or other land managers using the BEC system for either site-level or landscape level management planning.

The black huckleberry patch model GIS map layers (Proctor et al. 2016) together with this BEC system site evaluation guide should provide complementary tools for effective management of habitat important to grizzly bears at both the landscape and site levels over both temporal and spatial scales.

7 Literature Cited

ABCFP; Association of BC Forest Professionals. 2012. Principles of forest stewardship. Association of BC Forest Professionals, Vancouver, British Columbia. 9 pp.

MoFR and MoE; B.C. Ministry of Forests and Range and Ministry of Environment. 2010. Field manual for describing ecosystems, 2nd edition. Land Management Handbook 25, B.C. Ministry of Forests and Range and B.C. Ministry of Environment, Victoria, British Columbia.

MacKenzie, W. 2011. New coding schemes for Biogeoclimatic Site Units. Province of B.C., Victoria, B.C., Extension Note 106. 4 pp.

MacKillop, D.J. and A.J. Ehman. 2016. A field guide to site classification and identification for southeast British Columbia: the south-central Columbia Mountains. Province of B.C., Victoria, B.C., Land Management Handbook 70. 478 pp.

MacKillop, D.J., A.J. Ehman, and M. Ryan. 2016. A field guide to ecosystem classification and identification for Southeast British Columbia: four Biogeoclimatic Subzones/Variants in the Boundary-Okanagan. Province of B.C., Victoria, B.C., Temporary Supplement to Land Management Handbook 70. 73 pp.

Proctor, M.F., Lamb, C. & MacHutchon, G. 2016. Predicting huckleberry patches important to grizzly bears. Habitat Conservation Trust Foundation Project 4-523. Trans-Border Grizzly Bear Project, Kaslo, B.C.

RISC, Resources Inventory Standards Committee. 1998. Standard for Terrestrial Ecosystem Mapping in British Columbia. Terrestrial Ecosystems Task Force, Resources Inventory Standards Committee, Victoria, B.C. 100 pp.

RISC, Resources Inventory Standards Committee. 1999. British Columbia wildlife habitat rating standards. Version 2.0. Terrestrial Ecosystems Task Force, Resources Inventory Committee, Victoria, B.C. 97 pp.