Grizzly Bear Denning Habitat and Demographic Connectivity in Northern Idaho and Western Montana

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Model development: PS/MB;
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GRIZZLY BEAR DENNING HABITAT AND DEMOGRAPHIC CONNECTIVITY IN NORTHERN IDAHO AND WESTERN MONTANA

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Abstract—GRIZZLY BEARS (*Ursus arctos*) are protected in the contiguous United States under the federal Endangered Species Act. The conservation strategy for the species encourages population connectivity between isolated Grizzly Bear Recovery Areas through Demographic Connectivity Areas. Another goal is reestablishment of a breeding population in the Bitterroot ecosystem through natural immigration. Using the locations of 362 verified grizzly bear den sites, Maxent species distribution modeling and resource selection functions, we predicted 21,091 km^2 (8143 mi^2) of suitable denning habitats. Terrain features, distance to roads and land cover best explained suitable denning habitats in northern Idaho and western Montana. The results support the demographic model for population connectivity and independent of other factors there is suitable denning habitat for hundreds of grizzly bears in the Bitterroot analysis area. We suggest additions to the Bitterroot Grizzly Bear Recovery Area and that more effective motorized access management be applied to demographic connectivity areas.

Key words: grizzly bear, denning, den sites, selection, demographic connectivity, dispersal, Bitterroot ecosystem, northern Rockies.

Denning behavior in GRIZZLY BEARS (*Ursus arctos*) is thought to be an evolutionary adaptation to long winter periods where natural foods are unavailable. The vast majority of dens are excavated and seldom re-used and den site selection and construction are improved through learning and experience (Craighead and Craighead 1972, Jonkel 1987). In colder regions grizzly bears may remain in the den for up to six months with cubs born inside the den. Grizzly bears enter a deep sleep during hibernation but can easily be disturbed and aroused while in the den (Craighead and Craighead 1972). Linnell et al. (2000) review the denning process finding in general that bears select for steep slopes from 30-50° with stable snow conditions and 1-2km from roads and human habitations while avoiding valley bottoms, exposed ridge tops and high peaks. Human activities within 200m of an occupied den can cause physiological changes such as increased heart and breathing rate, wakefulness and even den abandonment leading to increased cub mortality (Linnell et al. 2000). Other causes of den abandonment include collapse of the den roof, excessive moisture within the den and snow melt entering through the roof. Mid-winter den abandonment can be catastrophic for the bears involved. Craighead and Craighead (1972) observed that human intrusion during the denning excavation and pre-entry period could also have critical impacts. The selection by grizzly bears for steep and remote den sites is likely an adaptation to seek greater security while stationary in the den and vulnerable to attacks by humans and other animals and thus providing a selective advantage. Steeper slopes tend to be well-drained and provide overhead soil insulation which is enhanced by digging the den under a tree. Aided by gravity, removal of excavated soil and rock away from the den entrance would be easier on steeper slopes.

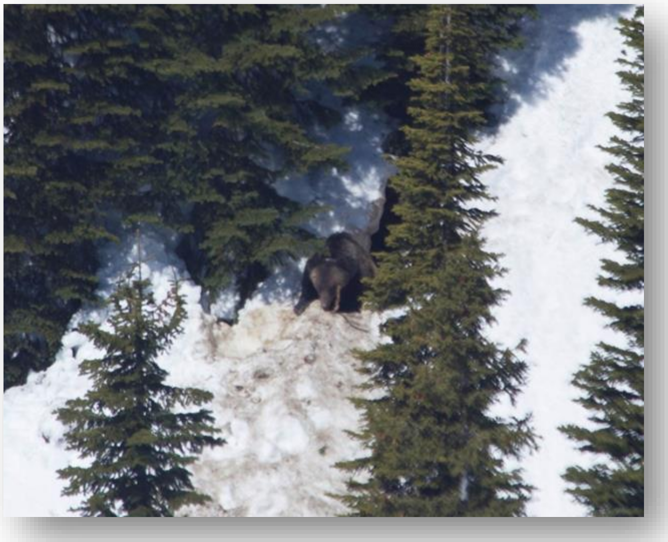


Figure 1. A female grizzly in northwest Montana at the entrance to her den.

Approximately 50,000 grizzly bears once inhabited the western US states but between 1850-1970 these were eliminated from the vast majority of the landscape until ≈ 1000 remained (Mattson and Merrill 2002). Isolation was one of the factors cited when the grizzly bear was listed in 1975 as a threatened species south of Canada under the U.S. Endangered Species Act. Grizzly bears have since expanded their total numbers and distribution in response to recovery efforts including the cessation of hunting, improved sanitation and road access management yet remain isolated as separate populations (USFWS 2021).

Allendorf and Ryman (2002) estimate 5000 grizzly bears may be needed in a single population or metapopulation to ensure long-term viability. None of the current recovery areas are of sufficient geographic size to independently support that number of bears: the most recent population estimate for the US is ≈ 1800 (USFWS 2021). To achieve long term viability isolated populations must be linked while reestablishing a breeding population in north-central Idaho (Metzgar and Bader 1992, Allendorf et al. 2019, Allendorf 2020, Mattson 2021). The metapopulation has been defined as a collection of populations with some rate of interchange between them and the metacommunity has been defined as a set of local communities linked by dispersal or a "community of metapopulations" (Hanski and Gilpin 1991). Linkage of the isolated grizzly bear populations into a metapopulation would increase the probability of long-term survival (Allendorf et al. 2019). van Nouhuys (2016) wrote "Reserve design that is based in metapopulation ecology emphasizes networks of sites rather than isolated sites, with the implicit or explicit understanding that regional persistence of species will be greater in a network of patches within dispersal range than in isolated sites (unless very large)." The Conservation Strategy for Grizzly Bear in the Northern Continental Divide Ecosystem (NCDE) (USFWS 2018) designated two Demographic Connectivity Areas (DCA) to provide habitat for resident female grizzly bears and connectivity between the NCDE, Cabinet-Yaak (CYE) and Bitterroot Grizzly Bear Recovery Areas (BE) as shown in Figure 2.

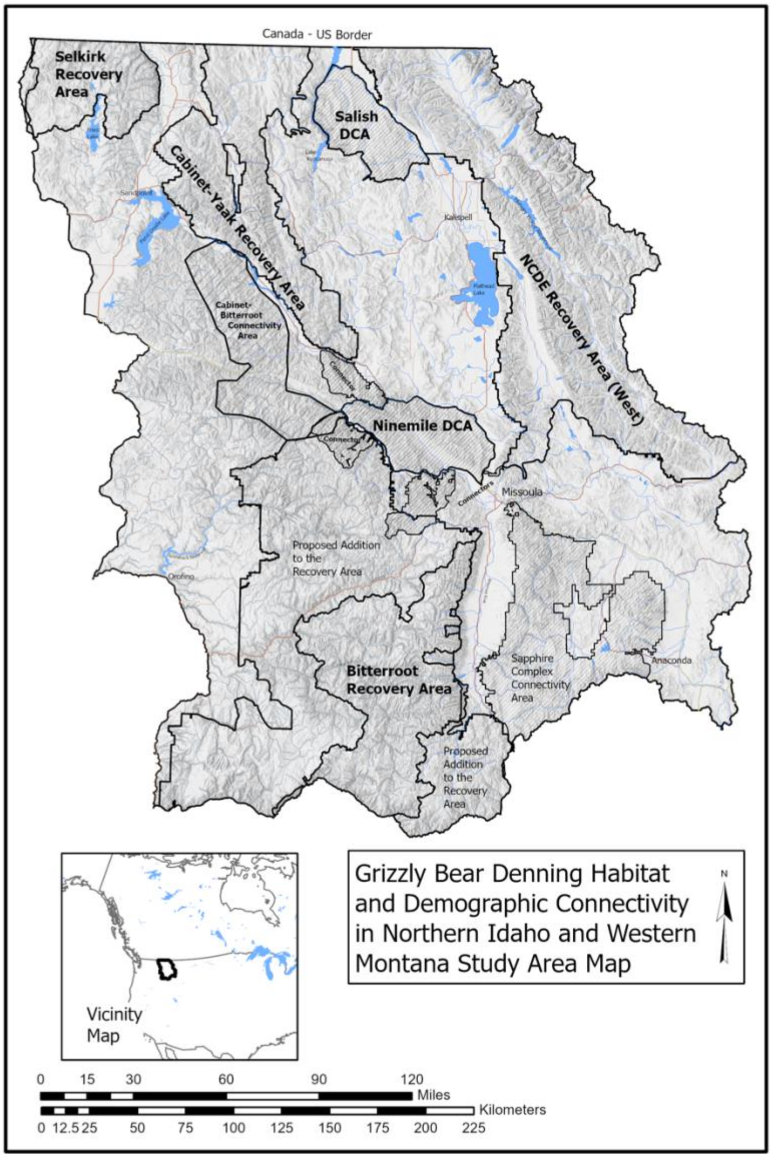


Figure 2. The northern Idaho and western Montana study area.

There are two habitat-based models for grizzly bear population connectivity. The male-mediated model (Peck et al. 2017) was investigated for its potential to support maintenance of genetic diversity in the Yellowstone population based on long distance dispersals of male grizzly bears from the NCDE. This genetic rescue model might work to prevent further loss of genetic diversity in the long-isolated Yellowstone population depending on whether the immigrants breed and the offspring survive to breed. The other is the demographic model based on "stepping stones" of secure suitable habitats that are occupied by resident female and male grizzly bears within known dispersal distances (Mattson et al. 1996). Due to the much shorter dispersal distance of female grizzly bears (McLelland and Hovey 2001, Proctor et al. 2004, Graves et al. 2014), rather than a sprint, this demographic model relies on multi-year dispersals or a genetic relay. This gradual process points to wider linkage areas where females can reside to promote successful inter-subpopulation movement (Proctor et al. 2015). The male-mediated genetic rescue model is not applicable to the reestablishment of a breeding population in the Bitterroot ecosystem where there is no population to supplement or heterozygosity to maintain. Therefore, we evaluate and discuss our results within the context of the demographic model whose ideal performance would enable consistent flow and occupation of habitats between core populations and serve as the source of female grizzly bears into the Bitterroot ecosystem.

By definition, residential occupancy requires availability of suitable habitats in all four seasons. Therefore, the presence and identification of primary denning habitats is central to the efficacy of the demographic model and essential to explaining landscape potential and design of bear management units with large secure core areas and motorized access management to lower open road density in the intervening areas.

Denning habitat for grizzly bears has not been previously analyzed across the northern Idaho-western Montana region. We address these fundamental questions: 1) where are suitable grizzly bear denning habitats located? 2) compared to metrics from the NCDE, is there an adequate amount and distribution of suitable denning habitat to support reestablishment of a resident breeding population in the Bitterroot Recovery Area? 3) does the availability and spatial distribution of suitable denning habitats support the demographic model for connecting isolated grizzly bear populations and providing a source of female grizzly bears to the Bitterroot ecosystem?

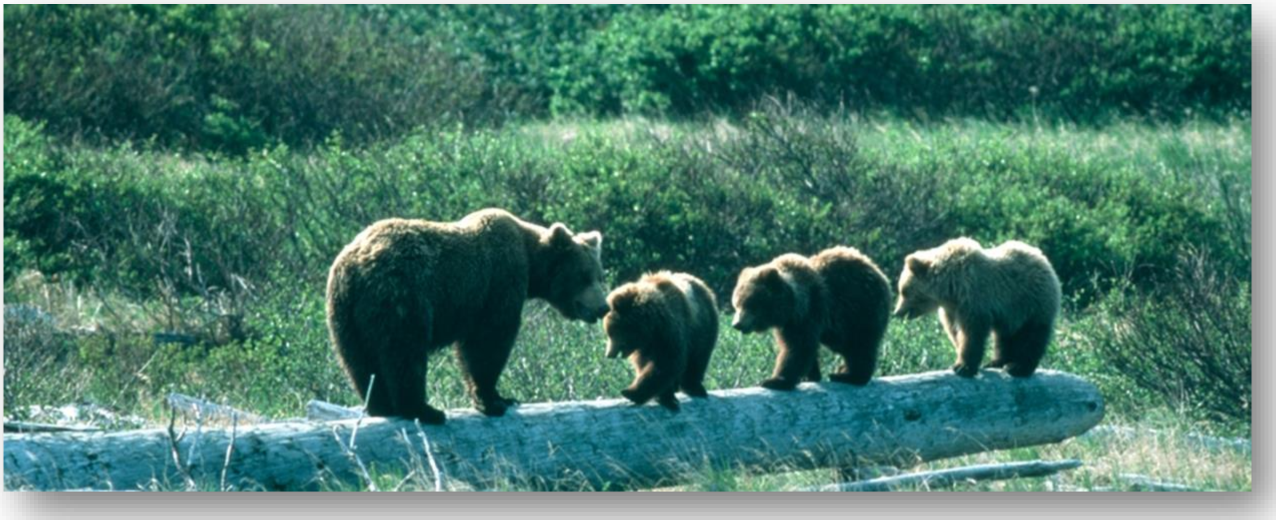
Methods

Study Area—. The study area (108,750km^2) (41,989mi^2) includes all or significant portions of four Grizzly Bear Recovery Areas, the two Demographic Connectivity Areas and five other potential connectivity areas (USFWS 2000, Proctor et al. 2015, Peck et al. 2017) as shown in Figure 2. It includes the portion of the NCDE Recovery Area that is a source of dispersing grizzly bears and the portion of the Bitterroot Recovery Area most likely to receive immigrating grizzly bears. Under the influence of the maritime climate pattern this area generally receives greater annual precipitation than areas east of the Continental Divide and south of the Salmon River. A major defining feature is the Bitterroot Mountain Range which runs much of the length of the study area from north to south.

Literature Review—. In addition to the review by Linnell et al. (2000) we used search engines BioOne, ScienceDirect, JSTOR and GoogleScholar and the key words grizzly bear, dens, denning and den-site selection to identify and review 30 published papers and reports relevant to denning in North American grizzly bears, including 18 from interior, non-coastally influenced populations. The review found the most frequently reported descriptive statistics for den sites were elevation, slope, aspect and landcover (shown in Table A-2, Appendix). Some authors discussed snow for its insulative and security values, its association with the unavailability of natural food sources, as a trigger for final den entry and as part of denning chronologies. The review revealed no significant differences in den site selection and construction between male and female grizzly bears (Aune and Kasworm 1989, Mace and Waller 1997, Pigeon et al. 2016) and we did not differentiate between the sexes for our analyses. We derived descriptive information for the verified den sites for slope, elevation, aspect, land cover and remoteness (Table A-1, Appendix). Based on the review we assumed that grizzly bears in the study area would select den sites in higher terrain with relatively steep slopes, away from close proximity to human habitations and areas with high human activity and away from water bodies.

Den Locations—. Verified grizzly bear den site locations (n = 364) were provided through data sharing agreements with the USFWS and the Montana Department of Fish, Wildlife and Parks (MDFWP). Due to the status of the grizzly bear as a federally protected species we agreed the coordinates of the locations would not be shared or displayed in figures. The locations come from four isolated population areas: the western half of the Northern Continental Divide Ecosystem (NCDE West), the Cabinet Mountains, Yaak Watershed-Purcell Mountains and the Selkirk Mountains and come primarily from bears radio-collared for population trend monitoring from 1985-2019 (Mace and Waller 1997, Costello et al. 2016, Kasworm et al. 2021). Site by site visual analysis using Google Earth Pro revealed two atypical locations that were removed from further evaluation, resulting in study sample n = 362.

Aspect—. We found that the distribution of aspect is not uniform. We used the Rayleigh Test of Uniformity in the R circular package (Rao Jammala-Madaka and SenGupta 2001). A test statistic of 0.0965 with P-value of 0.0342 < 0.05 for a circular mean of 166.5738 degrees disproves the null hypothesis that there is a uniform distribution. We did not assess multimodal distribution.

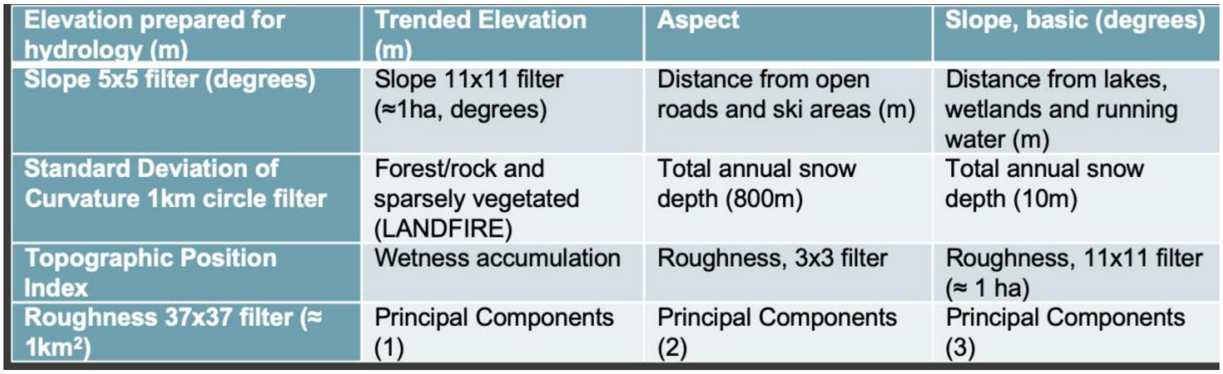


Spatial Autocorrelation of Dens—. We tested the den sites for spatial autocorrelation using Moran's I test in ArcGIS Pro (ESRI 2020). The resultant z-score of 31.77 indicates that there is < 1% probability (p = 0.000) that the clustered pattern is the result of random chance. Verified sites are often naturally clustered due to use by the same bear in consecutive years owing to den area fidelity (Aune and Kasworm 1989, Pigeon 2014) and clusters have also been documented from multiple bears contemporaneously. Others factors may be a lack of sufficiently secure and dispersed denning habitat. We developed a model using spatially rarified den locations and compared AUC (area under curve) and TSS (True Skill Statistic, Allouche et al. 2006) values to the six variables model run with the 362 den locations. The rarified model was based on removing spatial autocorrelation from 5 den clusters after outliers were removed. Autocorrelation distances were developed using the incremental autocorrelation tool in ArcGIS Pro. First peak z-score values of the 5 ecosystems were averaged ($\bar{x}$ = 5.6km). We used this lag distance in the SDM toolbox for spatial rarefaction. The process reduced the number of points from 362 to 92. The model using all 362 dens had an AUC score of 0.884 and a TSS of 0.467 while the spatially rarified dens had a lower AUC (0.85) and a higher TSS (0.54). Warren et al. (2019) found that model prediction based on withheld occurrences has questionable reliability for estimation of the interactions between environmental gradients and habitat suitability. Based on this and the test scores we retained all 362 dens in subsequent models. The number of dens that are detected is a small fraction of the total dens. For example, NCDE population trend research (Costello et al. 2016) seeks to maintain approximately 50 grizzly bears with radio collars on an annual basis, which is ≈ 5% of total N. Significant reduction of the sample size would reduce the amount of variation captured by the data set.

Model Development—. Maxent (Phillips et al. 2004) was used to develop a series of models. We used default 10,000 background sample points and kept them throughout the process for consistency. Low elevation heavily populated areas were included to show variation across the large landscape and for contrast between suitable and unsuitable denning habitat (Saupe et al. 2012). Model results were evaluated using AUC, TSS, Percent Contribution of the individual variables and visually.

Environmental Variable Creation and Selection—. We developed and selected a set of 16 rasters with 10m resolution depicting environmental variables for use in Maxent as shown in Table 1. Continuous variables were re-projected to WGS 84 then converted to an identical extent and cell location using the Project Raster to Template tool from the Marine Geospatial Ecology Toolset (MGET, Roberts et al. 2010). Categorical variables were resampled to 10m using the "nearest" parameter to preserve values then run through MGET for alignment with the continuous environmental variables.

Table 1. Environmental Variables Used for Models.



Elevation prepared for hydrology (m)	**Trended Elevation (m)**	**Aspect**	**Slope, basic (degrees)**
Slope 5x5 filter (degrees)	Slope 11x11 filter (≈1ha, degrees)	Distance from open roads and ski areas (m)	Distance from lakes, wetlands and running water (m)
Standard Deviation of Curvature 1km circle filter	Forest/rock and sparsely vegetated (LANDFIRE)	Total annual snow depth (800m)	Total annual snow depth (10m)
Topographic Position Index	Wetness accumulation	Roughness, 3x3 filter	Roughness, 11x11 filter (≈ 1 ha)
Roughness 37x37 filter (≈ 1km²)	Principal Components (1)	Principal Components (2)	Principal Components (3)

Snow and Trended Elevation—. Total snow accumulation from the years 1981-2010 was extracted from PRISM (Daly et al. 2020) raster data. Two 10m downscaled versions were created using ClimateNA (Wang et al. 2016) and by inverse distance weighting. We included snow as an environmental variable for initial model testing. However, ideal snow depths have not been documented in relation to grizzly bear denning and precipitation and snow are difficult to model with any specificity in mountainous terrain (Larson et al. 2013). The snow variable also had high predictive power which led to misleading model values. We eliminated both of the snow accumulation environmental variables and adopted a modified (trend surface) elevation raster based on the following rationale. The study area increases in base elevation from the northwest to the southeast, varying from 222m at the confluence of the Snake and Clearwater Rivers to 830m on the Pend Oreille River at the Washington-British Columbia Border to a higher range of 1916m at Elliston, Montana and 1950m at Butte, Montana on Blacktail Creek. Known den sites are clustered in the north and eastern portion of the study area where grizzly bear research studies are focused. Model runs using an elevation variable resulted in suitable denning habitat being projected to much lower elevations than one would biologically expect in the southeastern portion of the study area. We developed a trended elevation variable with base elevations adjusted using points spaced 500m-1km apart on major rivers. The trended elevation model produced better results except along the Snake River where the large elevation difference in the Hells Canyon area caused an anomaly in the trended surface, giving an appearance of relatively high elevations at the top of the canyon. The study area extent was reduced to eliminate this anomaly.

Distance from Roads, Downhill Ski Resorts and Water—. As a proxy for remoteness and disturbance from human activity we created a distance from roads, motorized trails and downhill ski areas raster with open roads and motorized trail data extracted from the USFS MUMV data, and data from the states of Idaho and Montana. Downhill ski areas were extracted or recreated from ski area parcel polygons from USFS Region 1. Open roads, motorized trails and ski areas were rasterized and a distance surface was created using ArcGIS Pro. Initial model test runs showed a drop-off in denning habitat probability as the distance from roads increased beyond 1206m. Subsequent investigation of den distances derived from the initial distance surface showed den density declined as distance from road increased (e.g., Bob Marshall Wilderness, Glacier National Park due to remoteness and grizzly bear study areas being located in accessible areas). To compensate, we assumed that the probability of denning became constant past 1206m from an open road which approximated the peak in the histogram of den distances from roads. Distances > 1206m from the open road were changed to 1206m as a constant. For avoidance of water we used distance from water bodies. Combining rasterized National Wetland Inventory water bodies (lakes and wetlands) with rivers and streams (USGS 2004), we created a distance from water raster using the Euclidean Distance tool in ArcGIS Pro.

Land Cover—. A 10m or less classification was not available for the study area so we resampled the LANDFIRE 30m vegetation classification data to 10m using nearest to maintain values to make the data compatible with Maxent. Using ArcGISPro we attached vegetation type attributes from the LANDFIRE dataset to the data set of 362 den locations. Ninety-five percent of the den locations (n = 343) were in the forested classifications and five percent of den locations (n =19) were in the barren rock and sparsely vegetated classification groups as shown in Figure 3.

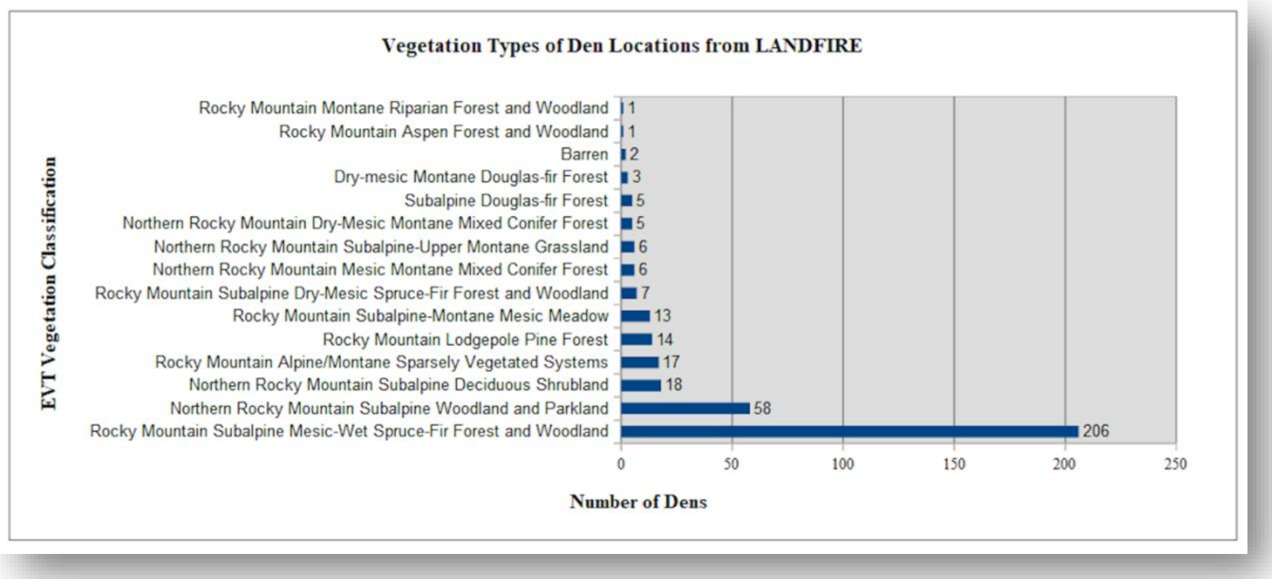


Figure 3. LANDFIRE Vegetation Classification of Den Sites (n = 362).

Rock and sparsely-vegetated classifications mostly occur at the highest elevations in denning habitat. Adding the forest/non-forest-sparse vegetation categorical variable reduced overestimation of the relative probability of den occurrence in rocky and open high elevation habitats and it was more consistent with the literature review and the site by site visual analysis using Google Earth Pro.

Standard Deviation of Curvature—. We created a standard deviation of curvature raster with a 500m radius (Ironside et al. 2018) to identify highly variable areas of the landscape.

Correlation testing—. We tested the 16 continuous variables for correlation using R Project (illustrated in Figure 4). Environmental variables used in the model are highlighted with a red

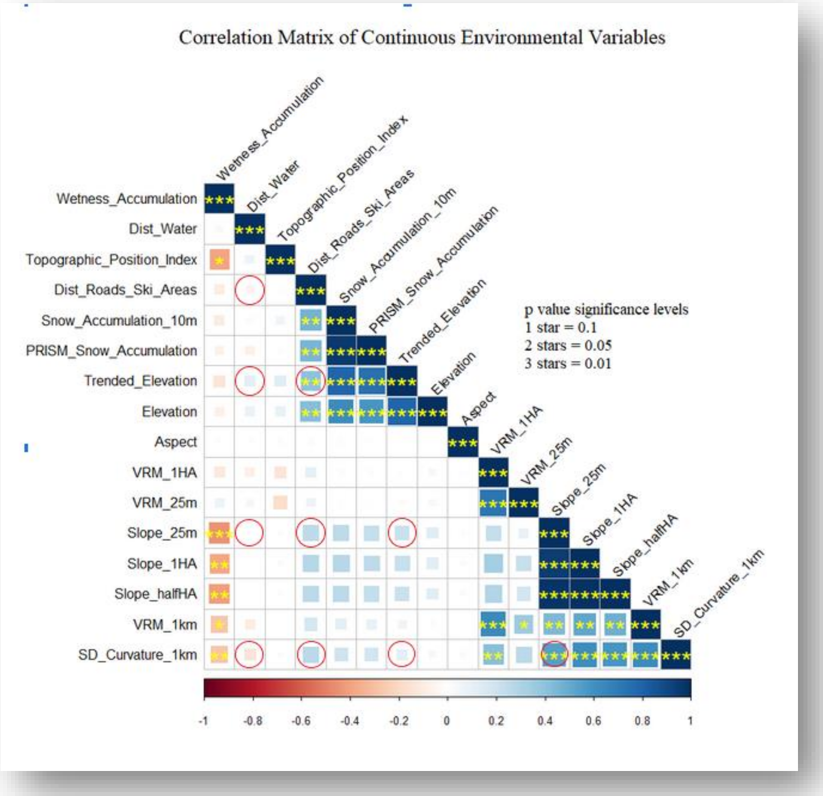


Figure 4. Correlation Matrix of Environmental Variables.

circle to show pairwise correlations. Most selected variable pairs lacked significance at the ≤ 0.1 p values. Exceptions included the Slope_25m (standard slope calculation from ArcGIS) paired with SD_Curvature_1km and the Trended Elevation paired with Distance from Roads and Ski Area variables. The Slope 25m/SD_Curvature_1km pair was positively correlated because many areas with steep slopes are rough while areas with low slope values usually occur in relatively flat areas with low topographical roughness. When distance from roads and downhill ski areas increases, trended elevation also increases because most roads are located in valley bottoms or sidehills and are not generally constructed on ridgelines.

While the Wetness Accumulation variable showed significant negative correlations with the other environmental variables and would normally be included in a model run, comparing Wetness Accumulation to Distance from Water indicated that there was no (0) contribution of Wetness Accumulation to the model. Distance from water had a contribution of 1.6% and was retained.

Model Evaluation—. Using the raster layers and the verified data set we developed and tested 17 models with differing combinations of variables, reporting results and statistical scores for the top three models. We used AUC and TSS to evaluate model fitness. AUC is the area under the Receiver Operating Characteristic plot. AUC values range from 0 to 1 with 0 indicating all predictions are wrong and 1 indicating all predictions are right. Values of TSS range from -1 to 0 and 0 to 1 with zero being co-equivalent to randomness with values trending towards 1 indicating a better model.

Comparing Projection of Buffered Minimum Convex Polygons (MCP) to the Study Area vs Using the Entire Study Area—. To assess the value of projecting a localized model to the study area, we compared a restricted background model projected to the study area versus running the model over the entire study area. Minimum Convex Polygons (MCP) were created around den sites from the four grizzly bear population areas. The MCPs were then buffered 6.3km based on the radius of an average 125km^2 female grizzly home range expressed as a circle (Mace and Waller 1997, n = 29) to encompass the range of environmental variables for females with dens at the edge of the MCP**.**

These areas were sampled with the default 10,000 background points and projected to the entire study area. The projected model had a slightly lower AUC (0.846) than the model that was run over the entire study area (AUC = 0.88). We chose the un-projected model based on a slightly higher AUC and the fact that the selected environmental predictors in the final model are fairly consistent throughout the study area. Comparing similar AUC scores may be misleading (Jimenez-Valdere 2012). The higher score of the un-projected model may have been due to the increased variability of environmental predictors in a larger landscape or a function of the random sampling of background data points. Morales et al. (2017) cited several papers raising the issue that default parameters may produce over or under fitted results and that Maxent parameters used in research papers were not published. We eliminated parameters used to develop Maxent models to reduce complexity and eliminate issues caused by base elevation difference, snow shadows and lack of den locations with increasing distances from roads due to capture and study area bias. We kept the regularization parameter at 1 for consistency after testing a model using a parameter of 0.1 showing little difference. Data was un-projected (WGS 84). A bias file was incorporated to compensate for the change in raster cell area due to latitude.

We found that using linear and quadratic feature parameters created optimal models. The incorporation of product features caused a slight reduction in relative probabilities of dens past the 1206m threshold distance from roads. We believe this was due to Maxent incorporating both the distance constant and the decreasing number of den locations with distance from roads due to research being concentrated in more easily accessible areas or the reduced availability of secure denning habitat. Using hinge features only produced a similar model to our Model13_VEG but with slightly lower AUC score so it was eliminated. We eliminated the Extrapolate, Do Clamping and Fade by Clamping parameters to keep the model simple. We selected Model13_VEG based on acceptable AUC and TSS Scores and the inclusion of the standard deviation of curvature for a 1km radius raster. We selected the three best model candidates and report results for them.

Den sites have a wide ecological amplitude as shown by the den distribution histogram of relative probabilities for Model13_VEG shown in Figure 5.

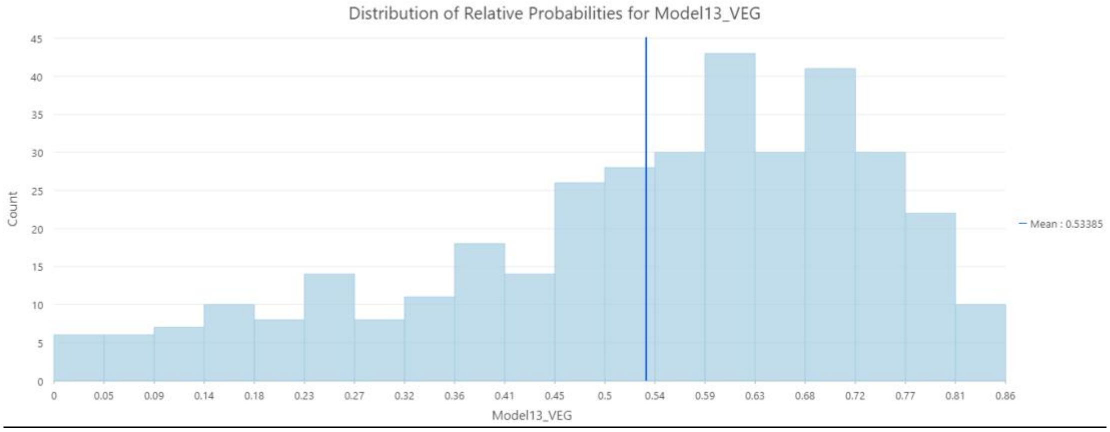
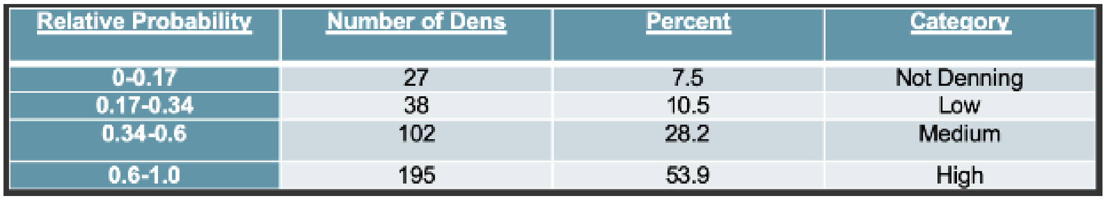


Figure 5. Distribution of Relative Probabilities.

The majority of dens occur at higher model values with a negative skew showing fewer dens occurring in the extended left tail. The model was classified into four categories; Not Denning Habitat, Low, Medium and High. Table 2 shows the ranges of relative model probabilities for the four categories.

Table 2. Relative Probabilities Used for Categories.



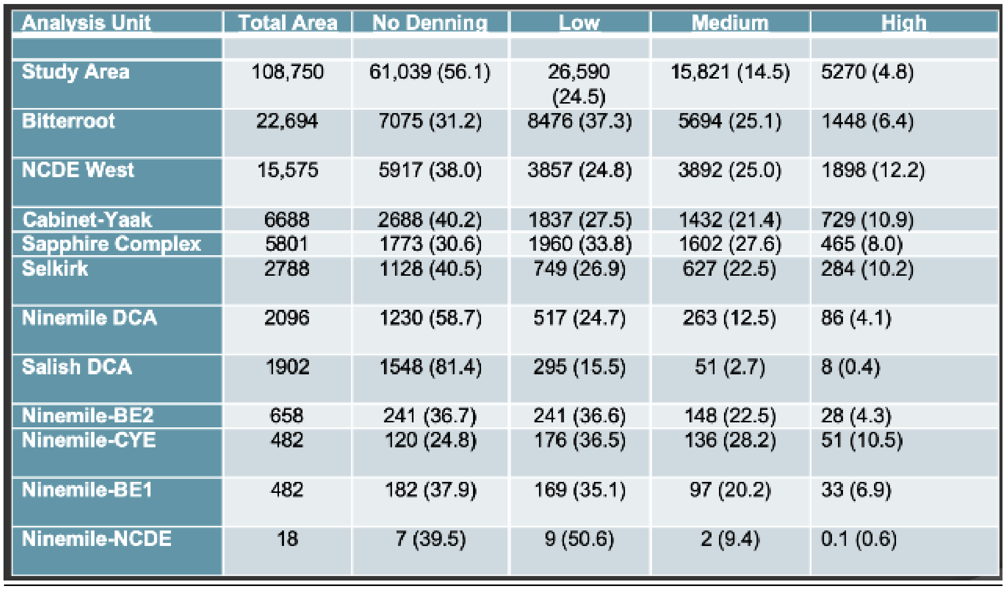
Relative Probability	Number of Dens	Percent	Category
0-0.17	27	7.5	Not Denning
0.17-0.34	38	10.5	Low
0.34-0.6	102	28.2	Medium
0.6-1.0	195	53.9	High

Analysis of Results—. We used the denning results for the NCDE West as a baseline for a rough comparison with the Bitterroot analysis unit as the NCDE Recovery Area is believed to be at or near K (Costello et al. 2016) and there are similarities in habitat security and productivity (Boyce and Waller 2003). The NCDE West analysis unit is 67.4% of the Recovery Area. The current estimated N = 1069 (USFWS 2021) includes a larger Demographic Monitoring Area. Assuming ≈ 85% of the population resides in the Recovery Area (n ≈ 900) and assuming equal distribution, ≈ 600 grizzly bears reside in the NCDE West. We also reviewed our results in the context of previous grizzly bear habitat studies and estimates of potential K (Merrill et al. 1999; Carroll et al. 2000; Hogg et al. 2001; Boyce and Waller 2003; Mowat et al. 2013, Mattson 2021). The NCDE Conservation Strategy habitat management standards define secure core habitat as areas >500m from an open road and at least 10km^2 in area. Using these metrics for secure core we evaluated the current habitat situation in the two DCAs and the other identified potential linkage areas.

Results

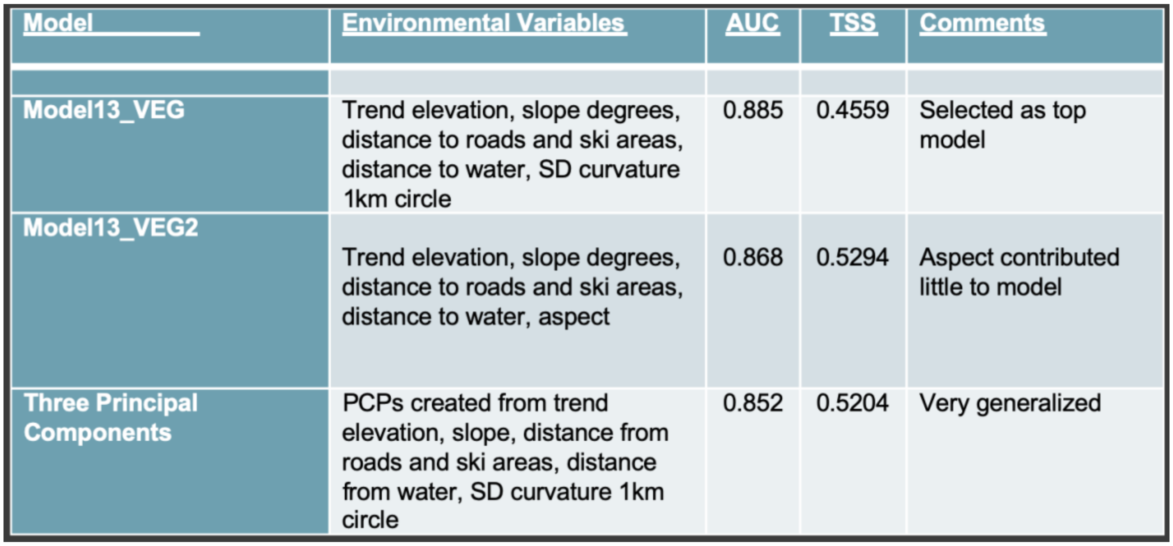
We selected Model_13_Veg with slope, trended elevation, land cover, distance to roads, ski areas and water and standard deviation of curvature at 1km as our best model and the results are shown in Tables 3 and 4 and in Figures 8-11. The highest quality habitats comprise < 5% of the study area.

Table 3. Spatial Results (km^2) and Percentages by Analysis Unit.



Analysis Unit	Total Area	No Denning	Low	Medium	High
Study Area	108,750	61,039 (56.1)	26,590 (24.5)	15,821 (14.5)	5270 (4.8)
Bitterroot	22,694	7075 (31.2)	8476 (37.3)	5694 (25.1)	1448 (6.4)
NCDE West	15,575	5917 (38.0)	3857 (24.8)	3892 (25.0)	1898 (12.2)
Cabinet-Yaak	6688	2688 (40.2)	1837 (27.5)	1432 (21.4)	729 (10.9)
Sapphire Complex	5801	1773 (30.6)	1960 (33.8)	1602 (27.6)	465 (8.0)
Selkirk	2788	1128 (40.5)	749 (26.9)	627 (22.5)	284 (10.2)
Ninemile DCA	2096	1230 (58.7)	517 (24.7)	263 (12.5)	86 (4.1)
Salish DCA	1902	1548 (81.4)	295 (15.5)	51 (2.7)	8 (0.4)
Ninemile-BE2	658	241 (36.7)	241 (36.6)	148 (22.5)	28 (4.3)
Ninemile-CYE	482	120 (24.8)	176 (36.5)	136 (28.2)	51 (10.5)
Ninemile-BE1	482	182 (37.9)	169 (35.1)	97 (20.2)	33 (6.9)
Ninemile-NCDE	18	7 (39.5)	9 (50.6)	2 (9.4)	0.1 (0.6)

Table 4. Results for Top Three Models.



Model	Environmental Variables	AUC	TSS	Comments
Model13_VEG	Trend elevation, slope degrees, distance to roads and ski areas, distance to water, SD curvature 1km circle	0.885	0.4559	Selected as top model
Model13_VEG2	Trend elevation, slope degrees, distance to roads and ski areas, distance to water, aspect	0.868	0.5294	Aspect contributed little to model
Three Principal Components	PCPs created from trend elevation, slope, distance from roads and ski areas, distance from water, SD curvature 1km circle	0.852	0.5204	Very generalized

The results were consistent with what was expected based on the literature review. This model shows the highest probability denning habitat in areas with suitable slopes (range), position on the landscape and distance from open roads. While having comparable AUC/TSS scores, we chose Model13_VEG using the SD Curvature 1km variable over aspect because at a large landscape level bears select den sites on relatively equal aspects as shown in the polar plot (Jennes 2014) in Figure 7.

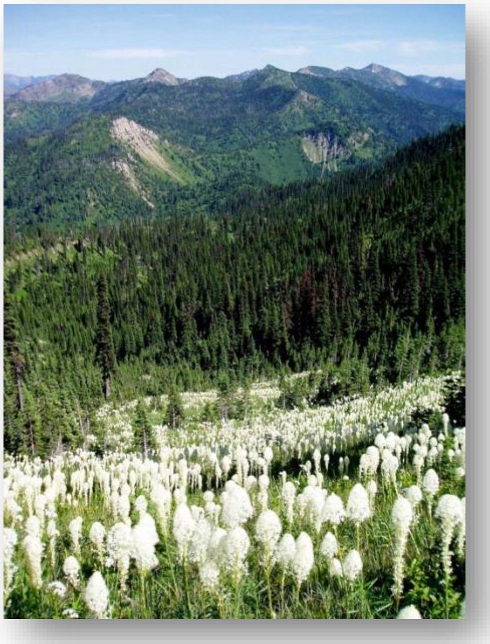


Figure 6. Denning Habitat in the Swan Mountains, Montana.

We eliminated the Three Principal Components Model based on a visual inspection which showed that it was too generalized. For example, it did not show lower relative den probabilities along gently sloping ridgelines. It also had a lower AUC but a higher TSS score than the Model13_VEG.

We found support for the demographic model for population connectivity in that denning and secure core habitats are present in the potential connectivity areas with the exception of the Salish DCA analysis unit. The Sapphire and Pintlar Ranges, where there have been persistent verified observations of grizzly bears (Jonkel, MDFWP 2021) and where berry-producing shrubs important to grizzly bears are abundant (Hogg et al. 2001) has the largest amount of secure core habitat in the largest sizes as shown in Table 5 with 2486km^2 (614,215 ac).

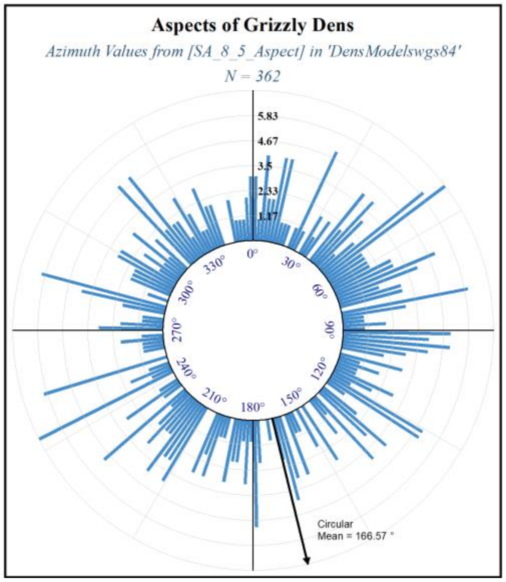


Figure 7. Aspect of Verified Dens (n = 362).

Table 5. Secure Core Habitat in Previously identified Connectivity Areas in km^2 (acres).

Area	Small 10-40 km^2 (2500-10000ac)	Larger > 40km^2 (10000ac)	All
Sapphire-John Long	166 (41,067)	2319 (573,148)	2486 (614,215)
CYE-BE Connector	469 (115,994)	524 (129,469)	993 (245,463)
Ninemile DCA Extenders	115 (28,460)	551 (136,120)	666 (164,580)
Garnet-Sapphire	296 (73,026)	327 (80,780)	622 (153,806)
Flint Range	32 (7,874)	413 (102,126)	445 (110,000)
Salish DCA	76 (18,807)	0	76 (18,807)

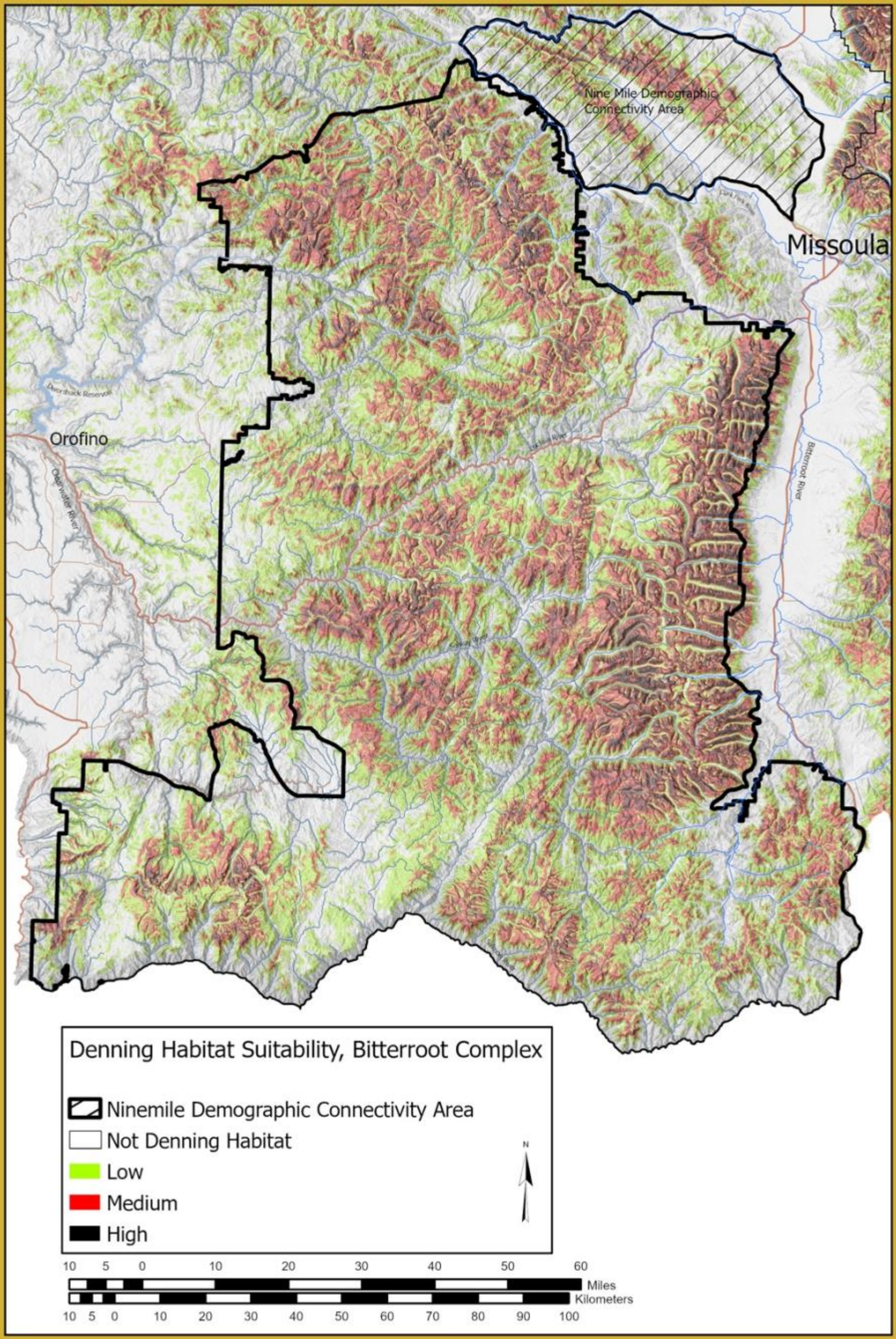


Figure 8. Denning Suitability in the Bitterroot Analysis Unit.

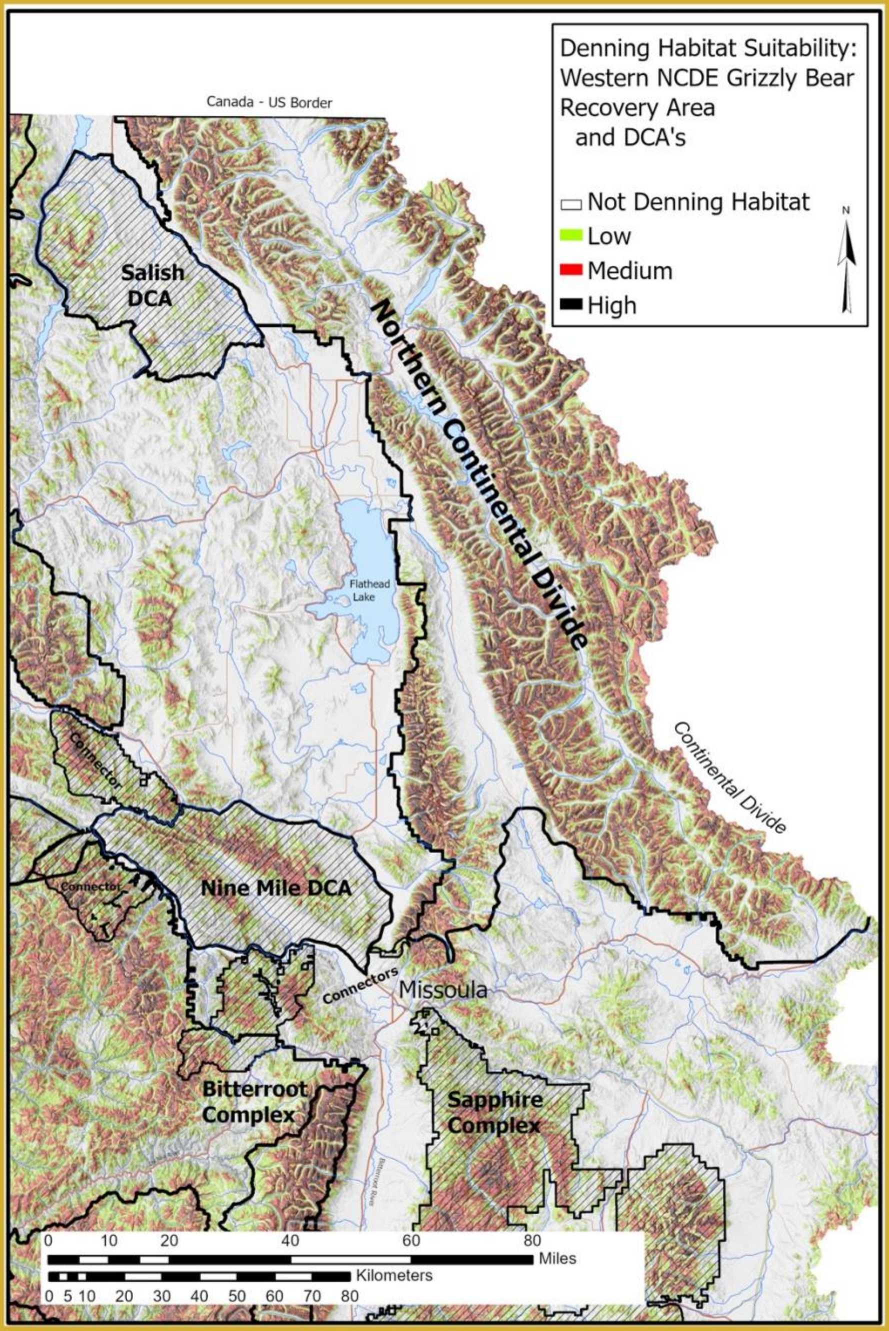


Figure 9. Denning Suitability in the NCDE West, Ninemile DCA and Salish DCA Analysis Units.

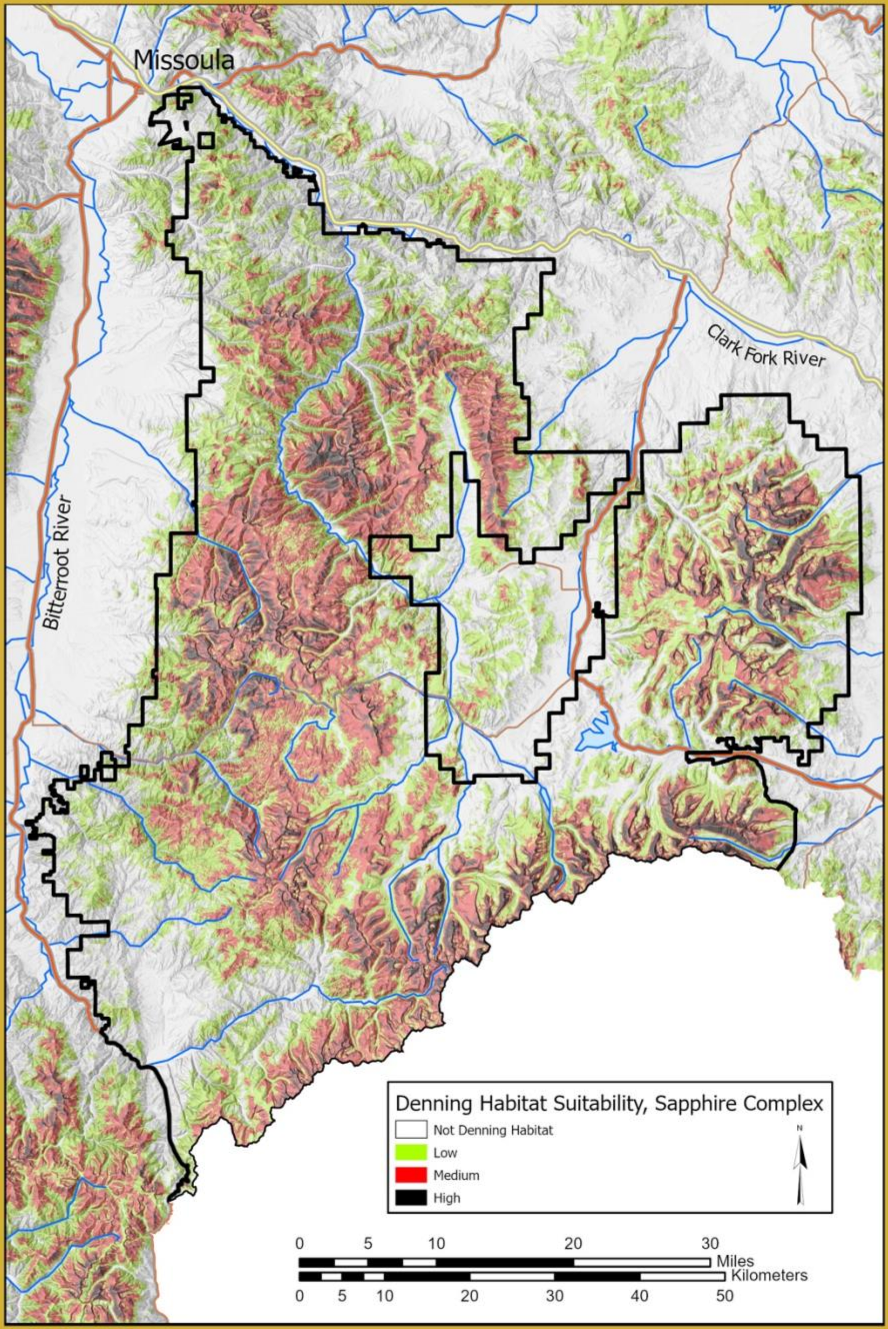


Figure 10. Denning Suitability in the Sapphire Complex Analysis Unit.

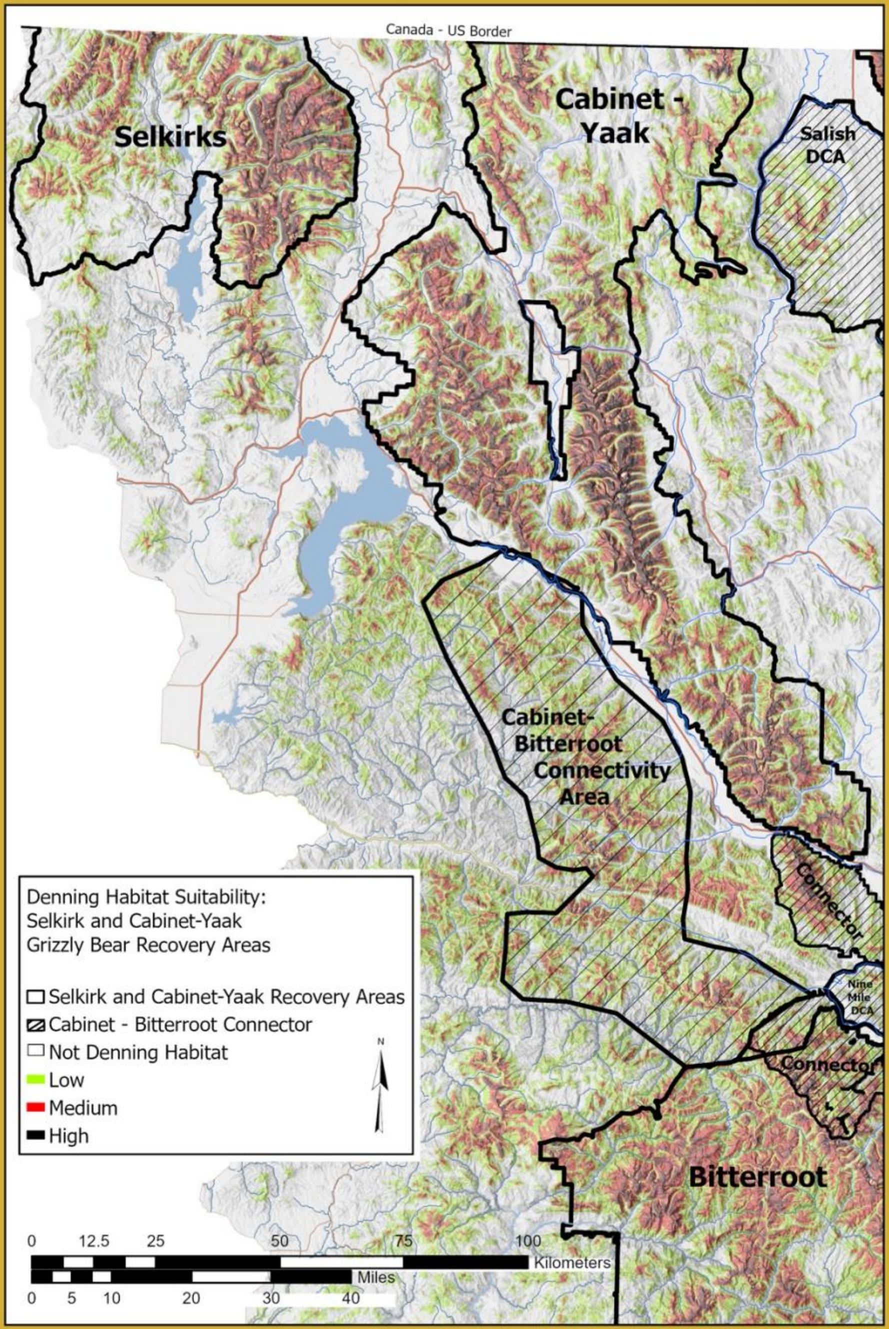


Figure 11. Denning Suitability in the Cabinet-Yaak and Selkirk Recovery Areas and Cabinet Bitterroot Connector.

The Ninemile DCA, a crucial component of the demographic model, has contiguous denning habitat likely sufficient to support a small resident population. The presence of females with cubs has been verified (Jonkel, MDFWP 2021).

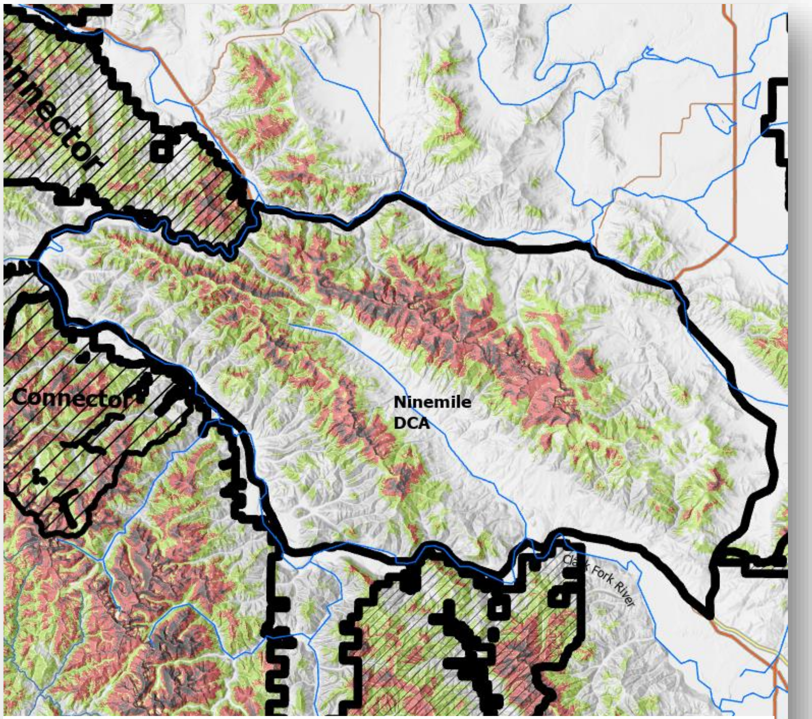


Figure 12. Closeup of the Ninemile Demographic Connectivity Area.

However, conditions in the Salish DCA are not currently conducive to female residency on a continual occupancy basis due to just a few small secure core areas which are spatially distant with high open road densities in the intervening areas. The area between the CYE and BE along the northern Bitterroot Divide has high public ownership and secure core areas within short distance of each other. The USFS (2020:83) describes the area as containing year-round suitable habitat similar to that which supports grizzly bears within recovery zones and habitat could be used for either short-term movements or for low population densities between higher-population density recovery zones.

Measured against the NCDE West metrics and based on similarities in habitat productivity and security, it is reasonable to assume the amount of suitable denning habitats in the Bitterroot analysis unit could support well over 500 grizzly bears, which would satisfy the denning requirements for population estimates based on habitat productivity and others factors (N = 321-445) calculated for smaller areas than our analysis unit (Boyce and Waller 2003, Mowat et al. 2013, Mattson 2021), as shown in Figure 13. There is also abundant Spring, Summer and Fall grizzly bear habitat (Merrill et al. 1999, Carroll et al. 2001, Boyce and Waller 2003) including broad spatial distribution of key berry-producing plants known to be important to grizzly bears (Hogg et al. 2001) shown in Figure 13.

Our results were consistent with the literature regarding declining selection in the highest, rockiest and most exposed terrain. Vegetative cover is an important factor due to the stability the roots provide to the structure of the den. Grizzly bears line the floor of their dens with vegetative matter including boughs and needles from SPRUCE (*Picea*), FIR (*Abies*) and where available, BEARGRASS (*Xerophyllum tenax*) (Craighead and Craighead 1972, Jonkel 1987, Servheen and Klaver 1983). Bedding materials consist of what is available at the den site and not on any preference (Judd et al. 1986). While grizzly bears have long claws that enable digging for food and den excavation, they cannot dig through solid bedrock. These two factors mitigate against denning in areas of rock devoid of nearby vegetative groundcover.

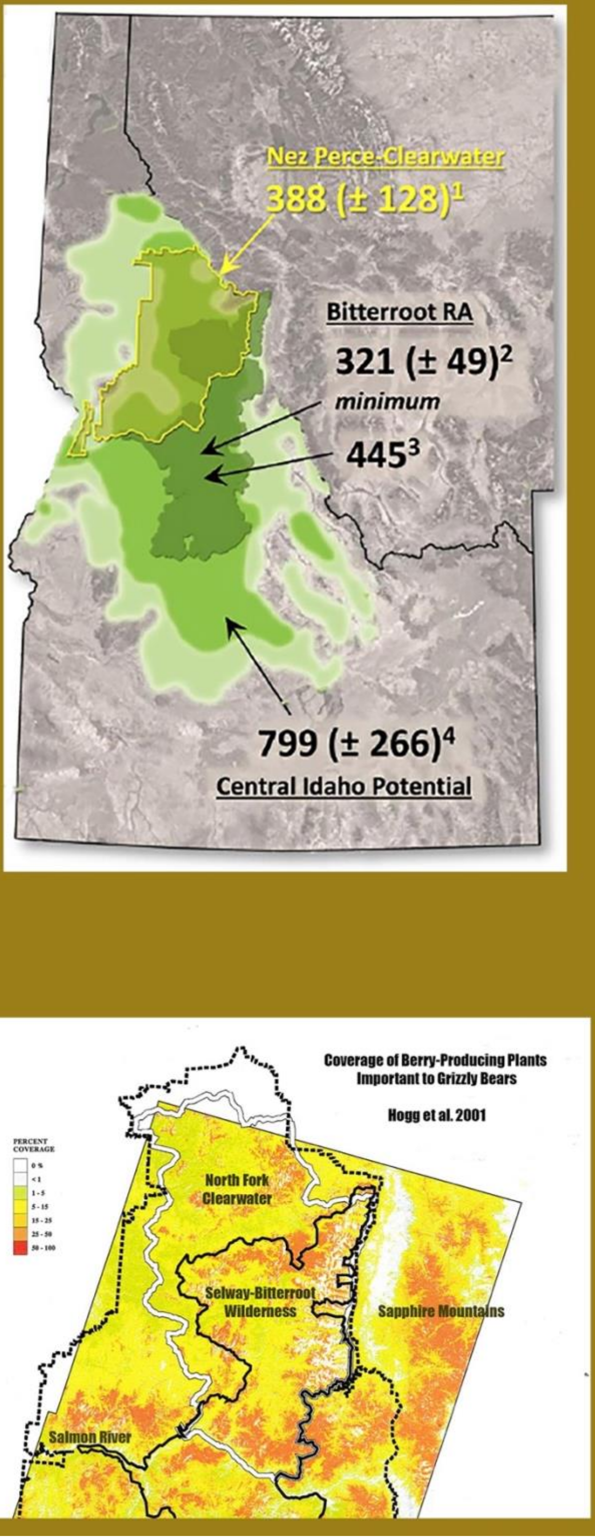


Figure 13. Population Potential for Grizzly Bear, Habitat Quality and Berry Production. Map Sources: Mattson (2021); Hogg et al. (2001).

The model may slightly overestimate denning suitability in the highest elevations of the Selway-Bitterroot Wilderness and Glacier National Park unless there is a relative abundance of natural cave-like openings. This is because the LANDFIRE EVT vegetation dataset did not classify rocks and sparse vegetation at high elevations in a manner that we perceive grizzly bears select den sites. At the scale of the study area we considered this insignificant.

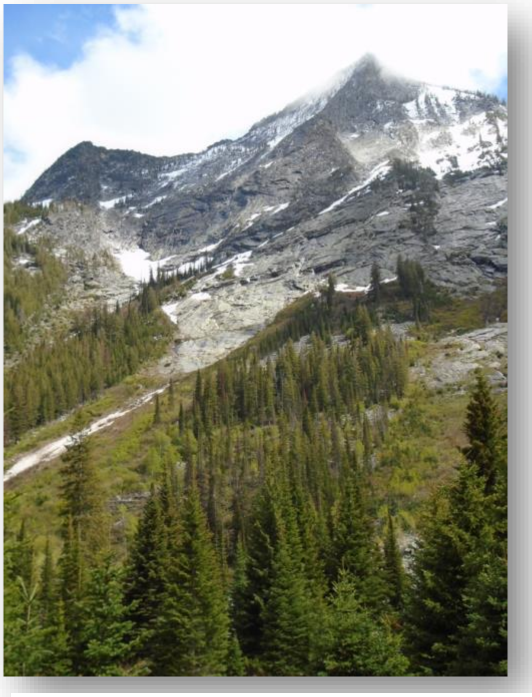


Figure 14. The Bitterroot Mountains on the Montana and Idaho border.

Discussion

In regards to the core recovery areas, we suggest there is merit to incorporating additional areas in the Bitterroot Recovery Area, particularly north of the Lochsa River as shown in Figure 15. This was part of the area of investigation in the Draft Recovery Plan (USFWS 1982), the Bitterroot Experimental Population Area and was analyzed in two alternatives in the Final Environmental Impact Statement for Grizzly Bear Recovery in the Bitterroot Ecosystem (USFWS 2000). Carroll et al. (2001) identified this area as having the largest concentration of contiguous high quality grizzly bear habitat in the Rocky Mountains. Immigrating grizzly bears from other Recovery Areas in this area have been verified (USFWS 2021) and its inclusion in the Recovery Area would likely enhance the prospects of population recovery.

In terms of potential connective habitats, there are three major requisites for the demographic model which also apply to the male-mediated model for dispersal.

1) Denning Habitats Within Secure Core Areas That Are Within Dispersal Distance for Female Grizzly Bears

The availability of denning habitats within large secure core areas is a fundamental requirement of the demographic model and there should be a goal of no additional loss of secure core. These are areas where females can survive and raise offspring who become a source of dispersals and can serve as anchor points for the design of bear management units encompassing all four seasons of habitat requirements for female/cub groups. Outside these core roadless areas effective motorized and mechanized access management limiting open road and motorized trail density should be applied along with limiting industrial activity to low-intensity short term projects.

The NCDE Conservation Strategy standards for the NCDE Recovery Zone define secure core as areas >500m from a road and at least 10km^2 (2500ac) in area. Secure core comprises at least 68% of a bear management unit (BMU) and 16% of a BMU may have Open Motorized Route Density (OMRD) up to 0.6km/km^2 and no more than 16% of the BMU may have OMRD of 1.2km/km^2. Scaled to an annual female home range size (125km^2, 37,500ac) $\approx$103km^2 (25,500ac) of a BMU in connectivity areas should be secure core, preferably in one piece but in no more than 3-4 separated by one road which together total 103km^2; about 24km^2 with OMRD $\leq$ 0.6km/km^2 and 24km^2 with OMRD up to 1.2km/km^2. We suggest that BMUs be identified within key linkage habitats with these standards applied. These should be considered minimum requirements and not standards to be managed down to. While the NCDE standards allow for core to shift every ten years this disrupts female grizzly bears who learn that areas are secure and pass a significant portion of the home range to their female offspring. A sudden shift in security conditions would not be conducive to the demographic model and we recommend that secure core be non-shifting.

In connectivity habitats, these larger secure areas should be within known dispersal distances for female grizzly bears. From the information shown in the histogram in Graves et al. (2014) 74% of females (n = 31) dispersed from 0-10km, 19% from 10-20km and 6% from 20-30km. From the histogram in Proctor et al. (2004) 85% of females (n = 55) dispersed < 22km and 15% dispersed > 30km with a maximum of 78km. McLellan and Hovey (2001) found female grizzly bears (n = 12) dispersed an average of 10km with a maximum of 20km while Almack (1986) documented a one-way single season female dispersal of 46km. This information indicates that stepping stones from 0-10km apart might work for 64% and 74% of females, respectively while stepping stones from 20-

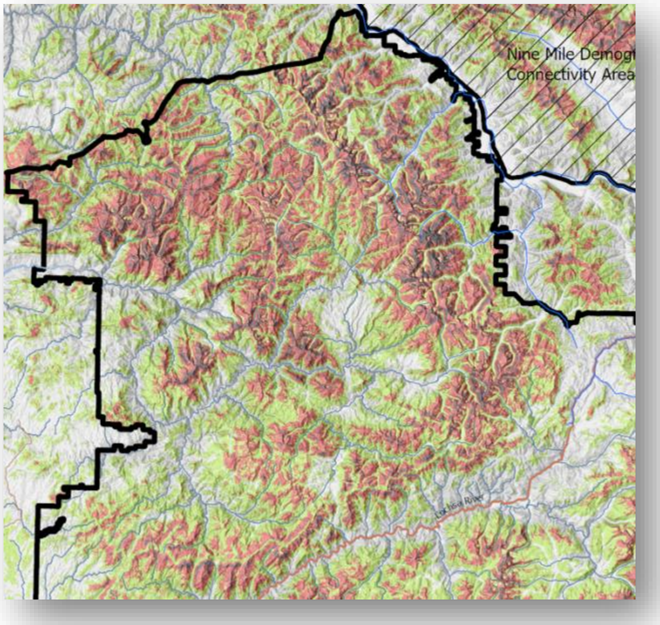


Figure 15. The area north of the Lochsa River in the Kelly Creek-North Fork Clearwater drainages proposed for inclusion in the Bitterroot Recovery Area.

30km apart might work for 22% and 19% of females, respectively. There is evidence that female grizzly bears have dispersed over longer distances than the averages reported. For example, the source of grizzly bears in the Ninemile DCA is most certainly the NCDE as it is the closest known population source. There were at least two different females documented in the DCA in 2020 (Jonkel, MDFWP 2021). A female grizzly with cubs was 36km from the Rattlesnake portion of the NCDE and 44km from the Mission Mountains portion of the NCDE and < 3km from the south side of the Clark Fork River (Bitterroot Mountains). A verified female with cubs in 2008 was even further from the NCDE. This information may indicate that females make longer dispersals into areas with low bear density where they are not pushing into territories occupied by more dominant bears. If so, the dispersal rate may be higher than previously known and the efficacy of the demographic model increased.

How grizzly bears might best move between and within the stepping stones awaits a future analysis based on habitat quality, least-cost path analysis and circuit theory, as in Proctor et al. (2015) or similar methods.

Motorized access management is most beneficial in areas including "…threatened populations, in areas where roads occur in the highest quality habitats, within and adjacent to identified linkage areas between population units…" (Proctor et al. 2019). However, the standards in the two DCAs are much less stringent than in the NCDE Recovery Area, with allowable OMRD of 1.24km/km^2 and no net increase in the total linear kilometers or miles of open roads. There are no requirements for the percentage of secure core areas. This level of OMRD is twice that identified as the point where female grizzly bear survival declines and above which population density declines and den selection probability declines to 30%, as shown in Table 6. We recommend that the Ninemile DCA and connectors be upgraded to be more consistent with the standards within the Recovery Area. Our results for the Salish DCA are indicative of the highly fragmented, high road density environment in this area as shown in Figure 16. While there would naturally be less denning

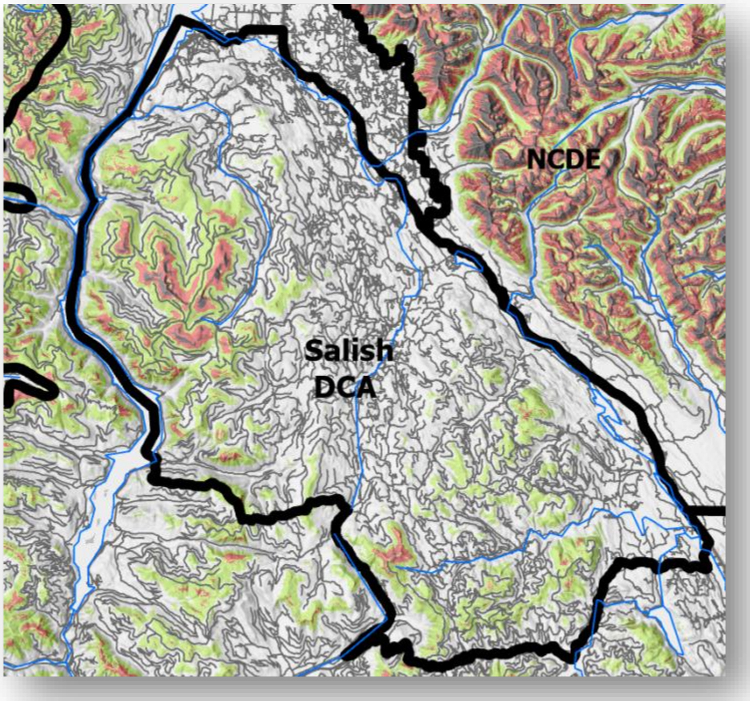


Figure 16. The High Road Density Environment in the Salish Demographic Connectivity Area (roads shown as gray lines).

Table 6. Road Density Impacts on Grizzly Bears.

Road Density km/km^2	Survival Rate	Growth Rate	Density Bears/1000km^2	Den Selection Probability
0	≈ 100%	Positive	≈ 30	N/A
0.6	95%	Static	≈ 30	70%
1.2	85%	Negative	≈ 10	30%
1.4	75%	Rapid decline	Lower	N/A
1.6	Lower	Rapid decline	Lower	N/A
2.0	Lower	Rapid Decline	Lower	≈ 0%

Sources: Proctor, et al. (2019), Boulanger and Stenhouse (2014), Pigeon et al. (2014).

habitat due to the lower elevation terrain, this has enabled extensive road construction for forest management. There are 12,875km of roads on the Kootenai National Forest of which 6437km are open to public use (Kolman 2016) and there has been no documented natural exchange of genetic material between the NCDE and CYE Recovery Areas (Kasworm 2020, IGBC meeting). We recommend that motorized access management focus on creating additional secure core areas and strips of lower road density habitats along the routes within the DCA displayed by Proctor et al. (2015).

2) Coexistence Strategies

Due to their restricted habitat availability bears within connective habitats will be more vulnerable to illegal killing as well as being attracted to human foods than bears in the interior of the large core population areas. The loss of even one reproductive age female would eliminate potential dispersers into the next stepping stone of secure habitat and delay the process of successful dispersal. Permanent funding for Bear Aware programs (IGBC 2021) would provide information and education programs on bear safe practices which are necessary on all lands including tribal, federal, state, county and private. These include securing food attractants in campgrounds and all other lands using methods such as bear-proof garbage storage, electric fencing around chicken coops, fruit trees and bird feeders. Voluntary retirement of cattle grazing allotments on federal lands, range rider and livestock carcass removal programs are also important components. Due to its powerful olfactory sense the grizzly can detect garbage, baits and other attractants from many miles away, easily attracting grizzly bears in narrow linkage habitats. Black bear hunting using baits should be prohibited due to the threat to grizzly bears.

3) Highway Passage Structures

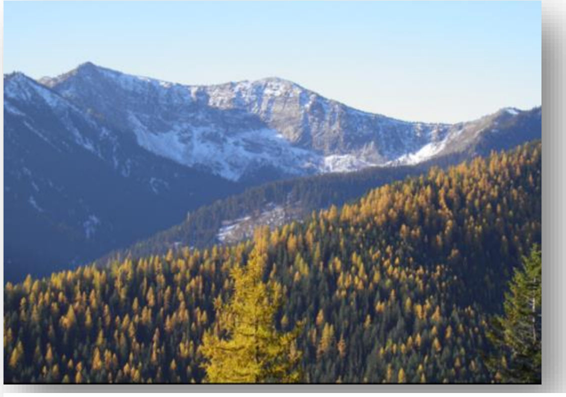


Figure 17. Connective Habitat along the Northern Bitterroot Divide, Montana-Idaho border.

Highway and rail transportation corridors are fracture zones that fragment grizzly bear populations into isolated demographic units (Proctor et al. 2002). The two biggest obstacles to female grizzly bear dispersal in the study area are the Interstate 90 corridor, bisecting the region north and south and US Highway 93 from Whitefish to Darby, Montana, bisecting the region from east to west (Mattson 2021). These high-speed, high volume pathways have been a significant source of grizzly bear mortality (USFWS 2021). However, the first verified female grizzly with cubs south of I-90 was documented in 2018 within the John Long Mountains adjacent to the Garnet Range (Jonkel, MDFWP 2021).

The big issue is the number of dispersing bears and the number that choose to disperse plus the limited number of crossing structures such as the one constructed by the Confederated Salish and Kootenai Tribes shown in Figure 18 which are essential to successful demographic dispersion into historic habitats (Ford et al. 2017). Having “multiple shots on goal” would provide a higher likelihood of success. Additional structures along US 93 are being planned by CSKT and structures along I-90 are currently under consideration.

Expansion in the distribution of an established population and dispersals are driven by male bears (Itoh et al. 2012, Peck et al. 2017) and they are the most likely to use new denning areas. Eriksen et al. (2018) analyzed brown bear denning at the male-dominated population expansion front, finding virtually no competition for prime denning sites. While males selected denning sites well beyond the core area inhabited by females, they returned to the core during breeding seasons. If this behavior applies to the northern Rockies landscape, in the early phase of recolonization competition for prime denning sites would be minimal. Since grizzly bears rarely re-use dens and dens are often clustered in prime areas (Jonkel 1987, Aune and Kasworm 1989), there could be increased competition for prime denning sites within smaller demographic units.

Figure 18. Wildlife Overpass on US 93 Constructed by the Confederated Salish and Kootenai Tribes.

We identified ranges of suitable denning habitats but grizzly bears may select den sites outside these ranges. There are several factors which can lead to poor den site selection in lower terrain. Both literature (Servheen and Klaver 1983) and anecdotal information show orphaned cubs with no experience have denned in valley bottoms or did not den. Sick or injured bears may be forced to select poor den sites due to an inability to travel or dig. As hunting seasons overlap the denning process, some grizzly bears have stayed out late in the Fall feeding on gut piles. By the time they move to den the snow depth at higher elevations may force selection of lower elevation sites. There are also outliers at the highest portions of the available terrain which may be selected by grizzly bears who have the least tolerance for disturbance and conversely the greatest need for security, including females with cubs.

***Management Implications and Future Prospects*—.** Open roads had a significant effect on grizzly bear den site selection in our model as shown in Figure 19. In smaller isolated areas like the Yaak, denning habitat is less abundant and more vulnerable than in large secure core areas like the Bob Marshall and Selway-Bitterroot Wilderness because the areas have a 360^o exposure to motorized and industrial activities and shorter distances from the core to perimeter. Further incursion into these areas could reduce or eliminate denning potential and impede the function as demographic connective habitat. Larger secure areas provide lower chances of detection and disturbance and presumably higher availability of quality denning sites. Maintaining existing roadless secure areas and limiting road and motorized trail densities above 1800m would provide some protection for denning habitats. Grizzly bear survival, habitat use and selection are all affected by the presence of open roads (Proctor et al. 2019) and over a 30-year period 84% of all grizzly bear mortalities occurred < 120m from a road (McLellan 2015). Therefore, the application of road access management based on the best available science is essential to achieving connectivity and landscape permeability.

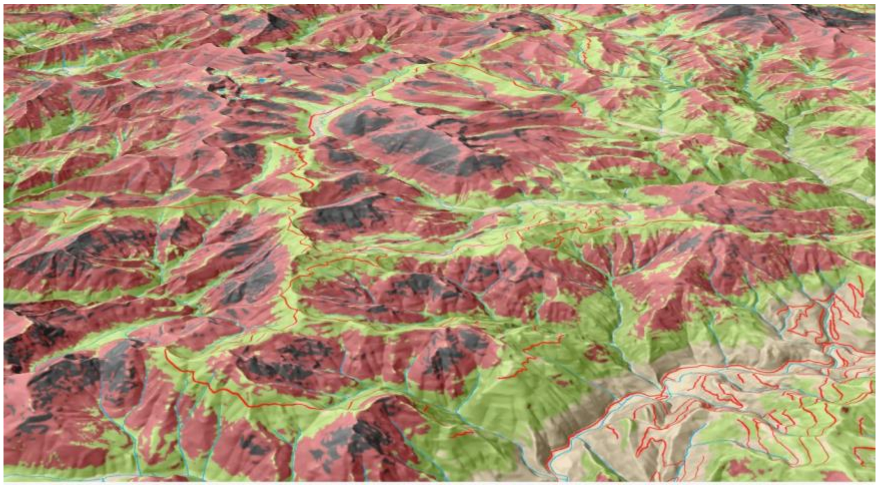


Figure 19. The Impact of High Elevation Roads (shown as red lines) on Denning Habitat Suitability in the North Fork Clearwater, Idaho.

Recreation activity has the potential to disturb denning grizzly bears, beginning with the site selection and den excavation process. This period overlaps the general rifle hunting season when hunters access high elevation roads closed to motor vehicles by foot and on mountain bike and these roads are subject to illegal motorized use (USFS 2020).

Mountain biking allows access to high elevation roads and trails closed to motorized use. Downhill ski resorts, which are located in the same terrain as denning habitats, have large multi-use four-season footprints that make denning habitats unavailable. Seasonal restrictions on snowmobile use are intended to protect emergent bears yet the practice of illegal off-trail “high-marking” on steep alpine slopes is common and could disturb the denning process due to noise, vibrations and avalanches. Hilderbrand et al. (2000) document a female grizzly bear and cubs killed by an avalanche triggered by snowmobiles. New technology including motorized snow bikes with tracks instead of wheels and bicycles modified with large, low pressure tires designed for over-snow use enable more extensive reach into backcountry areas. If dependable snowpack levels increase in elevation, winter recreation use will likely follow, posing additional challenges for species dependent on higher elevation remote areas in the Rocky Mountains for denning and hunting, including grizzlies, WOLVERINE (*Gulo gulo*) and LYNX (*Lynx canadensis*).

In addition to the management considerations discussed above, climate change will affect the denning process and den site selection. Evan and Eisenman (2021) predict that interior areas like the Canadian Rockies and the northern Rocky Mountains of the US will see less change in the rate of snowpack melt and the timing of spring runoff than coastal areas while climate models for Montana show that even in areas > 1800m a 12% reduction in snow water equivalent is expected (Whitlock et al. 2017). Musselman et al. (2021) found 34% of snow monitoring stations in western North America exhibit increasing winter snowmelt trends. Pigeon et al. (2016) note snow depth is associated with food availability and postulate climate change effects are likely to shorten the denning period for grizzly bears. A key factor may be the rate of change and whether plant phenology adapts at the same rate. A possible consequence of earlier den emergence is that natural foods may be largely unavailable, leading some bears to seek out human related foods, which leads to management actions and increased mortality. Another observation associated with changing climate are severe oscillations leading to mid-winter thaws. Rain on snow events can cause leakage into the den interior or even collapse of the structure. These thaws have been followed by cold fronts with temperatures as low as -40C. Both denning and emergent bears, particularly females with cubs could be adversely affected. The combined effects of climate change, development and recreation pressures could drop denning habitats one level of suitability from suitable to low and low to none, especially at the lower end of the ranges. Based on the erroneous assumption that bears are largely immune to impacts from both motorized and non-motorized winter recreation the National Forest Plan amendments for NCDE grizzly bear habitat management (USFS 2018) have no management standards specific to grizzly bears during the denning period. Evidence suggests land managers develop standards that will more adequately protect this resource.

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Appendix

Table A-1. Descriptive Statistics for the Verified Den Sites (n = 362).

Variable	Min/Max	Mean	SD	Range (+-1SD)
Elevation(m)	1051.3/2426.4	1836.5	221.9	1614.6-2058.4
Slope(°)	3.2/56.0	28.6	8.98	19.6-37.6
DISTRSA(m)	6.2/14595.0	1960.2	1941.0	56.8-3901.2
DISTW(m)	-/2284	721.9	391.7	330.2-1113.6

Note: Information for aspect and land cover are shown in Figures 3 and 6.

Table A-2. Variables Reported for Grizzly Bear Den Sites in Interior Populations in North America.

Area	Variables	Source
Yellowstone	1, 3, 4, 6	Craighead and Craighead (1972)
Yellowstone	1, 2, 3, 4	Judd et al. (1986)
Yellowstone	1, 2, 3, 4	Podruzny et al. (2002)
NCDE-East Front	1, 2, 3, 4	Aune and Kasworm (1989)
NCDE-Swan Range	1, 2, 3, 4	Mace and Waller (1997)
NCDE-Mission Range	1, 2, 3, 4	Servheen and Klaver (1983)
Cabinet-Yaak	1, 2, 3, 4	Kasworm et al. (2021)
Selkirk Mountains	1, 2, 3, 4	Kasworm et al. (2021)
Alberta-Banff NP	1, 2, 3, 4, 7	Vroom et al. (1977)
Alberta-Southwest	1, 2, 4, 6, 7	Pigeon et al. (2014)
British Columbia	1, 4, 6	Ciarniello et al. (2005)
Alaska- Denali NP	1, 2, 3, 4, 5, 7	Libal et al. (2011)
Alaska-NE	1, 3, 4	Reynolds et al. (1980)
Alaska	1, 2, 3, 4, 5	Sorum et al. (2019)
Alaska-South Central	1, 2, 4	Miller et al. (1990)
Yukon-SW	2, 4	Libal et al. (2012)
Northwest Territories	2, 3, 4,	Smereka et al. (2017)
Northwest Territories	2, 3, 4	McLoughlin et al. (2002)

Key: 1 = elevation; 2 = slope; 3 = aspect; 4 = land cover; 5 = snow; 6 = remoteness; 7 = avoid water.

Parameters for Model13_VEG:

```
Regularization values: linear/quadratic/product: 0.050, categorical: 0.250, threshold: 1.000, hinge: 0.500
Feature types used: linear quadratic
response curves: true
jackknife: true
output format: logistic
environmental layers: E:\GrizzlyDenning\SDM\projectasc
write clamp grid: false
writemess: false
biasfile: E:\GrizzlyDenning\SDM\SDMBiasFile\sa_lat_bias_mget.asc
write background predictions: true
product: false
hinge: false
write plot data: true
extrapolate: false
autofeature: false
doclamp: false
bias type: 3
allow partial data: true
```

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