Regional Habitat Connectivity Analysis: Crown of the Continent Ecosystem

American Wildlands

The Corridors of Life Program

2006

American Wildlands

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The technical work for this project was completed by American Wildlands (U.S. data layers and modeling), with support from the Miistakis Institute (Canada input and cost surface layer). This report was prepared by AWL Geographic Information Systems (GIS) specialist Sarah Olimb and edited by AWL GIS lab manager Elizabeth R. Williamson, AWL Corridors of Life Program Coordinator – Southern Wildlands April Johnston, AWL Corridors of Life Program Coordinator – Northern Wildlands Kim Davitt, Miistakis GIS Spatial Analyst Greg Chernoff and Miistakis Executive Director Danah Duke based on the scientific analysis, reports, and notes of Dr. Richard Walker, Dr. Lance Craighead, Elizabeth R. Williamson, Lauren Oechsli, Debbie Kurtz, and Kim Davitt.

Special thanks to **LaSalle Adams** for funding this project.

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Executive Summary

In 1997, Dr. Lance Craighead and Dr. Richard Walker spearheaded the American Wildlands' *Corridors of Life* (COL) program by designing one of the first intensive regional habitat connectivity models of the U.S. Northern Rockies. The COL model uses Geographic Information Systems (GIS) and the best available data on habitat and human use to identify priority areas that maintain connectivity between large protected areas. Over the last decade, American Wildlands has expanded the model, using the results to identify and prioritize key habitat corridors for protection and leading the regional conservation community in corridor recognition and preservation.

This project was designed to update the decade-old portion of the COL model (the Crown of the Continent Ecosystem of western Montana), visualize the change in corridor status over the last 10 years, and expand the model to cover the entire ecosystem by including portions of Canada instead of only the U.S. portion. To complete this, we expanded our analysis boundary to include the Canadian portions of the Crown of the Continent (CoC) and Purcell-Cabinet Ecosystem. The Purcell-Cabinet Ecosystem was included in order to evaluate habitat connectivity between the CoC and surrounding ecosystems. We reanalyzed the U.S. portion of the CoC Ecosystem using the same methodology as the original model, but with recent transportation data and expanded boundaries. The method balances the factors of habitat quality and barriers with the shortest possible distances between core habitat areas.

The high quality lands, suitable for long term wildlife foraging and reproduction, were identified as core areas (Figure 1). In the United States and Canada, the Crown of the Continent core habitat area occurs in all jurisdictional possibilities including federal, provincial and private lands.

There were varying degrees of connectivity between the core areas (Figure 1). Core areas connected with red and orange corridors indicate a higher level of connectivity than core areas connected by green and blue corridors. Areas without cores or corridors are either outside the study area or areas with low connectivity (i.e., below the threshold of our scale). In the United States, there was high connectivity between Glacier N.P. and the Bob Marshall Wilderness and between the Bob Marshall Wilderness and smaller surrounding core areas. The quality of corridors decreased to the west of Glacier N.P. and the Bob Marshall Wilderness. Low quality corridors connected the Crown of the Continent to the Purcell-Cabinet and Salmon-Selway Ecosystems. In Canada, there was high connectivity between all of the identified core areas. Core habitat lining the U.S./Canada border either merged or was connected with high quality corridors. Based on connectivity and location, we identified six major corridors in the U.S. portion of the CoC as high priorities for protection or restoration: 1) Purcell-Cabinet – Crown Corridor 2) Interior Glacier N.P. Corridor 3) Glacier – Great Bear Corridor 4) Mission Mountains – Bob Marshall Corridor 5) Scapegoat – Helena N.F. Corridor 6) Salmon-Selway – Crown Corridor. Since our on-the-ground work is limited to the U.S., we have not identified, at this time, individual corridors in Canada.

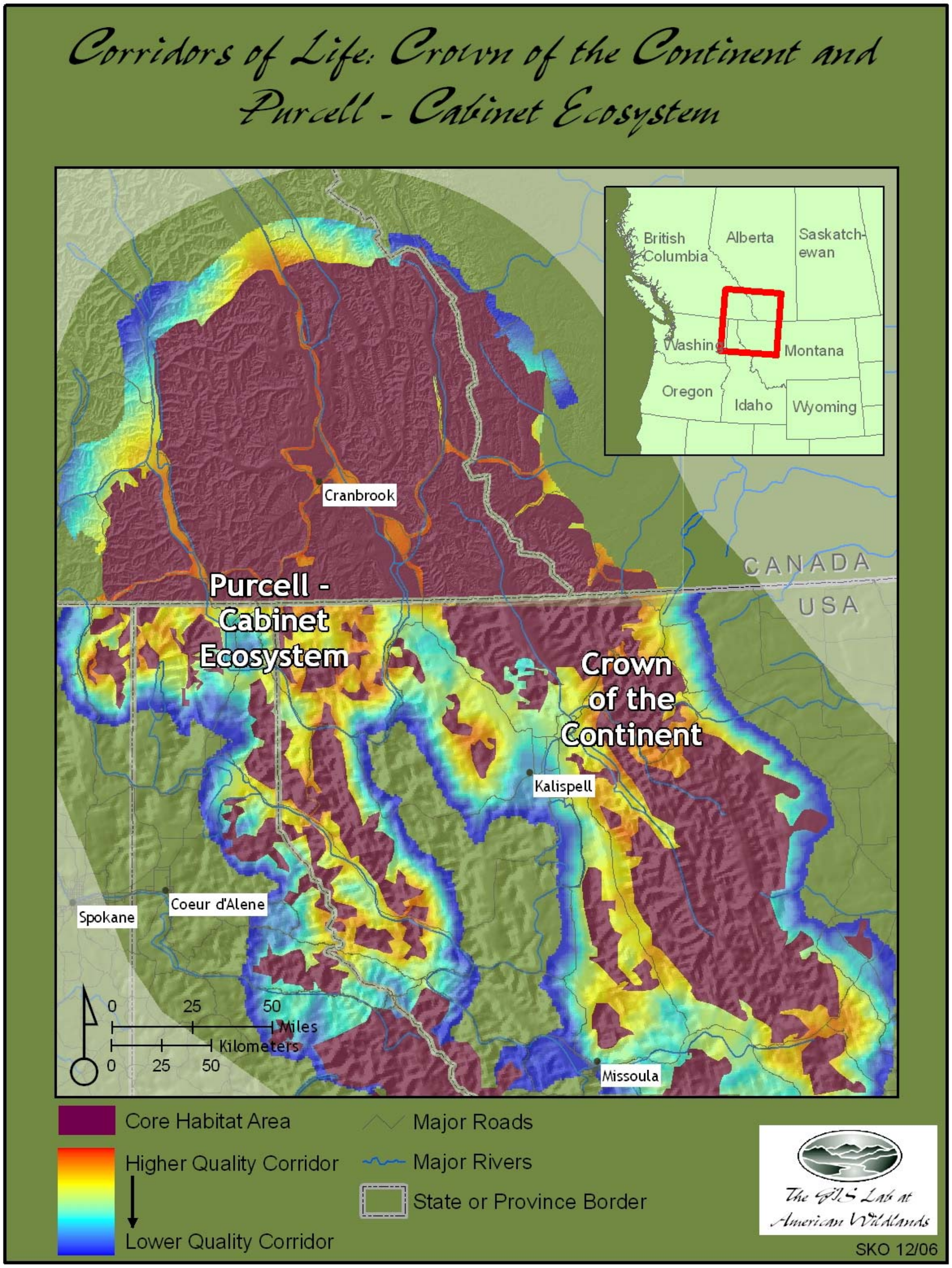

Figure 1. Habitat core area and connectivity of the Crown of the Continent and Purcell-Cabinet Ecosystem (shown with previous analysis of the U.S. portion of the Purcell Ecosystem). Suitable wildlife corridors are shown in shades ranging from red to blue. Core areas connected with red and orange corridors indicate a higher level of connectivity than core areas connected by green and blue corridors. Areas without cores or corridors are either outside the study area or areas with low connectivity.

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Introduction

Context and Project History

In the Northern Rockies of the United States, remaining wild lands are essentially islands of habitat within a sea of human development. Roads, towns and other enterprises have fragmented a once contiguous natural environment: the smaller and farther apart these islands become, the fewer species they will retain (MacArthur and Wilson 1967). The spectacular wild country of Glacier, the Salmon-Selway, and the Greater Yellowstone still abundantly support the Northern Rockies' world-class wildlife species. But many of the lands between these great ecosystems are fragmented and isolated. So isolated, in fact, that some wildlife species must "thread the needle" just to get from one food source, den site or watering hole, to the next. The linkages connecting critical habitat areas, often termed biological corridors, are linear sections of habitat that allow animals to successfully travel from one secure area to another (Beier & Noss 1998). Keeping these corridors protected is imperative to maintain sustainable breeding populations of many species vying for survival in the remaining habitat patches of the Northern Rockies (Mace & Waller 1998).

To identify corridors connecting the ecosystems of the U.S. Northern Rockies, Dr. Lance Craighead, a bear ecologist, and Dr. Richard Walker, an information specialist, developed a Geographic Information Systems (GIS) model, termed *Corridors of Life*, using roads and vegetation data as inputs. The original model used three species--grizzly bears, elk, and mountain lions--as focal species. These species were selected because they required the largest corridors to successfully traverse between core habitats. The first phase of the model, completed in 1997, showed that the corridors predicted for each species overlapped greatly. Therefore, in subsequent phases, only the grizzly bear--whose habitat requirements and sensitivity to regional-scale disturbance make it an ideal umbrella species--was used as a predictor (Walker & Craighead 1997; Carroll et al. 2001).

Over the last decade, American Wildlands has completed three phases of the *Corridors of Life* model: Montana and portions of Idaho and Wyoming in 1997 (Figure 2), Idaho and small portions of Oregon and Washington in 2000 (Figure 3), and Wyoming and small portions of Utah and Colorado in 2001 (Figure 4). The combined results of these analyses provided a regional-scale view of habitat and connectivity in the entire U.S. Northern Rockies. American Wildlands has been, and will continue to use, this regional data to identify and prioritize key habitat corridors for protection and preservation. However, with the original analysis approaching 10 years, it is timely to rerun the model--focusing on the Crown of the Continent Ecosystem (CoC, also known as the Northern Continental Divide Ecosystem), the part of Montana *not* reanalyzed in subsequent analyses--with updated roads data. This will not only provide an updated assessment of habitat quality and connectivity, it will also allow us to visualize how increased development and anthropogenic disturbance (reflected by the increased presence of roads) in the past decade has impacted the CoC. Also, since habitat and connectivity do not end at the U.S. border, it is imperative to include the Canadian portion of the CoC as well as the Purcell-Cabinet Ecosystem (i.e., to visualize the connectivity between the CoC and surrounding ecosystems) in the reanalysis. Expanding the focus area will strengthen our own knowledge of threats and opportunities in the CoC as well as provide the basis for international cooperation in conservation efforts affecting this transboundary ecosystem.

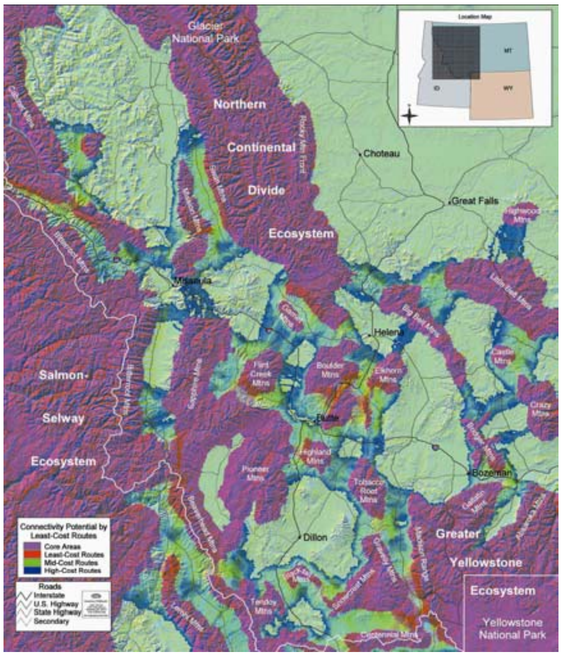

Figure 2. First *Corridors of Life* analysis completed in 1997 including portions of the U.S. Northern Rockies falling in Montana, part of Idaho, and part of Wyoming.

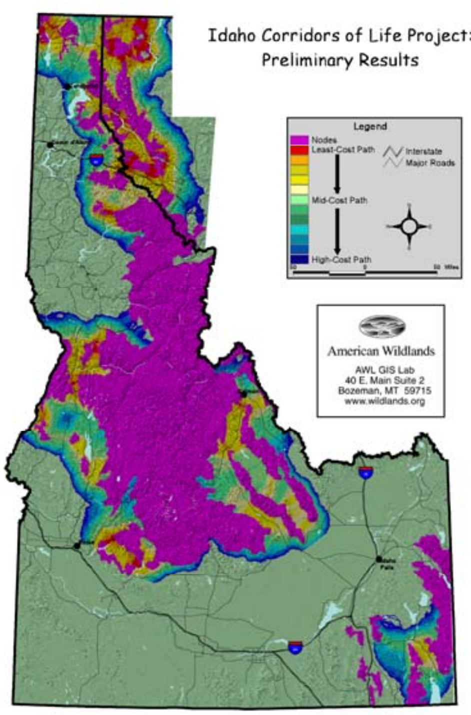

Figure 3. Second *Corridors of Life* analysis completed in 2000. This analysis expanded the focus area to the portion of the U.S. Northern Rockies falling in Idaho and parts of Oregon and Washington (not shown). This analysis replaced the portion that overlapped with the 1997 analysis (northwestern Montana and eastern Idaho).

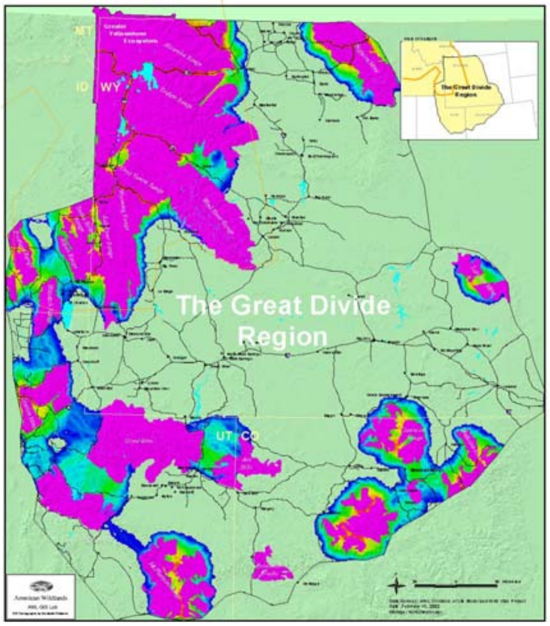

Figure 4. Third *Corridors of Life* analysis completed in 2001. This analysis expanded the focus area to the portion of the U.S. Northern Rockies falling in Wyoming and parts of Colorado and Utah and replaced the portion that overlapped with the 1997 analysis (northwestern Wyoming).

Description of Study Area

The CoC of western Montana, U.S., southwestern Alberta, Canada, and southeastern British Columbia, Canada, is one of six recognized grizzly bear recovery areas (U.S. Fish and Wildlife Service 1993, Figure 5). The ecosystem is roughly 16158 square miles (42000 square kilometers) in size, an area larger than the state of Maryland. Located in the Montane Cordillera Ecozone, the CoC is bisected by the continental divide, and hence experiences vastly different climatic conditions on its eastern and western slopes. The eastern slope reflects the intra-continental climate including year-round xeric conditions, hot summers, and cold winters. The western slope reflects the Pacific maritime climate with mesic conditions and less extreme temperatures in both summer and winter.

Figure 5. The Crown of the Continent Ecosystem of western U.S. and Canada and the study area (including the Canadian portion of the Purcell-Cabinet Ecosystem) for this analysis.

Ownership within the CoC includes a mixture of federally- and provincially-managed and private lands. In the U.S., Glacier National Park lines the border and is surrounded by a combination of roadless areas, wilderness areas, Bureau of Indian Affairs Trust Land, and private land. On the Canadian side, the CoC is composed of national and provincial parks and wilderness, wildlife sanctuaries and ecological preserves, and private land.

Also in the study area is the Canadian portion of the Purcell-Cabinet Ecosystem (PCE) which is included to show the connectivity between the CoC and surrounding ecosystems. Like the CoC, the PCE has xeric conditions on the eastern side and mesic conditions on the western slopes. Land ownership in the PCE also spans all jurisdictional possibilities including federal, provincial, and private land.

GIS Modeling

In order to model the best potential connectivity for grizzly bears, we derived three GIS coverages for incorporation in the Geographic Information Systems (GIS) model: 1) habitat suitability; 2) habitat complexity; and 3) road density. Habitat suitability and complexity both reflect the quality of the habitat in terms of grizzly bear preference. Road density acts as an indicator of the amount of anthropogenic disturbance. A number of studies looking at the impact of roads on grizzly occurrence and movement have shown that increased road density decreases the security of habitat and leads to avoidance, decreased fecundity, and increased mortality (e.g. Lyon 1983; Archibald et al. 1987; Mattson et al. 1987; McLellan and Shackleton 1988; Kasworm and Manley 1990; Mace et al. 1996; Chruszcz et al. 2003; Waller and Servheen 2005). U.S. and Canadian portions of the model followed the same basic methodology (Figure 6); however, due to differences in the source data available for deriving the coverages, we have described the model inputs and treatment separately.

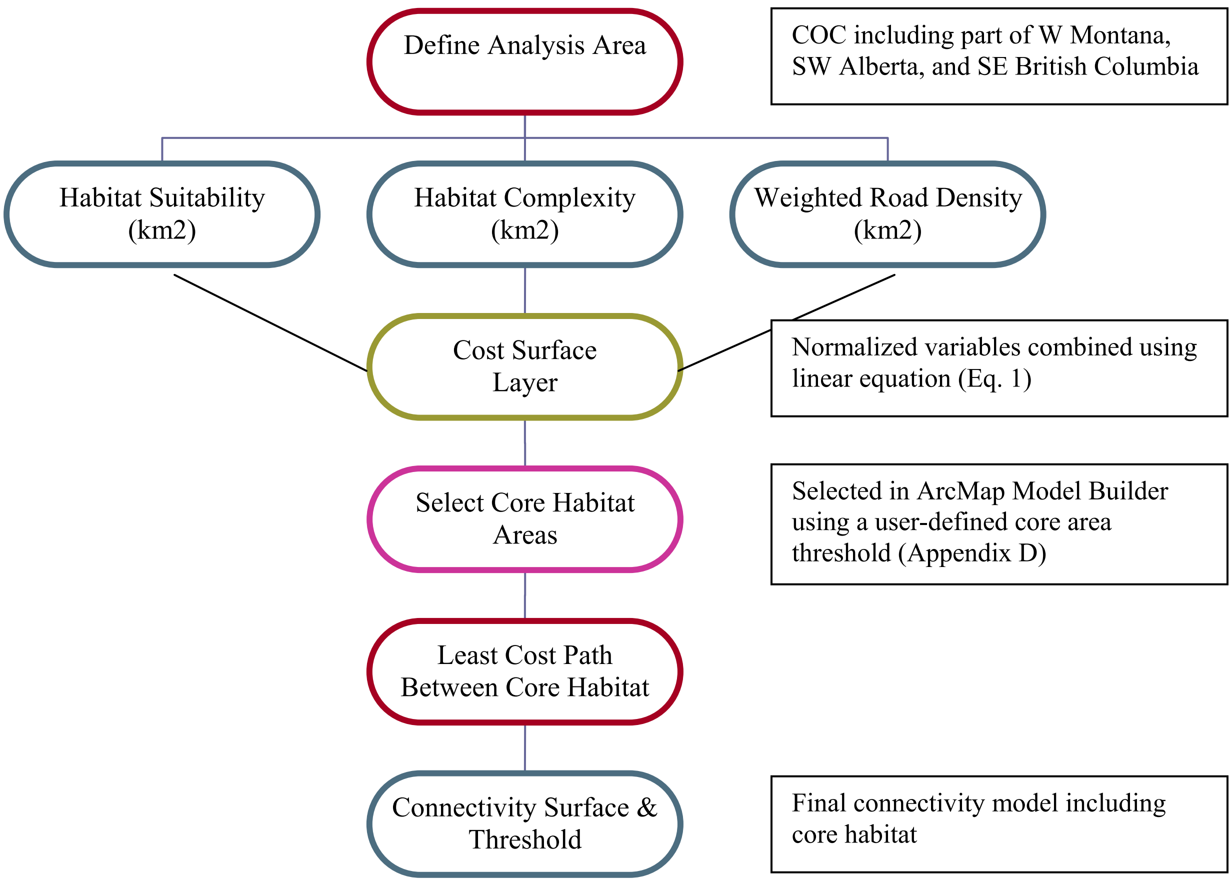

Figure 6. Basic methodology for defining core habitat and connectivity between core habitat in the Crown of the Continent Ecosystem. Due to differences in input data, the methodology differs slightly for U.S. and Canadian portions of the model (see U.S.-Model inputs and Canada-Model inputs for detailed methodology).

U.S. – Model inputs

Habitat suitability and habitat complexity were calculated from land cover data extracted from the Montana Gap Analysis coverage, a digital raster land classification system compiled between 1991 and 1997 that includes 50 native and non-native (e.g., agriculture, developed) dominate land cover types in 90 meter pixels (Fisher et al. 1998). For habitat suitability, land cover types were rated from 0 (unsuitable) to 3 (highly preferred) based on literature review and expert opinion (Appendix A). The land cover types were then merged into uniform blocks based on the assigned rate

Published literature and expert opinion also show that grizzlies prefer a mixture of covered (for security) and open habitat (for foraging or hunting; Walker & Craighead 1997). To provide a measure of habitat complexity, we identified edges between forest and open lands such as grasslands, scrublands and wetlands (based on Montana Gap land cover pixels). It is important to note that this method does not allow the distinction of natural (e.g. meadows) versus anthropogenic (e.g. logged) clearings which may have important connotations for grizzly movement.

Roads and railroads were extracted from 2005 U.S. Census Bureau TIGER files (1:100k resolution). As previous studies have shown that roads vary in their impact on grizzly behavior (e.g., Mace et al. 1996), roads and railroads were rated on a scale from 1 to 3 based on estimated use. Interstates were given a weight of 3, U.S. and state highways were weighted a 2, and all other roads and railroads were weighted a 1 (Appendix C).

In order to spatially integrate the habitat and road data, generalize the landscape in terms of grizzly sensory perception, and allow integration with previous *Corridors of Life* analyses as well as higher-resolution Canada land cover data, we generated a grid overlay to conform the three coverages into uniform square kilometer cells. In the habitat suitability coverage, a value for each $1km^2$ cell was calculated by multiplying the area of the cell times the assigned rate (0-3) of the habitat within the cell. If more than one ranking of habitat fell within a cell, the values were calculated separately for the area of each type and then added together to result in one value per cell (Figure 7). For habitat complexity, the total length (m) of edge between forest and grassland or shrubland was summed for each $1km^2$ cell. For road density, the length of each road segment within the $1km^2$ cell was multiplied by the assigned ranking value and all of the calculated values within the cell were added together for an overall cell value.

Canada – Model Inputs

Habitat suitability and habitat complexity were calculated from land cover data extracted from Landsat ETM+ satellite imagery (30m pixel resolution) and classified into 17 distinct land cover classes by Greg Chernoff of Miistakis Institute, Calgary, Alberta, Canada. Based on the Montana GAP land cover descriptions, each of the 17 land cover classes was matched as closely as possible to a Montana GAP land cover class (Appendix B). Each was then assigned a habitat suitability ranking, from 0 (unsuitable) to 3 (highly preferred), and a measure of habitat complexity following the methodology used for the U.S. data.

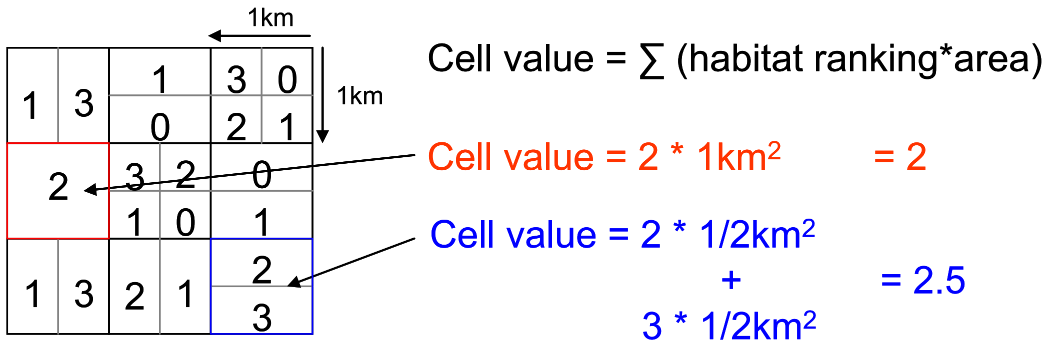

Figure 7. A simplified diagram of how habitat suitability values were integrated into 1km^2 cells. Habitat rankings (see Appendix A) were assigned to each Gap coverage pixel (divided in figure by gray lines). The pixels were aggregated by the ranking value. The ranking value was then multiplied by the total area of all pixels within the 1km^2 cell with that ranking value. In 1km^2 cells with only one ranking value (i.e., the red cell above), the ranking value ("2") was multiplied times the entire area of the cell. In cases where multiple ranking values fell within a 1km^2 cell (i.e., the blue cell above), values were calculated separately for each ranking value ("2" and "3") and then added together for a total value for the cell.

Roads and railroads were extracted from the Canadian National Roads Network (NRN, 1:100k resolution) and ESRI rails dataset (1:250k resolution). Based on the class descriptions from the U.S. TIGER road files, the NRN and ESRI classes were matched as closely as possible to TIGER classes and then rated on a scale from 1 to 3 based on the same methodology as the U.S. data.

The Canada coverages were next conformed into 1km^2 grid cells. The habitat suitability layer was resampled (averaging method) from 30m to 1km pixels. Edge density (m/km^2) was calculated on a 1km grid in the habitat complexity layer. Road density was calculated in ArcGIS spatial analyst by creating a 1km weighted density grid (using the same weights as the U.S. data) and a single pixel search radius. Instead of the grid overlay used with the U.S. data, the density function in ArcGIS spatial analyst uses a specified search radius of half the size of a grid cell (1/2km, Figure 8). In the function, the values for each coverage (length or area * ranking variable) were summed within all pixels intersected by a circle of specified radius. Therefore, the output grids were comparable to those produced with the U.S. data using the grid overlay function.

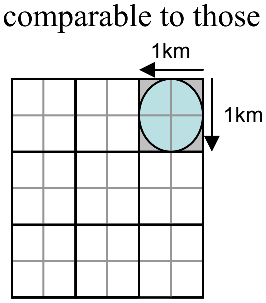

Figure 8. A simplified diagram of how the kernel density function was used to conform Canadian data layers into 1km^2 cells. All cells that were intersected by the search circle (in figure, cells shaded in gray) with radius of half a final grid cell (1/2 km) were included in the calculation therefore making the final grid comparable to the grid produced with the U.S. data.

Developing the Cost Surface Layer

The 1km^2 grids (U.S. and Canada) developed for each of the three coverages were next merged into a single cost surface layer that reflected the resistance or "cost" of movement by grizzlies through each 1km^2 cell. To adjust habitat suitability, habitat complexity and weighted road density to the same scale, the values were normalized based on the relative importance and the relationship between the factors (Walker & Craighead 1997). Walker & Craighead (1997) originally established these values based in part from results of the Cumulative Effects Model (CEM) developed for grizzly bears based on vegetation, disturbance, and edge parameters (ICE6 1994). Habitat suitability was adjusted to a 0 to 1 scale simply by dividing all of the cell values by the overall maximum cell value. Habitat complexity and weighted road density were both adjusted to a 0 to 2 scale by adding 1 to each cell value, taking the natural log of each cell value (necessary because of the skewed distribution of the data), and then dividing each by a number that resulted in the cell with the maximum value becoming a value of "2."

The cost surface layer was calculated by the following linear equation:

Eq. 1. Cell Resistance = ((-1.0 *(Habitat Suitability * Habitat Complexity)) + 2) + Weighted Road Density*

*Values included in the equation are the normalized values

The structure of the equation takes into consideration the relationship between habitat suitability and habitat complexity. These values are first multiplied into a value of "overall habitat quality" before being combined with weighted road density.

Selecting Core Habitat Areas

The cost-surface layer produced using Eq. 1 had a potential value for each cell starting at 0 (excellent habitat) and increasing to 4 (poor habitat) as the habitat quality decreased and weighted road density increased. Based on expert opinion (as applied in previous iterations of the *Corridors of Life* model), we built a model in Model Builder© (ArcGIS 9.1) to select core habitat areas (i.e., top-quality grizzly habitat) based on habitat quality, patch size and arrangement, and absence of high-traffic roads (i.e., roads with weight ≥2; Appendix D). Management was not included as a parameter in core area selection; therefore, both protected lands (e.g. wilderness, roadless, etc.) and unprotected lands (e.g. private, etc.) could be included. Since the cost-surface layer was derived from a grid, the resulting nodes would by default be boxy in appearance. To round the edges and eliminate small protrusions, we used the 'simplify' command in ArcMap with an extent of 5000m (equal to the width of 5 grid cells). Finally, to validate our selection results, identified core habitat areas were presented to four expert reviewers in the U.S. (Figure 9, Appendix E) and top grizzly habitat was discussed with one reviewer in Canada (Appendix E). No changes were made based on expert opinion because the experts differed drastically in whether too much or not enough core habitat was included in our selection (Appendix E).

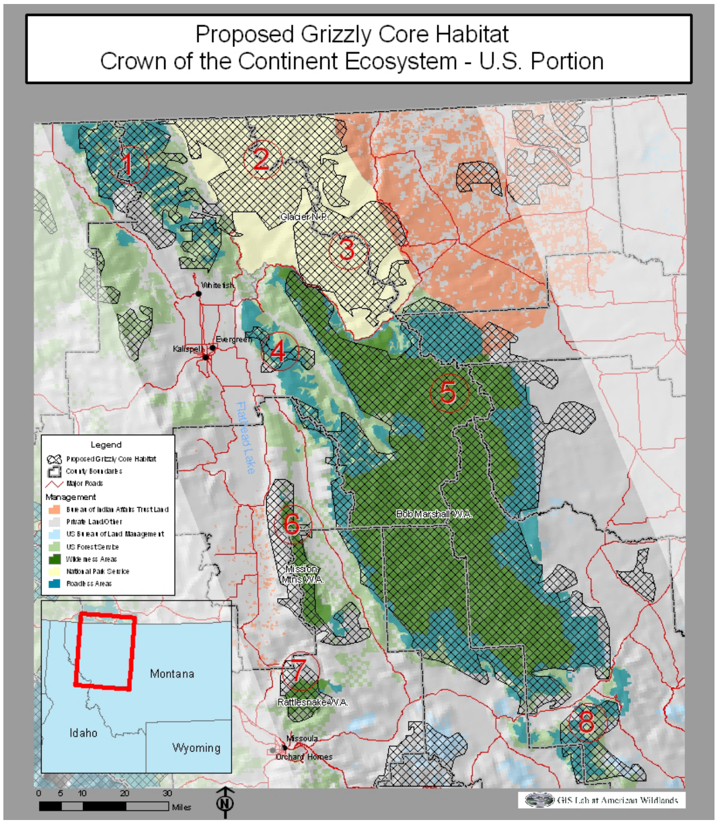

Figure 9. Map of proposed habitat core areas in the U.S. part of the CoC that was presented to expert reviewers for input. A summary of expert responses is found in Appendix E.

Least-Cost Path Connectivity Model

Using the 'Corridor' and 'Costdistance' functions in Arc/Info, cumulative cost values for movement between each of the core habitat areas were calculated. Using the 'Lpick' function, the least-cost path routes between cores were determined. Routes were then subdivided into either corridors or areas of no connectivity. Corridors had cumulative costs that were identified as low enough for wildlife movement. No connectivity areas had cumulative cost routes too high for wildlife movement. The costs were then adjusted to fit into a spectrum ranging from 1 (high quality corridors/lowest cost routes) to 255 (lower quality corridors/higher cost routes), and 0 (core habitat areas).

Results and Discussion

High quality areas suitable for long term wildlife foraging and reproduction were identified as core habitat areas and include both protected and unprotected lands (Figure 1). In the United States, the CoC core habitat area is primarily composed of portions of Glacier National Park (N.P.), Flathead National Forest (N.F.), Helena National Forest, Lolo National Forest, Lewis and Clark National Forest, Kootenai National Forest (including within the forest districts the Bob Marshall, Great Bear and Scapegoat Wilderness Areas), Flathead Indian Reservation and some private land. In Canada, the core habitat area is primarily composed of portions of National Parks (e.g. Waterton Lakes N.P.), Wildlands, Provincial Parks, Wildlife Management Areas (e.g. Midge Creek, Hamling Lakes), Ecological Reserves (Gilnockie Creek, Ram Creek, Mount Sabine, Columbia Lake), other conservation lands and private land.

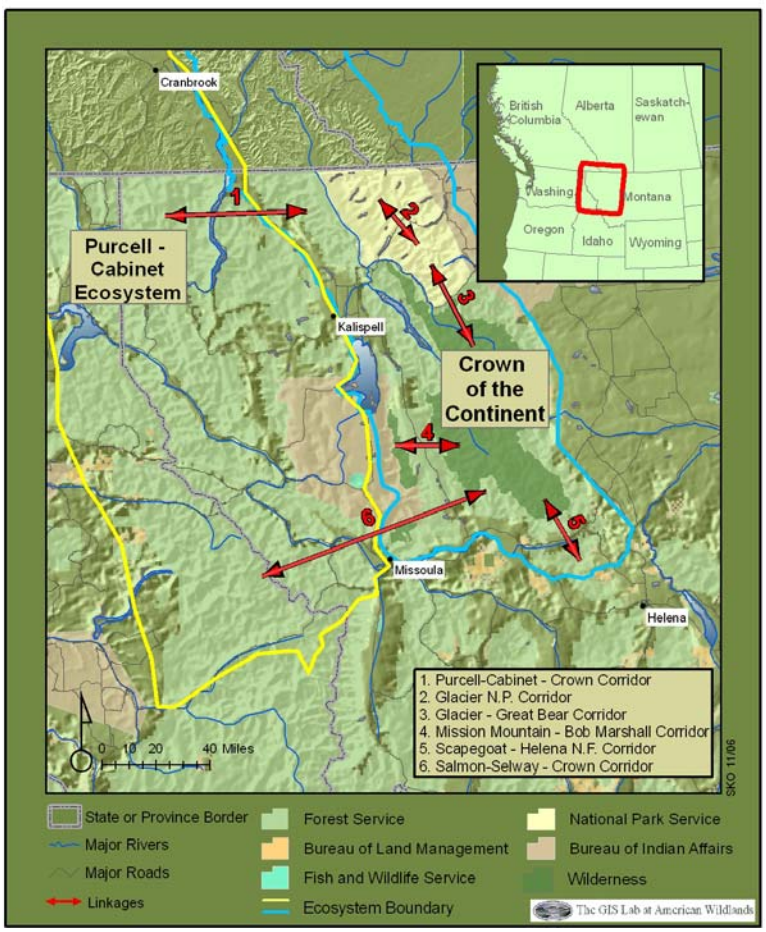

Figure 10. High quality corridors of the U.S. CoC (referenced by number) and select land ownership. Corridors are described in detail in the section, *High Quality Corridors in the U.S. Crown of the Continent.*

There are varying degrees of connectivity between the core areas (Figure 1). In the United States, there is high connectivity within Glacier N.P., between Glacier N.P. and the Bob Marshall Wilderness and between the Bob Marshall Wilderness and smaller surrounding core areas. Low quality corridors connect Glacier N.P. to the Purcell-Cabinet Ecosystem (Figure 10, Corridor 1) and the Rattlesnake Wilderness to the Salmon-Selway Ecosystem (Figure 10, Corridor 6). The "best" corridors in the U.S. portion of the CoC are described in more detail in the following section, *High Quality Corridors in the U.S. Crown of the Continent* (Figure 10, Figure 11).

In Canada, there is high connectivity between all of the identified core areas. Core habitat lining the U.S./Canada border either merged or was connected with high quality corridors. Since the vast majority of American Wildlands' work focuses in the United States, we did not at this time describe individual corridors in Canada.

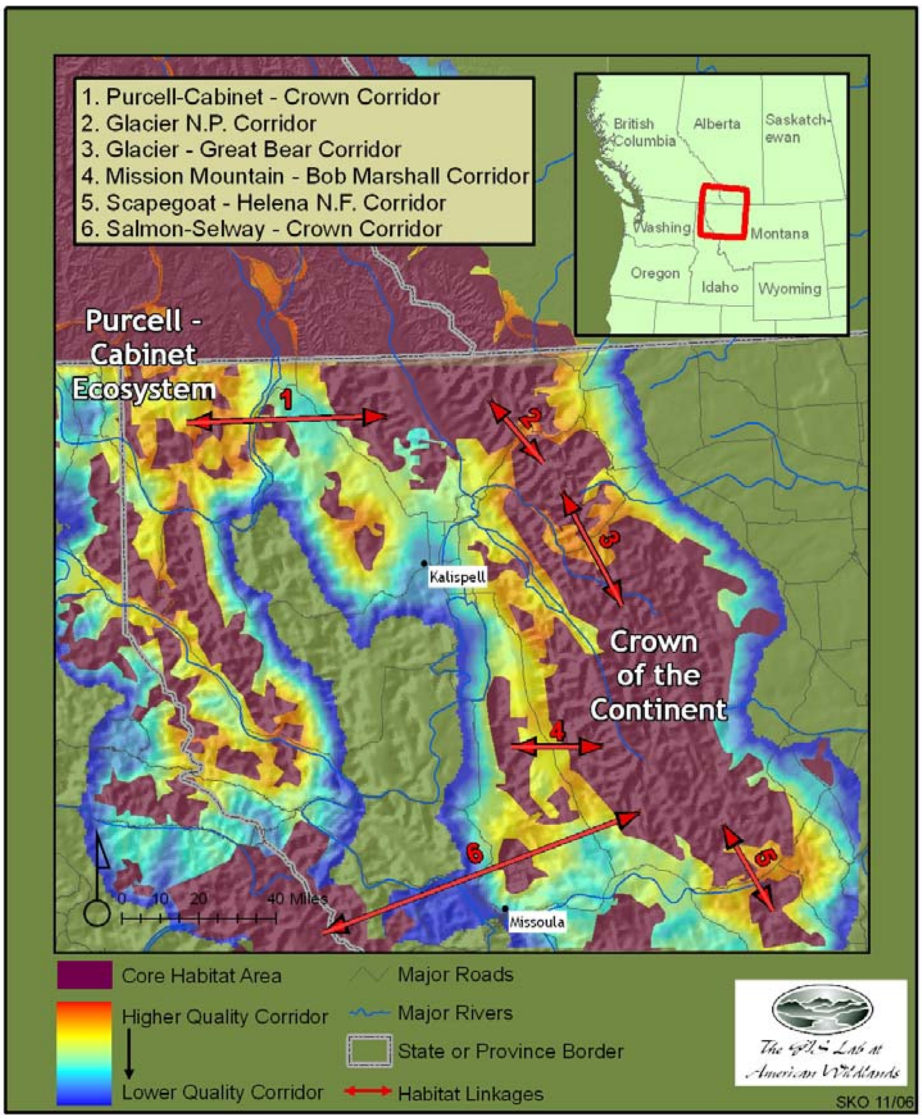

Figure 11. High quality corridors of the U.S. CoC (referenced by number) and *Corridors of Life* habitat connectivity model. Please see Figure 1 caption for information about core habitat areas and corridors.

High Quality Corridors in the U.S. Crown of the Continent

1) Purcell-Cabinet – Crown Corridor

This corridor is one of two that connect the U.S. portion of the CoC with the scattered, but highly connected core habitats of ecosystems (Purcell-Cabinet and Salmon-Selway) to the west. The second corridor is over 75 miles (120.7 km) to the south; the space in between is highly developed and populated and thus not conducive to grizzly movement. This corridor consists of low to medium connectivity over a span of roughly 50 north-to-south miles (80.5 km) beginning at the Canada border. The shortest route is less than 15 miles (24.1 km) in length while the "best" route (meaning highest quality corridor) edges the Canada border and is closer to 40 miles (64.4 km). All routes force crossing of U.S. Highway 93 and State Highway 37 to reach the bulk of the Purcell-Cabinet Ecosystem core habitat.

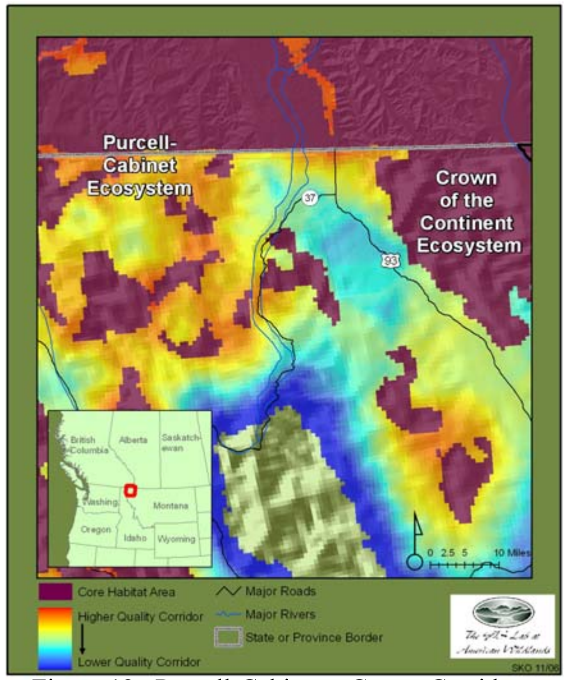

Figure 12. Purcell-Cabinet – Crown Corridor.

2) Interior Glacier N.P. Corridor

In American Wildlands' previous COL analysis, Glacier N.P. was delineated as solid core habitat (Figure 2). This analysis divided the park into two halves bisected by the "Going to the Sun" road. Though a few grizzly experts believe that Glacier is still uniformly top grizzly habitat, another expert that is very familiar with Glacier N.P. confirmed the division, stating that human influences are taking a toll and leaving certain sections of the park less suitable as core habitat. Our analysis showed that connectivity between the sections ranged from high quality to moderately-high quality. The shortest route between the core habitats is less than two miles (3.2 km) and extends up to 18 miles (29.0 km). All routes require crossing of the "Going to the Sun" road.

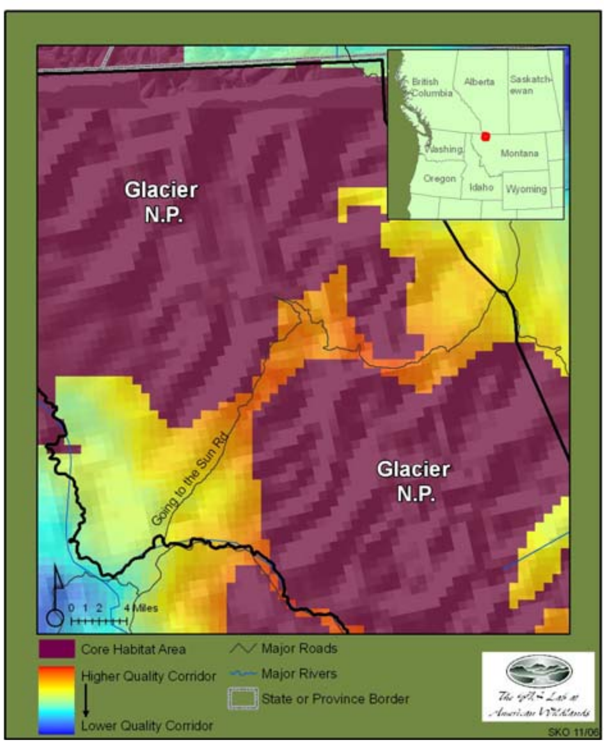

Figure 13. Interior Glacier National Park Corridor.

3) Glacier - Great Bear Corridor

Connecting the top quality habitat of Glacier N.P. and the Great Bear Wilderness, the Glacier – Great Bear Corridor is divided by US Highway 2, a highly documented barrier to wildlife movement. The shortest route between the core habitats is less than 2 miles (3.2 km) and even the longest route spans only 10 miles (16.1 km). Connectivity is high to extremely high along the entire southern border of Glacier N.P.

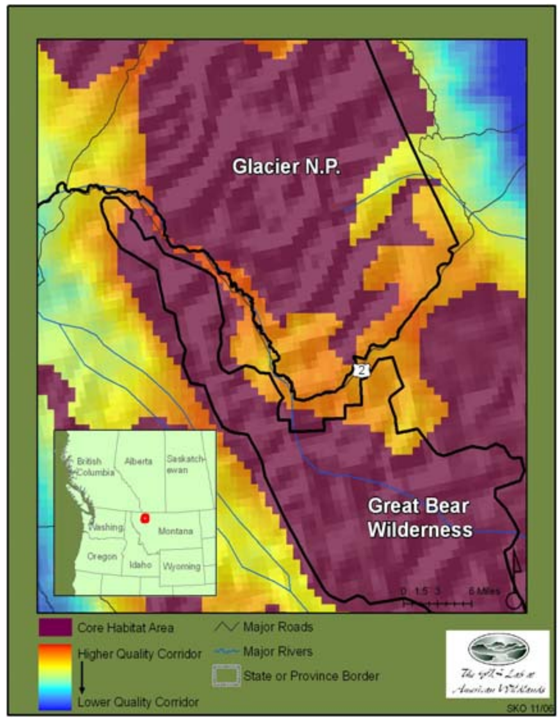

Figure 14. Glacier - Great Bear Corridor.

4) Mission Mountain – Bob Marshall Corridor

This corridor connects two high quality habitat areas: the Mission Mountain Wilderness area and the Bob Marshall Wilderness area. High quality corridors line the entire eastern edge of Mission Mountain Wilderness. The best quality corridors occur at northern and southern ends of the area where the core habitat extends eastward towards Bob Marshall. All routes are between six and 12 miles (19.3 km) and require crossing State Highway 209.

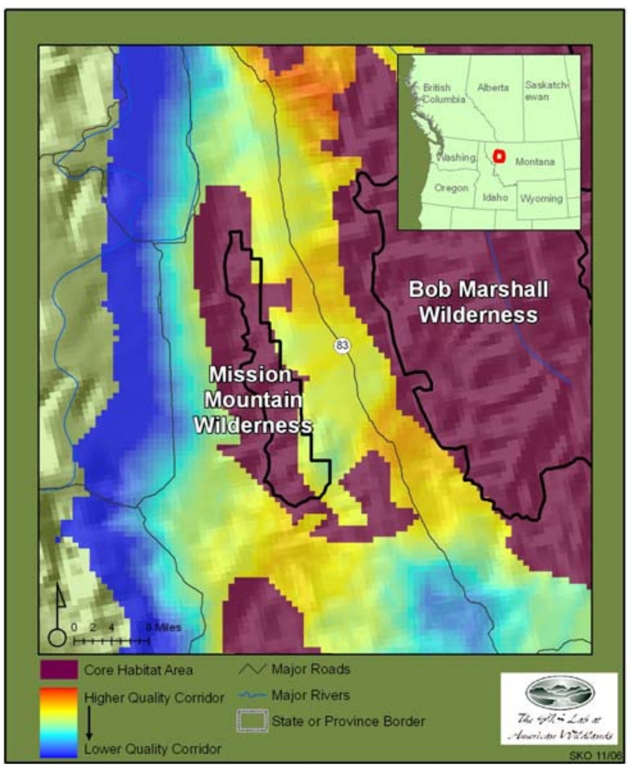

Figure 15. Mission Mountain – Bob Marshall Corridor

5) Scapegoat – Helena National Forest Corridor

At the southern end of the CoC, the Scapegoat – Helena National Forest Corridor connects the Scapegoat Wilderness, Lolo National Forest, and Lewis and Clark National Forest to the Helena National Forest. Though high quality corridors connect the entire northern edge of the Helena National Forest core habitat, the highest quality corridors span from 2 (3.2 km) miles to 5 miles (8.0 km) in length. All routes require crossing of State Highway 200.

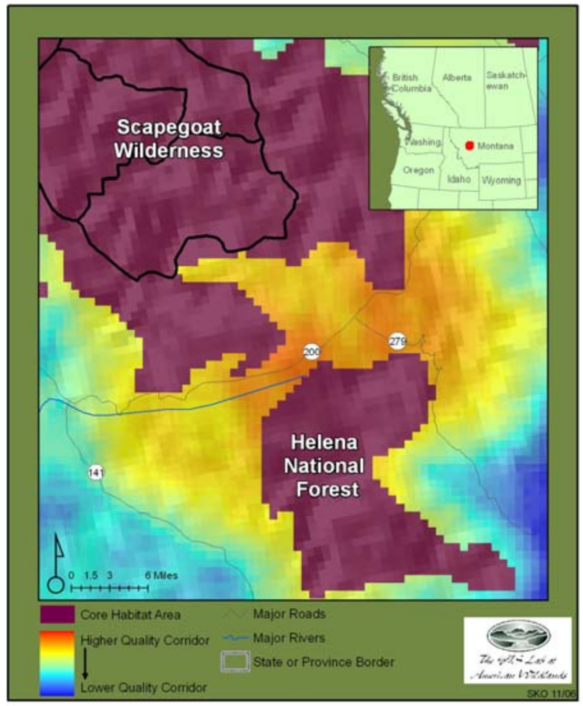

Figure 16. Scapegoat – Helena National Forest Corridor.

6) Salmon-Selway – Crown Corridor

This corridor is one of two connecting the CoC with the fragmented, but highly connected Purcell-Cabinet and Salmon-Selway Ecosystems in the west. The second corridor is over 75 miles to the north; the space in between is highly developed and populated and thus not conducive to grizzly movement. The Salmon-Selway – Crown is a lower quality corridor due to its length and the presence of major roads. The shortest route (Salmon-Selway Ecosystem to Rattlesnake Wilderness) is 30 miles (48.3 km) while longer routes require traveling 45 miles (72.4 km; S-S to Mission Mountain Wilderness), 60 miles (96.6 km; S-S to Bob Marshall Wilderness) or more. To add to the difficulty, most routes require crossing heavily traveled roads including Interstate 90 and US Highway 93.

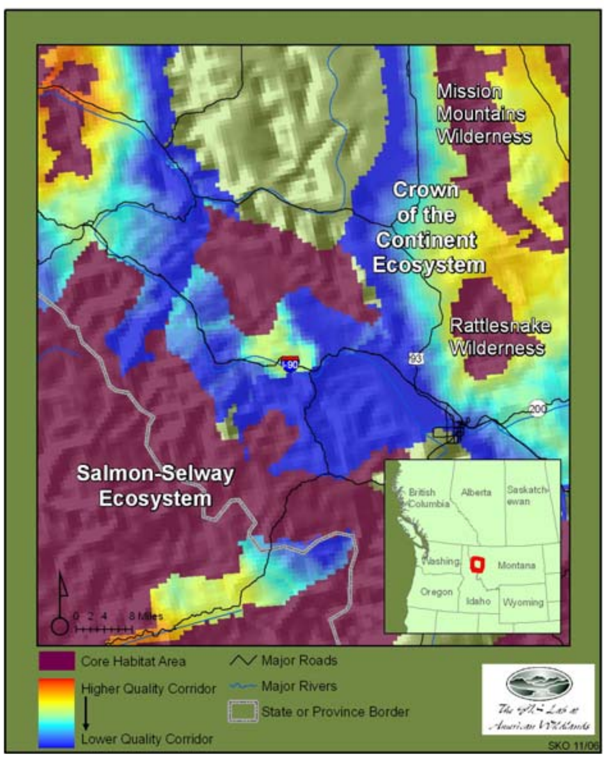

Figure 17. Salmon-Selway – Crown Corridor

Applications and Caveats

The final habitat core areas and connectivity surface represent the results of American Wildlands' science-based, least-cost path model for identifying critical wildlife corridors in the U.S. Rocky Mountains. As with all regional-scaled models, however, there are limitations to the use of this model. The inputs used in this analysis are necessarily generalized for running a model of this scale. Local expert opinion and previous studies have shown that the Montana Gap analysis coverage, used for both the U.S. habitat suitability and complexity inputs, is inadequate for landscape-level detail; however, most agree that it provides a good basis for small-scale (i.e., large area) studies. Also, the Canada land cover data was derived and categorized differently than the U.S. data. Although we attempted to match the coverages to the best of our ability, there is still the likelihood of discrepancies in the datasets which would lead to differences in the model outputs. A statistical analysis of the impact of misrepresentation of land covers suggested that the overall model would not show major differences, however we can not concretely conclude this since we lack the ability to determine how many grid cells (if any) were classified differently. This issue supports the increasing need for available and usable transboundary datasets.

We are also concerned with the adequacy of the roads layers used in modeling. The U.S. TIGER coverages are consistently updated and offer a detailed and accurate picture of public and many private roads. In Canada, however, there is not a good source of publicly-available roads data at this level of detail and accuracy. The roads layer we used accurately portrayed public roads, but likely missed some private roads. Since our model is largely road-driven, the disharmony between roads data used for modeling on either side of the border may result in discrepancies between model results in Canada and the U.S.

We strongly encourage that this data is only to be used on the regional level to identify areas of high potential connectivity. It is not meant to be applied at the landscape scale. It is necessary, therefore, to follow up on individual areas of high potential connectivity with landscape-level studies, using high-resolution data and collected information on species movement, to accurately identify and pinpoint wildlife corridors.

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Appendices

Appendix A. Land cover types extracted from the Montana Gap Analysis Project for use in the Habitat suitability input variable. The column on the far right shows the weight the land covers were assigned based on expert opinion and literature review.

Montana GAP code	Land Cover Description	Grizzly Bear Habitat Suitability Weight
1100	Urban	0
2010	Dryland Agriculture	0
2020	Irrigated Agriculture	0
3310	Salt Desert Shrub	0
3361	Greasewood/Big Sagebrush	0
3510	Mesic Shrub Grassland	0
5000	Water	0
7601	Shrub Badlands	0
3111	Non-Native Grass	1
3130	Very Low Cover Grassland	1
3140	Low Cover Grassland	1
3150	Low/Moderate Cover Grasslands	1
3304	Bitterbrush	1
3350	Big Sage Steppe	1
3352	Wyoming Big Sagebrush	1
3520	Xeric Shrub Grass	1
4206	Ponderosa Pine	1
4214	Rocky Mountain Juniper	1
4290	Mixed Xeric Forest	1
7301	Exposed Rock	1
3160	Moderate/High Cover Grasslands	2
3210	Mixed Mesic Shrubs	2
3212	Warm Mesic Shrubs	2
3351	Mountain Big Sagebrush	2
4020	Very Low Cover Forest	2
4140	Mixed Broadleaf Forest	2
4201	Engelmann Spruce	2
4203	Lodgepole Pine	2
4300	Mixed Broadleaf/Conifer Forest	2
6210	Gaminoid & Forb Riparian	2
3180	Montane Parklands & Subalpine Meadows	3
4205	Limber Pine	3
4208	Subalpine Fir	3
4212	Douglas Fir	3
4223	Douglas Fir/Lodgepole Forest	3
4260	Mixed Whitebark Pine	3
4270	Mixed Subalpine	3
6110	Conifer Dominated Riparian	3
6120	Broadleaf Dominated riparian	3
6130	Mixed Tree Riparian	3
6140	Mixed Forest/Non-forest Riparian	3
6310	Shrub Dominated Riparian	3
6400	Mixed Shrub/Herbaceous Riparian	3

Appendix B. Land cover types extracted from the Canada land cover dataset for use in the Habitat suitability input variable. The columns on the left shows the original code and description from the data set (commas separate co-dominant associated GAP cover types and brackets denote subordinate cover types) and the "corresponding Montana GAP code" shows how these were matched to the U.S. MT GAP data. The column on the far right shows the weight the land covers were assigned based on expert opinion and literature review.

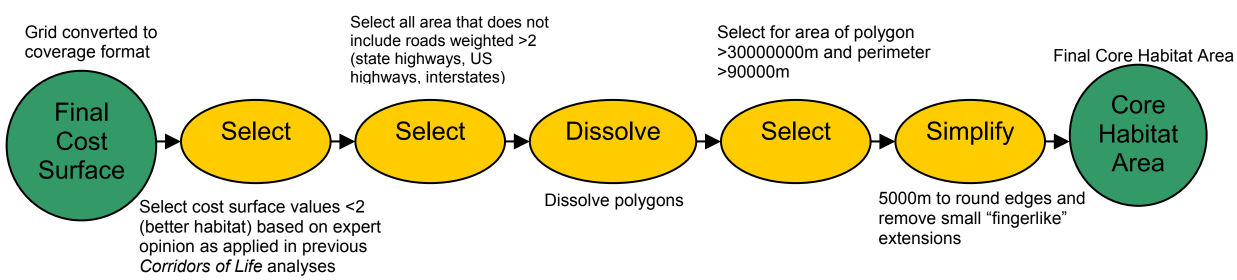
Value	Land Cover Description	Corresponding Montana GAP code	Grizzly Bear Habitat Suitability Weight
61	nodata and null classes	n/a	NoData
63	closed Pl-dominated forest (incl. Fd, Sw, A, etc)	4203 - Lodgepole Pine	2
65	closed Spruce (engelmann and white)-dominated forest; fir (mostly subalpine, some douglas) sub-dominant (also incl Pl, A, etc)	4201 - Engelmann Spruce (4208 - Subalpine Fir)	2
66	closed deciduous (Populus spp.-dominated) forest	4140 - Mixed Broadleaf Forest	2
75	fir (mostly douglas, some subalpine) dominated forest (also contains spruce)	4208 - Subalpine Fir, 4212 Douglas Fir (4201 - Engelmann Spruce)	3
76	open dry DF/PP forest	4223 - Douglas Fir/Lodgepole Pine	3
78	cedar & hemlock - dominated forest (some spruce and fir)	No corresponding designation	3
68	open forest and shrubland (incl. larch, krummholz alpine meadows, lower-biomass avy chutes, ridgetops, open aspen, riparian veg.)	4020 - Very Low-Cover Forest, 4270 - Mixed Subalpine, 3180 - Montane Parklands & Subalpine Meadows, 6310 - Shrub Dominated Riparian	3
69	lower-biomass open areas, like very low-density trees, shrubs, grassland (incl. some cutblocks)	4020 - Very Low-Cover Forest, 3210 - Mixed Mesic Shrubs, 3160 - Moderate/High Cover Grasslands	2
71	high-biomass grass and shrubs - includes denser-growth avalanche chutes, riparian areas, higher-regen cutblocks	6140 - Mixed Forest - Non-Forest Riparian, 6400 - Mixed Herbaceous Riparian, 6310 - Shrub Dominated Riparian (no corresponding designation for avalanche chutes/cut blocks)	3
70	grasslands and meadows, incl. some alpine, parkland, rangeland/agric.	3180 - Montane Parklands &Subalpine Meadows, 2010 - Dryland Agriculture (3111 - Non-Native Grass)	2
77	cultivated/irrigated crops and moist riparian herbaceous cover	2020 - Irrigated Agriculture (6210 - Graminoid & Forb Riparian)	1
74	alpine meadows with sparse veg and no tree cover (not discernible in n.divide ecoregion)	3180 - Montane Parklands & Subalpine Meadows	3
64	bare ground w/min veg (incl. Open Pit mines and very recent burns)	7301 - Exposed Rock, 3130 - Very Low Cover Grassland, 3140 - Low Cover Grassland	1
67	bare ground w/min veg - all other bare ground incl. scree, roads, riverbeds, urban, outcrops, etc.	7301 - Exposed Rock, 3130 - Very Low Cover Grassland, 3140 - Low Cover Grassland	1
73	snow patches and accumulation zones on glaciers	No corresponding designation	0
72	toes of glaciers, rock glaciers, ablation zones	No corresponding designation	0
62	water and shadows	5000 - water	0

Appendix C. Road types and descriptions extracted from the U.S. Census Bureau TIGER line files for use in the weighted road density input coverage. The weight (far left column) was assigned by literature review and expert opinion.

Weight	TIGER Code		Description of Road Type
			Primary Highway
3	A	10	Primary road with limited access or interstate highway, major category used alone when the minor category could not be determined
3	A	11	Primary road with limited access or interstate highway, unseparated
3	A	12	Primary road with limited access or interstate highway, unseparated, in tunnel
3	A	13	Primary road with limited access or interstate highway, unseparated, underpassing
3	A	14	Primary road with limited access or interstate highway, unseparated, with rail line in center
3	A	15	Primary road with limited access or interstate highway, separated
3	A	16	Primary road with limited access or interstate highway,separated, in tunnel
3	A	17	Primary road with limited access or interstate highway, separated, underpassing
3	A	18	Primary road with limited access or interstate highway, separated, with rail line in center
			Primary Road without Limited Access
2	A	20	Primary road without limited access, U.S. and State highway, major category used alone when the minor category could not be determined
2	A	21	Primary road without limited access, U.S. and State highways, unseparated
2	A	22	Primary road without limited access, U.S. and State highways, unseparated, in tunnel
2	A	23	Primary road without limited access, U.S. and State highways, unseparated, underpassing
2	A	24	Primary road without limited access, U.S. and State highways, unseparated, with rail line in center
2	A	25	Primary road without limited access, U.S. and State highways, separated
2	A	26	Primary road without limited access, U.S. and State highways, separated, in tunnel
2	A	27	Primary road without limited access, U.S. and State highways, separated, underpassing
2	A	28	Primary road without limited access, U.S. and State highways, separated, with rail line in center
			Secondary and Connecting Road
2	A	30	State and county highways, major category used alone when the minor category could not be determined
2	A	31	State and county highways, unseparated
2	A	32	State and county highways, unseparated, in tunnel
2	A	33	State and county highways, unseparated, underpassing
2	A	34	State and county highways, unseparated, with rail line in center
2	A	35	State and county highways, separated
2	A	36	State and county highways, separated, in tunnel
2	A	37	State and county highways, separated, underpassing
2	A	38	State and county highway, separated, with rail line in center
			Local, Neighborhood, and Rural Road
1	A	40	minor category could not be determined
1	A	41	unseparated
1	A	42	unseparated, in tunnel
1	A	43	unseparated, underpassing
1	A	44	unseparated, with rail line in center
1	A	45	separated
1	A	46	separated, in tunnel
1	A	47	separated, underpassing
1	A	48	separated, with rail line in center
			Vehicular Trail
1	A	50	major category used alone when the minor category could not be determined
1	A	51	unseparated
1	A	52	unseparated, in tunnel
1	A	53	unseparated, underpassing
			Road with Special Characteristics
1	A	60	Road with characteristic unspecified
1	A	61	Cul-de-sac

1	A	62	Traffic circle
1	A	63	Access ramp
1	A	64	Service drive
1	A	65	Ferry crossing
			Road as Other Thoroughfare
1	A	70	Other thoroughfare
1	A	71	Walkway
1	A	72	Stairway
1	A	73	Alley
			Railroad Main Line
1	B	10	Railroad main track major category used alone
1	B	11	Railroad main track, not in tunnel or underpassing
1	B	12	Railroad main track, in tunnel
1	B	13	Railroad main track, underpassing
			Railroad Spur
1	B	20	major category used alone
1	B	21	not in tunnel or underpassing
1	B	22	in tunnel
1	B	23	underpassing
			Railroad Yard
1	B	30	major category used alone
1	B	31	not in tunnel or underpassing
1	B	32	in tunnel
1	B	33	underpassing
			Railroad with Special Characteristics
1	B	40	Railroad ferry crossing
			Railroad as Other Thoroughfare
1	B	50	Other rail line
1	B	51	Carline
1	B	52	Cog railroad

Appendix D. Simplified Model Builder model for selecting habitat core areas. Intermediary steps have been eliminated to reduce the complexity of the model*.



*Please contact the American Wildlands GIS lab for the full model.

Appendix E. Summary of expert interviews regarding the core habitat areas identified in the U.S. and Canada

United States reviewers

Reviewer #1

Should change term "core area" - too confusing since our definition conflicts with gov't agencies accepted definition

Nodes: we've defined hit all of the important areas (roadless, lesser roaded) but may actually be too extensive for really great grizzly habitat

Should include a buffer (500 m is accepted by gov't agencies) next to the major roads

Reviewer #2

Summary: Several important, good habitat areas are missing. We should consider the management when defining core areas because, e.g., Glacier NP is strictly protected

"Occupied habitat" perhaps a good alternative to "core habitat"

Good areas that were not included: Abgar Ranger, wetland areas, Lake McDonald area, St. Mary Lake, Two Medicine Lake

Reviewer #3

Sound science! Be careful when extrapolating across ecosystems - unlikely that factors affecting grizzly bears will have the same importance in Yellowstone vs. CoC

There are areas in Glacier that are better than others - result of human influences

Very important to define the purpose of the model when evaluating the output

Consistency in modeling approach is very important - don't just accept that management means better core habitat - model has no value unless all areas are treated the same

Look into the impact of fires - this changes habitat drastically (and annually which is difficult to account for)

Reviewer #4

Why is an irregularly shaped swat across the southern Whitefish Ranger, including roadless areas, excluded as core habitat? Even more surprising is the exclusion of the North Fork floodplain and a fair chunk of the valley's east side in Glacier National Park

North Fork probably provides the most functional major valley bottom grizzly habitat and connectivity in the United States with the possible exception of the upper South Fork

Canada reviewers

Reviewer #1

The core habitat looks pretty good near the US border and there are a lot of bears in the northern portion of the study area. Overall it looks pretty good for such a general map at this large a scale.