Using GIS to Examine Potential Wolverine Habitat in Colorado: an Analysis of Habitat Fragmentation and Wildlife Corridors

Lucas J. Danzinger
Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987

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Abstract

In 2010, a single male wolverine (*Gulo gulo*) traveled from the Greater Yellowstone Area of Wyoming into Colorado, marking the first known wolverine in Colorado since they were extirpated in 1919. The return of this wolverine to part of its historic range has prompted several wildlife advocates to lobby for a reintroduction of wolverines into the state of Colorado. To understand the viability of a reintroduction of this rare animal, an analysis of potential habitat was conducted through several steps. First, a habitat suitability model was developed based on previous wolverine habitat models from throughout North America. Next, a habitat fragmentation Python script ("Landscape Fragmentation Tool v. 2.0") was utilized to understand the fragmentation dynamics of the predicted habitat. Finally, a wildlife corridor model was created to develop a least cost raster and finally, to propose possible routes between core habitat areas. The results of this study do not predict the likelihood of success of a reintroduction, as this determination would require several additional studies and analyses; rather, this study is meant to be one tool to help aid wildlife managers in making informed decisions regarding the potential success of wolverine reintroduction in Colorado. The results of this study indicate a large amount of potential wolverine habitat with limited fragmentation. However, major roads and development may inhibit wolverine dispersal among the major patches of habitat in Colorado.

Introduction

Wolverines (*Gulo gulo*) are currently endangered in the state of Colorado (Colorado Division of Wildlife, 2010) and are under a 12-month review to be listed as federally endangered under the Endangered Species Act of 1973 (USFWS, 2010; USFWS, 1973). Several wolverine habitat models have been developed and tested to predict current ranges and optimal locations to conduct surveys throughout North America. However, aside from a single male wolverine that traveled from the Greater Yellowstone area of Wyoming into Colorado in 2010, wolverines have been absent from Colorado since 1919, and because of their absence, studies are scarce in analyzing potential wolverine habitat within Colorado. Because there are now less anthropogenic threats of extirpation and an overall greater tolerance and understanding of the need for carnivores in an ecosystem, a reintroduction of wolverines may be viable (Aubry, McKelvey, and Copeland, 2007). A reintroduction of wolverines in Colorado would not merely expand the current range of wolverines but it could connect populations to habitats further south via the Rocky Mountains, thus helping the entire

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population in North America (USFWS, 2010).

The goal of this project was to provide some insight on the characteristics of potential wolverine habitat in Colorado. This included predicting areas wolverines would likely be able to survive based on statistically tested habitat modeling studies performed throughout North America. This also included analyzing habitat fragmentation dynamics through utilizing a habitat fragmentation Python script. Finally, this project proposed possible wildlife corridors between core habitat areas to ensure connectivity among the main habitat areas within Colorado. This was done through the development of a wildlife corridor model.

Biological and habitat requirements were first analyzed to understand critical factors contributing to survivorship of wolverines. In addition, several habitat suitability models were analyzed (Carroll, Noss, Schumaker, and Paquet, 2001; Edelmann and Copeland, 1999; Hart, Copeland, and Redmond, 1997; Heinemeyer, Aber, and Doak, 2001; Wisdom, Holthausen, Wales, Hargis, Saab, Lee, Hann, Rich, Rowland, Murphy, and Earnes, 2000; Raphael, Wisdom, Rowland, Holthausen, Wales, Marcot, and Rich, 2001; Rowland, Wisdom, Johnson, Wales, Copeland, and Edelmann, 2003) and incorporated into the final habitat model that was developed for this study. These models contained several different parameters including high elevations, low human population densities, low road densities, high snowpack, steep slopes, and north to northeast facing slopes, among others. However, after verification by aerial surveys, only three parameters proved to be statistically significant predictors of wolverine locations: elevations >2,400 m, human population densities $<3.9/km^2$, and road densities <0.44 km/km^2 (Wisdom *et al*., 2000; Raphael *et al*., 2001; Rowland *et al*., 2003). In addition, high elevations (>2,400 m) appeared to be the primary predictor of wolverine habitat largely due to the association between low human population and road densities and high elevations. Food availability was not included in any of the models largely because wolverines appear to be opportunistic feeders, generally scavenging on ungulate carcasses (Copeland and Kucera, 1997). The final wolverine habitat model only included three previously listed parameters (elevations >2,400 m, human population densities $<3.9/km^2$, and road densities <0.44 km/km^2).

A fragmentation Python script ("Landscape Fragmentation Tool v. 2.0") developed by Parent and Hurd (2008) at the University of Connecticut Center for Land Use Education and Research (CLEAR) was utilized to analyze fragmentation of the predicted habitat developed in the habitat suitability model. It was important to analyze fragmentation of the habitat for several reasons: (1) wolverines have extremely large home ranges (as large as 1,522 km^2) thus requiring large connected habitat areas (Copeland, 1996); (2) wolverines prefer to have little overlap in habitat; and (3) connectivity among habitats would create a more stable overall population and allow for more genetic variation among populations within and outside of Colorado (Kyle and Strobeck, 2001). Kyle and Strobeck found human development and major roads to be the primary anthropogenic barrier between habitats. The Landscape Fragmentation Tool v. 2.0 created a grid displaying four main habitat types: patch, edge, perforated, and core. This information was used to generate summary statistics and to visually understand fragmentation dynamics and spatial distributions of the predicted habitat in Colorado.

Finally, a wildlife corridor model was developed based on an adjusted version of the wolverine habitat model. The corridor model also utilized land use/land cover data from National Land Cover Dataset (NLCD) to develop a least cost route between the core habitat areas. Wildlife corridors are vital to ensure wolverines can move among core habitat areas to avoid forming unstable metapopulations which could ultimately lead to an unsuccessful reintroduction effort in Colorado.

An overall prediction of the likelihood of a successful wolverine reintroduction was beyond the scope of this project. Rather, this project was conducted to better understand the characteristics (amount, size, fragmentation, and connectivity) of potential wolverine habitat in Colorado. These findings, along with other future studies, would ultimately lead to a better understanding of the likelihood of success of a wolverine reintroduction.

Methods

Relevant Data

Esri's ArcMap and ArcCatalog (versions 9.3.1 and 10, license ArcInfo) were utilized for data analysis in all three steps of this project. Relevant data included a 30 m DEM from USGS, a roads shapefile from Colorado Department of Transportation (DOT), population information by zip-code from the U.S. Census Bureau, land use/land cover data from NLCD, and the Landscape Fragmentation Tool v. 2.0 from the University of Connecticut CLEAR. These data are available to the public for free from websites on the Internet.

Habitat Suitability Model

The habitat suitability model was developed after a thorough review of previous models, with three parameters proving to be statistically significant: elevations >2,400 m, human population densities <3.9/km^2, and road densities <0.44 km/km^2 (Wisdom *et al*., 2000; Raphael *et al*., 2001; Rowland *et al*., 2003). Through use of the 30 m DEM, roads shapefile, and U.S. Census population information, the model was constructed.

First, the DEMs that comprised Colorado (16 separate tiles in total) were mosaiced together to form one DEM representing Colorado. This allowed for easy manipulation of one grid rather than several. Next, cells >2,400 m were selected from the DEM, displaying suitable elevations.

Secondly, the roads shapefile gathered from the Colorado Department of Transportation (CODOT) including interstates, highways, major roads, and local roads) was processed using a line density tool. This tool evaluated each individual cell (30 m), drew an invisible one-kilometer circle (this was user-defined to account for density per km^2) around that cell, and calculated the length of line (i.e., roads) moving through that circle. This returned a road density layer that was subsequently queried to only display cells with a road density <0.44 km/km^2.

Finally, a zip-code shapefile was populated with U.S. Census population data. These data were used to create population densities and were then converted into raster files and queried to only display cells with population densities <3.9/km^2.

Once all the individual parameters were queried out, all cells that met all three individual parameters were selected through utilization of the raster calculator tool. The output grid displayed suitable habitat for wolverines within Colorado.

Habitat Fragmentation Python Script

The Landscape Fragmentation Tool v. 2.0 could only be run in ArcCatalog

9.3.1, as the tool was developed before ArcGIS 10 was released.

The required data for this tool was a binary grid displaying suitable and not suitable habitat (this tool was originally created for forest fragmentation, but can be utilized for other habitats as well) (Parent and Hurd, 2008). The habitat model developed earlier for this study was utilized as the input binary grid. In addition to the binary grid, this tool required a user-specified edge width. Edge is the area separating suitable and not suitable habitat areas. Selecting a smaller edge would result in more core habitat and selecting a larger edge would result in more patch habitat. There were no suggested edge widths in relevant literature, so the tool's default value of 100 m was accepted for this study.

This tool conducted a series of steps to determine habitat type. It first moved through each cell and determined edge habitat. Then, it evaluated the size of each habitat area and its distance to the edge habitat. Finally, through a series of reclassification steps, the tool determined the patch, perforated, and core habitat areas. The output raster consisted of four main habitat types: patch, edge, core, and perforated (Figure 1). Patch areas were small areas that did not contain any core habitat. Edge areas were 100 m areas between suitable and not suitable areas. Perforated areas were similar to edge, but they were only found within core habitat areas. Finally, core habitat were cells that were >100 meters from not-suitable habitat (Parent and Hurd, 2008). Core habitat areas were further broken into small (<250 acres), medium (250-500 acres), and large core (>500 acres) habitat.

In order to more easily summarize statistics from this fragmentation tool, the fragmentation grid was converted to vector polygons. Then, through utilizing the X-Tools extension for ArcGIS, the areas for each polygon were calculated and exported to a Microsoft Excel spreadsheet. Pivot tables were then utilized to create summary statistics.

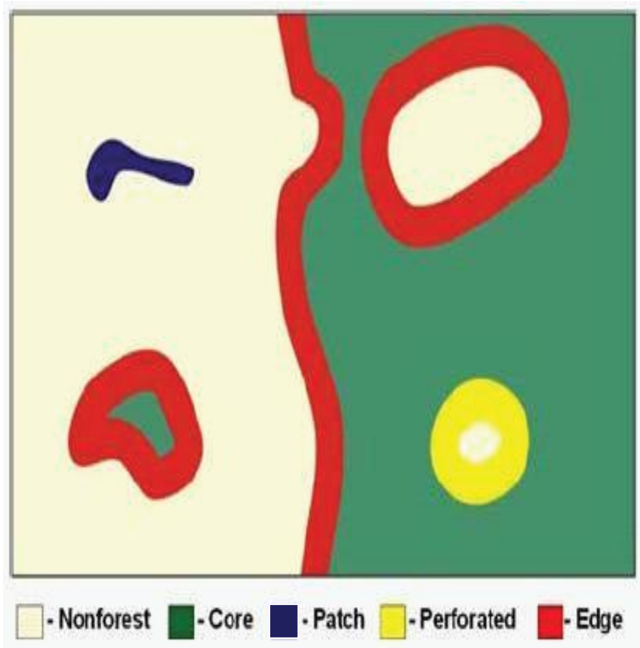

Figure 1. An example of forest fragmentation classes as a result of the Landscape Fragmentation Tool v. 2.0 (figure taken from Parent and Hurd, 2008).

Wildlife Corridor Model

The wildlife corridor was developed through examining the core habitat areas that were determined in the habitat suitability model and habitat fragmentation grid. Through looking at each individual layer that made up the wolverine habitat model, it became clear that human population density was the cause of fragmentation between the main suitable habitat areas. This became apparent after exploring different raster calculation equations. Human population density appeared to be related to development along the major highways and interstates in the Colorado Rocky Mountains. Subsequently, a new

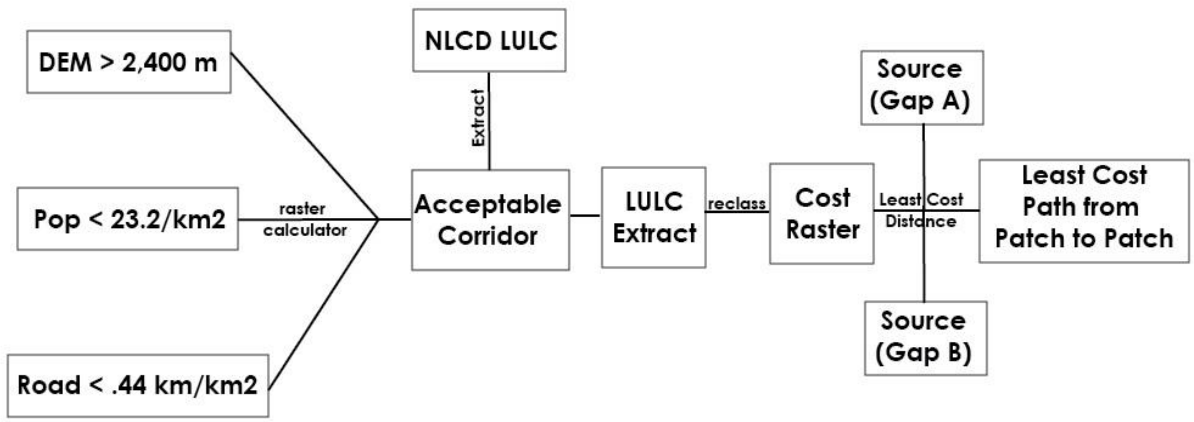

Figure 2. Wildlife corridor model workflow.

habitat model, with an adjusted human population density value (<23.2/km^2 – medium density) (Raphael *et al*., 2001), was developed; the results of this model would not display optimal habitat as in the original model but rather, the "next-best" habitat in Colorado. These "next-best" areas could be considered acceptable corridor areas because they would most likely be able to support wolverines that were migrating through the area, but may not be desirable for long-term settlement.

The acceptable corridor areas generated from the manipulated habitat model were next used to extract land cover/land use data. This resulted in a grid displaying land use/land cover data in the shape of acceptable corridor areas. This provided a better understanding of the land cover/land use within the acceptable corridor areas.

Next, each cell was reclassified so cells classified as forested areas were scored low (1), cells classified as grassy areas were scored moderately (5), and cells classified as urban/developed were scored high (10). These values were somewhat arbitrary, but were based off wolverine habitat preferences and were designed to create a grid that would emphasize both the high-density residential areas to stay away from and heavily forested areas that would be ideal for a wildlife corridor; the ultimate goal was to avoid urban/developed land when creating the wildlife corridors. The complete workflow developed for the wildlife corridor model is displayed in Figure 2.

After the least cost path finished processing, visual analysis was used to suggest a specific location for a wildlife corridor between the two core habitat areas. This process involved analyzing cells with the lowest values so the corridor could be constructed in forested areas and could avoid high density residential areas. The process also included finding the shortest path between each habitat. Finally, polygons were digitized over the areas with the least cost and shortest distance between the main habitat areas, representing corridor areas.

Results/Discussion

Habitat Suitability Model

The habitat suitability model returned a total of 4,517,387.86 ha (11,162,708.5 acres) of suitable habitat within Colorado. The suitable habitat appears to be split into three distinct sections: northern, middle, and southern. Figure 3 displays the final map of suitable wolverine habitat along with the three distinct sections. There appears to be a large amount of suitable wolverine habitat in Colorado. All suitable habitat was found in western Colorado and elevation appeared to be the most important variable;

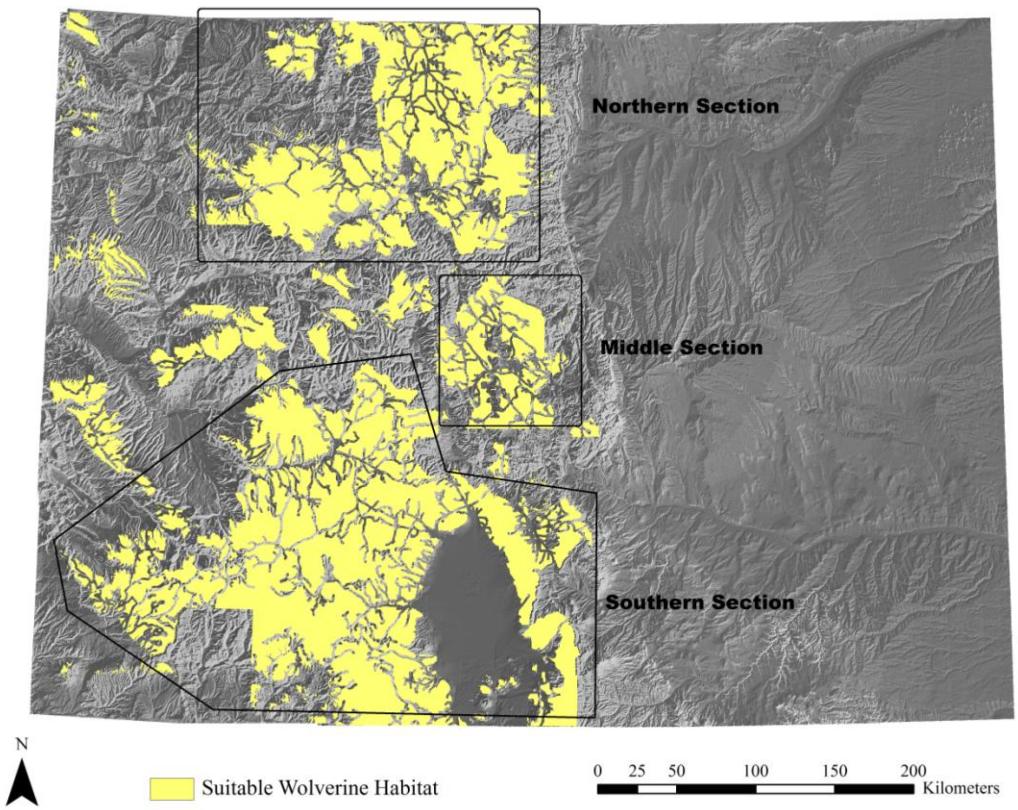

Figure 3. Predicted suitable wolverine habitat and the three distinct habitat sections in Colorado.

there are likely lower human population and road densities at higher elevations. The presence of major highways or interstates and the development around those areas are what most likely caused this split. Spatially, the habitat in the far western edge of Colorado appears to be somewhat disconnected to the middle section of the state which is likely due to lower elevations.

Habitat Fragmentation

The fragmentation analysis conducted through using the Landscape Fragmentation Tool v. 2.0 separated the predicted habitat into four main categories: patch, edge, perforated, and core (small, medium, and large).

Table 1 displays the summary statistics generated from the fragmentation grid.

Table 1. Habitat fragmentation summary statistics developed from the Landscape Fragmentation Tool v. 2.0.

habitat type	% of total area	sum of kilometers	sum of acres	sum of hectares
patch	0.04%	16.22	4006.86	1621.52
edge	5.57%	2516.33	621797.49	251632.52
perforated	0.01%	5.88	1451.75	587.5
core (small)	0.25%	114.98	28412.85	11498.27
core (medium)	0.27%	121.36	29988.8	12136.04
core (large)	93.86%	42399.12	10477050.75	4239912.01
total	100%	45173.88	11162708.5	4517387.86

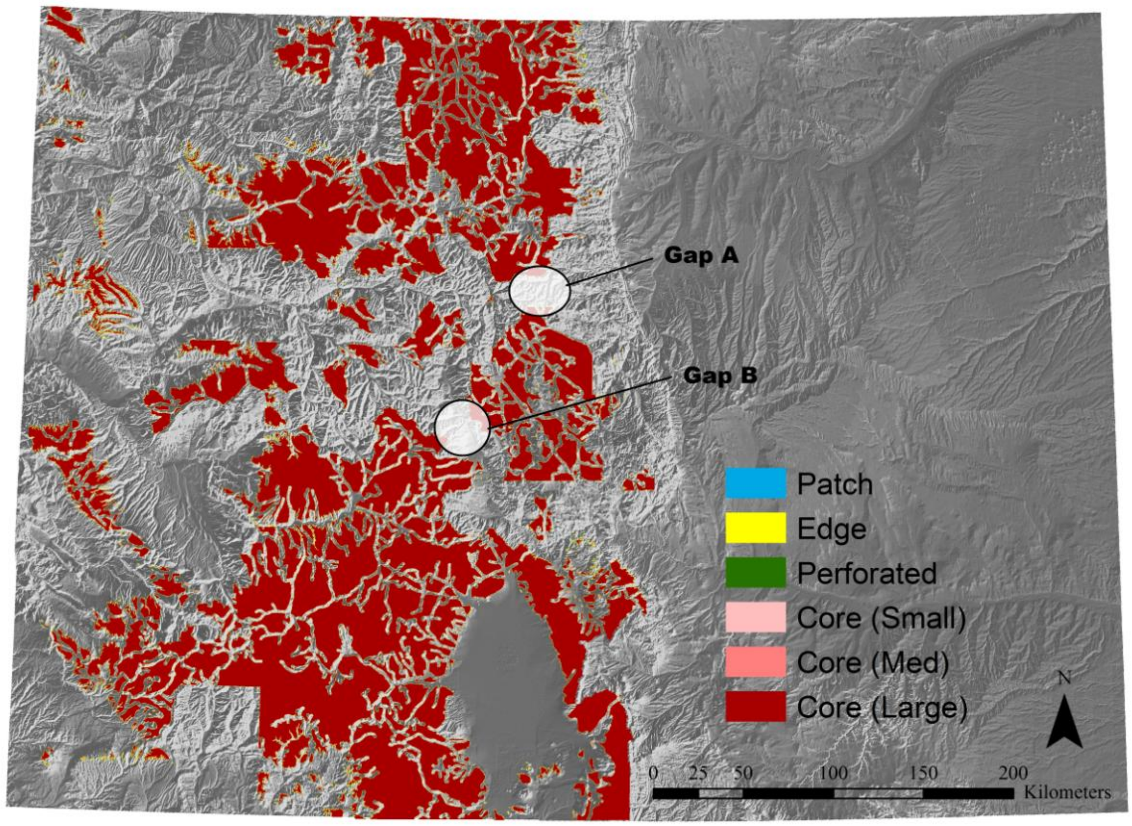

Figure 4. Habitat fragmentation results from the Landscape Fragmentation Tool v. 2.0.

Nearly 94% of the predicted wolverine habitat within Colorado was classified as large core (core habitat > 500 acres). Only 0.04% of predicted habitat was patch, suggesting that very little of the suitable habitat was fragmented. Figure 4 displays the spatial distribution of the habitat fragmentation analysis. Though it is difficult to discern patch habitat locations at this scale, largely due to the small size of patch habitat (< 200 m wide), the majority of patch habitat was concentrated near the core habitat areas and on the western edge of the state. Perforated and edge habitats were also located near core habitat areas, which was expected due to the definition of these habitat types as described in the methods section.

The results of the fragmentation analysis displayed two gaps that divided some of the largest areas of core habitat (northern, middle, and southern sections). Gap A is approximately 20 km at its shortest distance and Gap B is approximately 18 km at its shortest distance. Constructing a corridor through these two areas would be vital to connect suitable habitat areas in the northern and southern parts of the state. The presence of major highways and interstates, along with development around these areas, appears to be the cause for the disconnection. These apparent gaps prompted the development of the wildlife corridor model.

Wildlife Corridor Model

The wildlife corridor analysis focused on Gap A and Gap B, as displayed in Figure 4. These areas were the focus because they appear to be vital to ensure connectivity. Figure 5 and Figure 6 display the cost grids generated by the least cost analysis, along with the potential corridor locations.

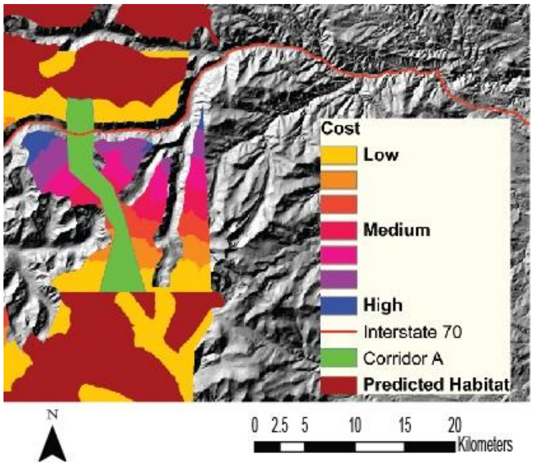

Figure 5. Gap A. least cost results, along with a suggested path for a wildlife corridor between the two main habitat areas.

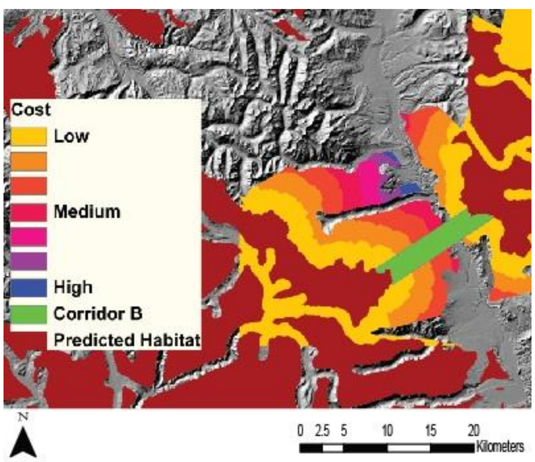

Figure 6. Gap B. least cost results, along with a suggested path for a wildlife corridor between the two main habitat areas.

The results of the least cost analysis for Gap A (Figure 5) showed a high cost area (high density residential areas) along Interstate 70, with heavily forested areas closer to the core habitat areas. These high cost areas along Interstate 70 could make connectivity between the northern and middle sections difficult.

The least cost analysis results for Gap B (Figure 6) largely showed low-to-medium cost areas throughout the gap, with high cost occurring only in the north. This suggests a corridor could be constructed in the southern portion as displayed in Figure 6.

Implications

The project found large amounts of suitable habitat in Colorado which was largely unfragmented. The largest issue with the predicted habitat is the separation between the main habitat areas (northern, middle, and southern). This disconnection could separate populations from each other creating unstable and unsustainable metapopulations with limited genetic diversity. In order to ensure the success of wolverines within the state of Colorado, wildlife corridors between these three areas would be vital. The least cost paths generated through the wildlife corridor model were used to determine the best location for those corridors and are displayed in Figure 5 and Figure 6. While the Gap B corridor could be successful because of the relatively low cost throughout the grid, Gap A had very high cost areas all along Interstate 70. These high cost areas could be problematic, and even if a wildlife corridor was constructed, it is possible it would not be successfully used by wolverines. Wolverines prefer seclusion and it could be difficult to coax them into utilizing these areas.

Limitations/Future Studies

As with any modeling project, several assumptions had to be made. For example, none of the habitat models created in the past were for the state of Colorado, so it was assumed wolverines in Montana, Wyoming, and Idaho would prefer similar habitat characteristics if they lived in Colorado. In addition, it was assumed the default value of 100 m for the edge width in the habitat fragmentation Python script would be sufficient because there was no literature speaking to edge preference by wolverines. Finally, while the cost values assigned to the land use/land cover grid were based off habitat preferences, they were still somewhat arbitrary. However, a value was needed to conduct this test and there are no wolverine studies documenting cost value designations.

Another limitation of this study was that it did not and was not intended to predict the viability of the return of wolverines. Additional studies needed to make this determination include analyzing the implications of wolverines on the surrounding ecosystem, the economic and land-use effects of a potentially endangered species living on private land, and the tolerance of the species by the current residents of the state. Several other states have reintroduced carnivores into their native range with some negative feedback from local residents.

Finally, a more in-depth analysis is needed for the wildlife corridor areas. This analysis simply looked at landscape and land-use to determine where hypothetical connections could be made. However, an economic analysis of the amount of money it would cost to build these corridors and to obtain conservation easements would be needed. There are several steps in the process of creating a wildlife corridor, and while highlighting specific areas where wolverines could potentially live is beneficial, a richer analysis could be valuable.

Conclusions

This study analyzed predicted wolverine habitat in Colorado, with the goal of developing a better understanding of the likelihood of a successful reintroduction. This was accomplished through creating a habitat suitability model, utilizing a habitat fragmentation Python script, and through development of a wildlife corridor model. The results show a large amount of predicted habitat (4,517,387.86 ha) with nearly 94% of that habitat identified as large core (> 500 acres). This is extremely important, especially due to the large home ranges of wolverines. However, the disconnection between some of the largest habitat areas (northern, middle, and southern sections) could be problematic and need to be studied more extensively.

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