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Bryn Karabensh
University of Denver

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Bryn Karabensh

University of Denver Department of Geography

Capstone Project

For Master of Science in Geographic Information Science

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Abstract

Wolverine research in the contiguous United States is not abundant and understanding of the ecology of this species is not fully understood in this ecosystem. Specifically lacking in research is data regarding wolverine movements. This paucity of data and analysis inhibits the ability to effectively develop and implement conservation and management strategies. This paper seeks to identify patterns and habitat preferences of wolverines with respect to their movements. Specifically, do they avoid roads and clear-cuts zones from timber harvest and do they display a preference to topography features during movements? Using GPS locations of wolverines a regression analysis was applied. We found that roads, clear cuts, slope or aspect do not influence wolverine movements in this study area.

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Introduction

Wolverines, *Gulo gulo*, are the largest and most elusive member of the mustelid family. As terrestrial furbearers with long bushy tails, they are adapted for cooler climates and high elevation zones of which they inhabit in northern ecosystems. This would include alpine, subalpine, tundra and coniferous mountainous regions. They are often said to resemble a bear with broad, round heads and small rounded ears and eyes. They have beautiful dark brown and reddish/beige pelage with markings similar to a badger.

Research and data on wolverines in the southern most circumpolar regions is sparse. The contiguous United States is the southern edge of the species distribution, where a significant range contraction has occurred. By 1930, it is believed that wolverines were extirpated, or nearly so, in the lower 48 of the U.S. (Aubry et al, 2007). This was due to over exploitation of hunting, trapping and poisoning. However, the population has rebounded over the last 50 years with little human assistance, but it is believe they are still vulnerable to extinction due to their natural geographic distribution and species fundamental niche. The biggest threats are climate change and

anthropogenic pressures. Additionally, wolverines are uncommon occurring at low densities, have large spatial requirements, low reproductive rates (Banci 1988, Persson 2003, 2006) and have been recognized as warranted for protection under the United States Endangered Species Act (U.S. Fish and Wildlife Service 2012). In August of 2014, the U.S. Fish and Wildlife Service withdrew a proposal to list the North American wolverine in the conterminous U.S. as threatened under the Endangered Species Act (ESA). They recognized the climate is warming but the effects of climate change will not cause wolverines to go extinct in the near or foreseeable future. Many scientists and biologist who have studied wolverines do not necessarily agree with the ESA's decision. A major argument is that wolverine's utilize deep, persistent snow pack and cover for a number of fundamental resources to survive. Specifically, females seek this deep snow pack to dig their elaborate natal dens for bearing their offspring. Most studies conducted in the contiguous U.S. observed the wolverine populations preferring higher elevations due to more persistent snow cover and cooler temperatures that can be found in the warmer southern circumpolar region compared the colder ecosystems found in Alaska and Canada (U.S. Fish and Wildlife Service). Many climatic models indicate that snow pack in the higher

elevations where wolverines survive will decrease 31 percent by 2045 and 63 percent by 2085 (U.S. Fish and Wildlife Service). Another reason for concern for the survival of wolverine populations in the lower 48 relates to the negative impacts of their habitat; increasing fragmentation in an already naturally fragmented ecosystem. Some potential sources of these negative impacts are more commonly human caused, such as road construction, increased winter recreational activities (Copeland 1996, Krebs et al. 2007), timber harvest, illegal hunting/trapping (Krebs et al. 2004) and in general an increase of human infrastructure (Gude et al. 2007). Natural threats to the species can include the negative impacts of inbreeding due to lack of genetic diversity. Other concerns for the survival of the species is their lack of presence in their historical distribution (Aubry et al. 2007)

There is a need to increase the understanding of the wolverines' ecology to develop more effective management practices and conservation strategies. Ruggiero et al. (2007) suggests that the ability to develop and implement an effective management and conservation plan is compromised while the data on wolverine ecology in the lower 48 is lacking. It is important to understand that their niche is not only vulnerable to increased fragmentation due to human encroachment but as well as the pressures of

climate change. It is crucial for research efforts to quantify and qualify sound empirical data that provides insight to wolverine ecology specifically for the contiguous U.S., both at a local and geographic level.

To protect the species and conserve the wolverines' habitat additional research is needed to better understand their ecology and make the most effective management decisions. Specifically, what are the influencing factors in wolverine movements? Copeland et al. (2010) found that snowpack coverage and ambient temperature from April 24-May 15 is a fundamental component to their niche. Brock et al. (2007) found influencing factors in habitat selection and movement of radio collared wolverines in Montana and Wyoming included road density, forest edge, conifer cover, snow depth, elevation and ruggedness. The research and analysis presented in this report seeks to identify the effects of anthropogenic features of the study area (roads and clear cuts) and topographical (aspect and slope). While the research took place during the winter months it is a safe assumption that the roads are being used for snowmobile use, snow shoeing or cross country skiing. Do wolverines avoid roads due to human activity or are they more inclined to utilize them for path of least resistance? I hypothesize that they prefer not to travel by way of roads and trails to avoid

human interaction. Do the clear cuts for timber sales influence wolverine movements? As stated earlier Brock et al. (2007) documented that forest edge was a preferred landscape for wolverine movements. I predict that we will observe this pattern as well with respect to wolverine movements along the edge of the forest and clear-cut. I hypothesize that they generally chose to avoid the open clear-cut zones and travel more frequently along the edge buffer or in the forested area in order to prevent detection. I hypothesize we observe patterns of wolverine movements based on preferences of least detections rather than path of least resistance. I think human disturbance is more of an influencing factor rather than steep and unforgiving terrain with respect to wolverine movements.

The geospatial analysis presented here focuses on identifying critical components for wolverine movements in the Bear Creek Drainage of southwestern Montana in the Absaroka-Beartooth mountain range. This analysis focuses on determining habitat selection for wolverine movements based on topography (aspect and slope) and anthropogenic features (roads and clear cuts). Providing crucial information of wolverine habitat selection in the lower 48 to ensure the survival of this threated species.

Literature Review

Adult males generally weigh 26-40 lbs. with females weighing 17-26 lbs. (Banci, 1994). They have 5 toes on each foot with semi-retractile claws that leave distinct tracks and can be identified when conditions are ideal with their signature gait and footprint. They often use their claws for climbing and digging (Banci, 1994) and tearing apart carcasses.

Wolverines are solitary animals that have large home ranges, 388-442 km^2 (Hornocker et al., 1983) with the males generally having larger home ranges. Copeland (1994) determined annual home ranges for resident adult wolverines in Idaho to be on average 384 km^2 for females and 1,582 km^2 for males. A study in the Greater Yellowstone Ecosystem discovered significantly smaller home range sizes for males in that ecosystem, averaging 797 km^2 (Inman et al., 2010). Female home range sizes were comparable. Wolverines occur at low densities and often travel long distances daily and/or seasonally. They typically only interact with other individuals of the opposite sex during breeding season, with very little overlap with home ranges. Copeland (1994) documented female home ranges overlapping less than 10% and male home ranges overlapping less

than 15%. Offspring generally remain within the natal area for up to 2 years. Inman et al. (2012) state that relative to body size wolverines have very large home ranges. This study documented individuals traveling long distances in a short amount of time. They reported average movement rates of 1.3km/2 hours, covering >75% of their multi-year home range in 32 days, on average (Inman et al. 2012). Considering this lack of overlap of home ranges among the same sex suggest territoriality (Inman et al. 2012).

Wolverines are carnivores that predominately scavenge on carrion, primarily ungulates. They have been observed utilizing wolf, bear and cougar kills. They have been found to occupy lower elevations during winter months. This could be due to the increase in carrion from big game hunters. Other food sources that have been documented are rodents, rabbits, squirrels, occasionally avian species and invertebrates (Copeland, 1994). Wolverines have very strong olfactory systems often relying solely on their nose at times to reach the food source, many times underneath snow. They rely heavily on scent marking as well for claiming territory. In Sweden they have been observed using their own trail repeatedly (Haglund, 1966). Wolverines have been documented caching excess food to later return to when resources are low. Cache sites have been in observed in snow banks, trees

and underground. In the winter, wolverines generally prefer montane coniferous forest types including Sub-Alpine fir (*Abies lasiocarpa*), Lodgepole Pine (*Pinus contorta*), and Douglas Fir (*Pseudotsuga menziesii*). Inman et al. 2010 found that wolverines preferred elevations above 2,600m, and avoided elevations below 2,150m in the Greater Yellowstone Ecosystem (GYE). In the summer months higher elevations were preferred with rock/talus cover types. Annual snow cover is an influencing factor to wolverine movement and habitat selection.

It is believed that due to the narrow ecosystem the wolverine inhabits, they are vulnerable to the drastic changes of climate and human encroachment. The historical distribution of wolverines in the United States was substantially larger than current distribution (Aubry, et al 2006). A few of the big drivers of habitat loss have been from timber harvest and road construction fragmenting valuable habitat and other anthropogenic disturbance and expansion. Copeland, 1994 observed females abandoning natal den sites when human disturbance occurred, but not kit abandonment. Additionally, it is suggested by Copeland (2010) that climate warming will likely reduce the extent of wolverine habitat. As a species is constrained by

their obligate association with persistent spring snow cover reductions in snow cover will result in an associated loss of connectivity.

There have been at least 2 petitions, one in 1995 and the other in 2000 attempting to change the status of the wolverine as 'threatened' under the Endangered Species Act (ESA) to protect and preserve the species. Both times the petitions were denied due to lack of substantial evidence that would warrant protection of the wolverine under the ESA. The most recent action was on August 13, 2014 the U.S. Fish and Wildlife Service withdrew a proposal to list the wolverine as 'threatened' under the ESA. They state that the wolverine was nearly extirpated from overharvest (trapping, hunting, poisoning). They have rebounded significantly since all states (except for MT) removed wolverines as a legally harvest furbearer, no longer allowing hunting or trapping of the elusive carnivore. It was only during the 2013-2014 season when the state of Montana decided to end the trapping and hunting season of wolverines indefinitely. While the wolverine population is sustainable at the current levels many scientist and biologist are concerned that it won't stay that way for long. Due to the fragile and narrow ecosystem zone, or climatic envelope, the wolverines occupy and the continual fragmenting of these habitats, the sensitivity of these regions to

climate change the growth of the species population will struggle to continue, most likely it will begin to decline. Furthermore, the southern distribution of the wolverines may become, if not already, an isolated population that could become prone to inbreeding without the genetic diversity that the northern U.S. and Canadian populations provide. It is critical to preserve natural corridors to allow migration (immigration and emigration) of individuals from different subpopulations to maintain the genetic diversity from source populations for conserving the species (Ruggiero, 1994).

The wolverine population and distribution in the conterminous United States is not entirely certain. The wolverine primarily inhabit remote wilderness in montane forests, alpine and tundra cover types. Due to the enigmatic nature of these creatures the research and understanding is not abundant and more understanding is needed specifically on populations in the contiguous United States. The more we know of the movements, driving factors, required resources of their habitat the more effective management decisions will be. It has been documented that the biggest influencing factors on the wolverine population is habitat loss and humans (Hornocker and Hash, 1981). There isn't abundant research that has been conducted on

the wolverine but most of the findings have been documented for wolverine populations in Alaska and Canada with minimal research on the wolverine population in the lower 48. The research that has been done has discovered significant differences from the Alaska/Canadian populations versus the southern populations in the conterminous U.S. These differences include lower pregnancy rates (Anderson and Aune, 2008); lower natal survival rates; differences of home range sizes; mortality rates; and distances traveled daily and seasonally. These findings of variations of subpopulations hold strong evidence that there is an absolute need to identify habitat requirements and preferences of the wolverines in the southern distribution of the species. Due to their ecological niche and naturally fragmented habitat these subpopulations are small and isolated and the exchange of genetic flow between mountain ranges is infrequent making them more susceptible to extirpation (Copeland and Whitman, 2003).

Design/Implementation

Description

This research took place in southwest Montana in the Gallatin National Forest, in the Absaroka-Beartooth mountain range just north of Yellowstone National Park. This study was conducted in the Bear Creek drainage that is northeast of Jardine, Montana more popularly known as the Gardiner Area (See Figure 1).

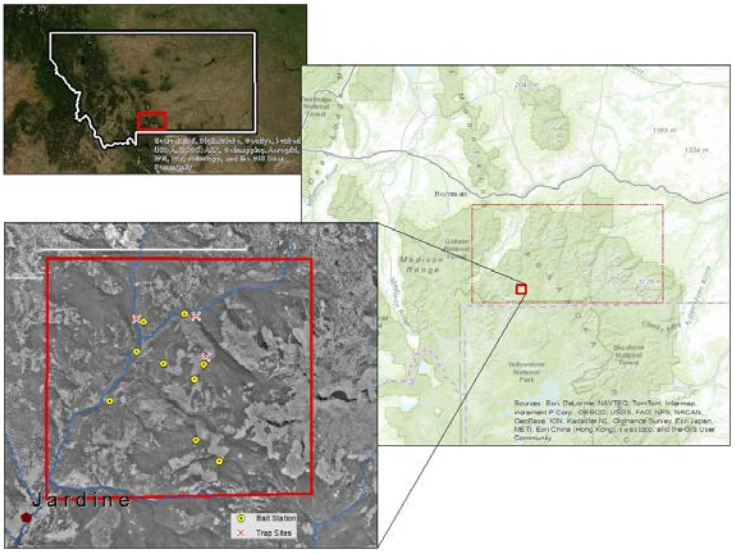

Figure 1: Map of study area in Southwest Montana. Northwest of Jardine, Montana.

The study area was approximately 11.7 km² that is bounded by Bear Creek and Crevice Creek. The elevation of the study area ranged from 2,100 to 2,600m with the highest mountain peaks reaching above 3,100m (> 10,000 ft). The higher elevations of the study area experience a significant snow

pack throughout the year, which is a key habitat preference for the species. While the lower elevations naturally experience considerably less snow pack the study area typically is snow covered from late October until May. According to the USDA in 2003 the average snow pack over the previous 60 years in the month of March on Crevice Mountain (2,560m) was 99 cm.

The study area is predominately coniferous forest. The following breakdown of cover type portions of the study area is based from a map developed by the Interagency Grizzly Bear Study Team (USDA, 1990) for the cumulative effects model (CEM). Higher elevations (above 2,280m) were dominated by lodgepole pine (*Pinus contorta*) covering 62% of the study area. The lower elevations (below 2,280m) the dominant cover type was Douglas Fir (*Pseudotsuga menziesii*) which covered 8% of the study area. This is a cover type map that is commonly used among biologist in the Greater Yellowstone Ecosystem to identify habitat types of the ecosystem. The dominant cover types descriptions of the Bear Creek Drainage, as described by Zimmer (2004) can be observed in the following table.

Table 1: Dominant Cover Types of the study area.

Dominant Cover Types in the Bear Creek Study Area

Cover Type	Percent of Study Area	Description
DF	7.9	Old growth Douglas fir forest. Canopy is broken and the understory consists of some small to large spruce and fir.
SF	15.9	Mature spruce fir forest. Stands dominated by Engelmann spruce and subalpine fir in both overstory and understory.
MF	8.4	Mature mixed forest, late succession to climax stage. Varied structure and age class representation with lodgepole pine, subalpine fir, Engelmann spruce, Douglas fir, and whitebark pine all in the overstory.
LP0	14.8	Lodgepole pine 0-40 years post disturbance. Recently disturbed areas of seedlings and saplings before canopy closure.
LP1	15.6	Lodgepole pine 40-100 years post disturbance. Closed canopy of even-aged, usually dense, lodgepole pine (In my study area, all LP1 had been thinned)
LP2	17.6	Lodgepole pine 100-300 years post disturbance. Closed canopy dominated by lodgepole pine. Understory of small lodgepole pine, whitebark pine, Engelmann spruce and subalpine fir seedlings.
LP3	13.3	Lodgepole pine 300 plus years post disturbance. Broken canopy of mature lodgepole pine, but whitebark pine, spruce and subalpine fir also present. Understory of small to large spruce and fir saplings.
SS	6.4	Sanitation salvages (mature forest partially harvested during 1986). Broken old growth canopy with a dense regenerating understory dominated by lodgepole pine.

In the late 1940's and the mid 1970's the Bear Creek drainage experienced extensive timber harvesting resulting in major areas clear-cuts, which is approximately 30% or 356 ha of the study area. In 1986, approximately 6% of the study area was subjected to sanitation salvage cuts and selective harvest. Selective harvest is a practice that does not destroy the understory or remove all the mature trees but rather removes the dead or dying trees, which is about 6% of the study area (USDA, 2002). After the 1940's clear-cutting, all those stands were thinned 20-30 years later. The thinning of the stands after the 1970's clear-cuts was suspended due to concerns of the negative impacts it would have on wildlife. A harvest was scheduled for 2001 but postponed due to litigation (USDA, 2002).

Besides the timber harvesting that the Forest Service allows in the study area, it also experiences winter recreational activities. This would include snowmobiling, snowshoeing, cross-country skiing, hunting, and firewood harvest. As the population continues to grow in the area and surrounding areas an increase of human recreation from year to year has been observed but not been measured or quantified. The study area consists of three recognized forest service roads that are open to vehicles in summer months and snowmobiles in the winter. There are a few trails and rough two-track

roads, or logging roads (not identified as a forest service road) that are also popularly used for ski and snowshoe trails in the winter.

There are several carnivores that share the study area including grizzly bear (Ursus arctos horribilis), black bear (Ursus americanus) gray wolf (Canis lupis), coyote (Canis latrans), mountain lion (Felis concolor), red fox (Vulpes vulpes), pine marten (Martes americana), and weasel (Mustela sp.) that also utilize this ecosystem. The prey species present in the study area for these carnivores included moose (Alces alces), elk (Cervus elaphus), mule deer (Odocoileus hemionus), porcupine (Erethizon dorsatum), red squirrel (Tamiasciurus hudsonicus), and grouse (Bonasa umbellus and Dendragapus sp.) as well as several various species of small rodents (Zimmer, 2004).

Data/Methods

This research took place during the years of 1999-2009, during the winter months. Since 1999 wolverine tracks have been observed in the Bear Creek drainage. The locations of wolverines were acquired by two different methods: GPS collars worn by individuals and field personnel backtracking wolverine tracks when they were intersected using a GPS device to mark locations. The individuals who were trapped were collared equipped with a

GPS- that records the position of the individual at regular intervals. These GPS collars were store-on-board data, which means that the actual collar must be physically retrieved after it has come off the animal in order for the data to be analyzed. The bait stations served as a means to observe individual visits, by using a trail camera mounted near the bait. This allowed the team to identify individual wolverines in the area with a time stamp. There were 9 bait station sites, and 3 traps sites established. These exact locations were used for every year of the study (See Figure 2).

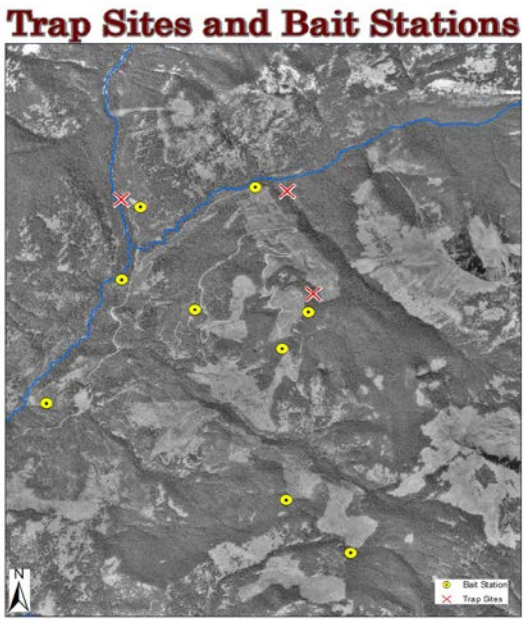

Figure 2: Wolverine bait stations and traps sites

When a wolverine track was observed or crossed, field crews attempted to follow, or back-track, the tracks using a GPS device marking each spot a wolverine track was observed to map the travel routes. The tracks were

followed as long as possible mapping the path and collecting sign and data along the way. These travel paths were studied to identify the to and from path of the sites of interest. The frequency of recorded wolverine visits in the study area was documented. Habitat is analyzed by identifying the amount of each route or degree of use in different cover types and topographical features.

Analysis

The spatial locations of wolverines provide valuable data that can be analyzed to identify patterns and trends of the locations with respect to habitat (See Figure 3 to provide an example of an individual wolverine path). The locations were compiled in a spreadsheet for all the years of the study. It was necessary to clean the data by addressing omissions, inconsistencies, 'dummy' data, and errors or outliers, to prepare the spreadsheet to be imported to ArcGIS for analysis. An event layer was created with the spreadsheet allowing the UTMs documented for each location to be geographically position and displayed. This layer was exported into a

feature class within a personal geodatabase for a smooth and in depth analysis.

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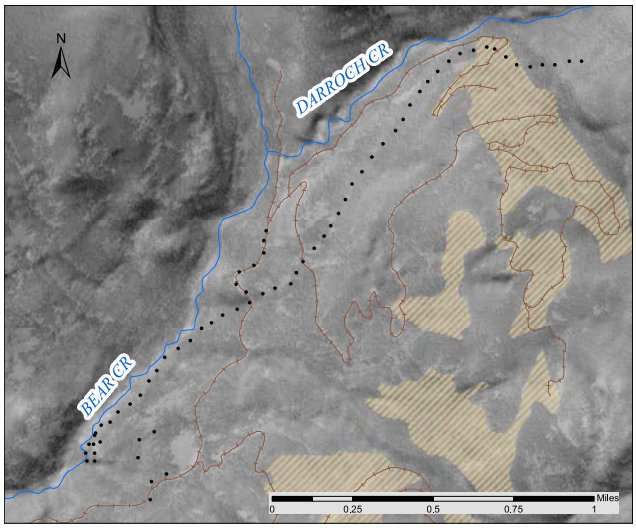

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Figure 3: An Individual Wolverine Path

Imagery of the study area allowed a valuable visual aid for analysis and as a source to create other necessary data layers. The imagery was used to digitize the clear-cut zones of the area as well as the roads. Both of these layers were used to create buffers that play a role in the analysis. The clear-cut boundaries have a buffer of 50 meters on each side. Locations were assigned a category number, value range 1-3. This provided a means to assess whether the wolverines were traveling along the forest/clear cut edge (1), in the forest (2), or in the clear-cut zone of the timber harvest (3). A 25-meter buffer was applied to the roads on each side to be used in the analysis. Additionally, buffers were created at 50, 75, and 100 meters to determine how far most locations are from roads. The buffers created provide data for the analysis to determine if there is a trend in wolverine movements in the study area. Are wolverines avoiding clear-cuts zones and roads to prevent detection and human interaction (See Figure 4)?

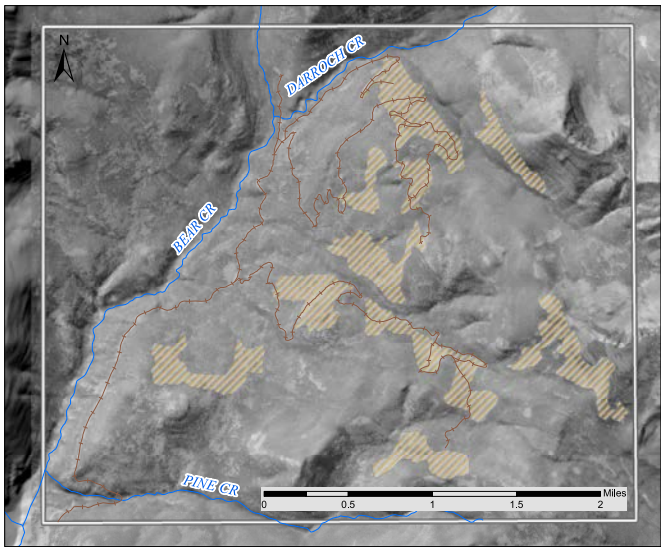

Figure 4: Roads and Clear Cut Zones in Study Area

The national elevation data (NED) was downloaded from the United States Geological Survey website for the study area to be used in analysis. To

prepare the NED for analysis it was necessary to get values of the raster based on slope (degree of rise over run) and the aspect (direction of slope). Additionally, an extract values algorithm was applied to the elevation raster to determine the slope and aspect values at every wolverine location. The output results provided data that was further analyzed with a regression analysis. These values allow us to identify if there is a relationship, the type (positive or negative) and the strength of the relationship with respect to wolverine movements. To determine the percent usage for each the slope and aspect rasters it was necessary to create categories. Aspect was generalized in the following manner:

1. North = 338-22°
2. Northeast = 23-67°
3. East = 68–110°
4. Southeast = 11-157°
5. South = 158-202°
6. Southwest = 203-247°
7. West = 248-292°
8. Northwest = 293-337°

Slope was broken down into 8 categories as well:

1. 0-5°
2. 6-10°
3. 11-15°
4. 16-20°
5. 21-25°
6. 26-30°
7. 31-35°
8. 36-40°

The NED was further manipulated to create a hill-shade layer that provides a valuable visual aid to map and display the other data of the study area.

A regression analysis was applied to the spatial locations of wolverines to identify relationships that may be present with respect to habitat features. As mentioned previously the focal points of this analysis were:

1. Terrain: Do wolverines select topographical features based on slope and aspect while traveling?
2. Clear Cuts: Do timber harvest areas influence wolverine movements?

3. Roads: Do wolverines utilize or avoid roads to travel?

Regression analytics were chosen for this data because this is an effective method to model, understand, predict and/or explain complex phenomena. It identifies variables that may help explain patterns or trends that are present in the data. Modeling the dependent variable, in this case wolverine routes, with explanatory variables provide insight to the relationship of the variables. The Ordinary Least Squares (OLS) regression is a suggested starting point to potentially explain spatial patterns and the influencing factors. It is the best-known regression analysis used by creating a single regression equation that represents the model of the variable or process. However, the model is a global regression equation, which is most likely not the most suitable model, but the results still provide valuable information about the data.

The OLS analysis provides a number of components that should be considered. The values that indicate model performance is reflected in the multiple R-squared and adjusted R-squared. These should range from 0.0 to 1.0. The strength and type of relationship that each explanatory variable has on the dependent variable is reflected in the coefficient. A negative

coefficient indicates a negative relationship and a positive value is positive relationship. In other words, by holding all other variables constant the coefficient reflects the expected change in the dependent variable for every 1 unit of change with the explanatory variable. Redundancies among the explanatory variables are measures with the Variance Inflation Factor (VIF) results. These values should be less than 7.5. Both the Joint F-Statistic and the Joint Wald Statistic assesses of the model significance. These both indicate the overall model significance. The Joint Wald statistic should be consulted if the Koenker statistic is statistically significant. The Koenker statistic is used to assess stationarity within the data. It identifies whether the explanatory variables have a consistent relationship to the dependent variable in both data space and geographic space. When the results of the Koenker test are statistically significant the robust coefficient standard errors and probabilities should be consulted to assess the effectiveness of each explanatory variable. Statistically significant nonstationarity within regression models are suggested to be better fitted with the Geographically Weighted Regression (GWR) analysis. Biased within the model is assessed with the Jarque-Bera statistic. This measure is an indicator whether or not the data has a normal distribution within the residuals. The residual spatial

autocorrelation was assessed by running the spatial statistics Global Moran's I tool on the regression residuals results. Moran's I measures autocorrelation based on attribute values and feature locations using the global statistic. This test was a strong indicator the OLS the global regression was not the best model for this data leading the analysis towards GWR.

The Geographically Weighted Regression is used to model spatially varying relationships by a form of linear regression on a local scale rather than global like OLS. By incorporating the dependent variable (wolverine locations), and the explanatory variable (habitat features) GWR constructs a separate equation for every feature in the dataset. The components of the results with this test are important and should be considered as well. The residual square is a diagnostic measure that is the sum of the squared residuals in the model. The residual is the difference between the observed value and the estimated value. The smaller the measure indicates GWR model is a better fit. Akaike's Information Criterion (AIC/c) is a measure of goodness of fit of the models performance and is helpful for comparing different regression models. The lower the AIC value the better the model is fit to the observed data. Although useful to compare models with different

explanatory variables, this test is not an absolute measure of goodness of fit. It is a good measure to compare to the OLS AICc result to assess the benefits of a local versus global regression analysis. The R-Squared is another measure of goodness of fit for the model. Values range from 0.0 to 1.0; higher values are more ideal and preferred. This value is an indicator of the proportion of dependent variable variance accounted for within the regression model.

The GWR results additionally produces an attribute table that was further analyzed to determine the character of distribution within the residuals. The test ran on the residuals was a spatial autocorrelation (Moran's I) tool. It is important that they are spatially random. If they are not spatially random and have statistically significant clustering of high and/or low residuals is an indicator that the model is misspecified.

Additional output within this feature class includes fields for observed and predicted values, condition number, local R2, predicted, coefficient standard error. The condition number is a diagnostic evaluating local multicollinearity; with a strong local multcollinearity the results are unstable. Condition numbers greater than 30 should most likely be considered

unreliable. The local R2 measurement is a diagnostic of how well the local regression model fits the observed values. Poor performance of the local model is reflected with low values. The estimated (fitted) values computed by GWR are the predicted values in this output feature class. The reliability of each coefficient estimate is reflected with the coefficient standard error value. When the standard error is small in relation to the actual coefficient value the confidence in those estimates is higher.

Results

A summary of the data is wolverine tracks were backtracked on 42 occasions covering approximately 103 km. As of 2009, there were a minimum of 10 individuals identified; 5 males, 4 females, and 1 unknown sex using the study area (See Figure 5). With a total of nearly 3,000 GPS wolverine locations used for analysis.

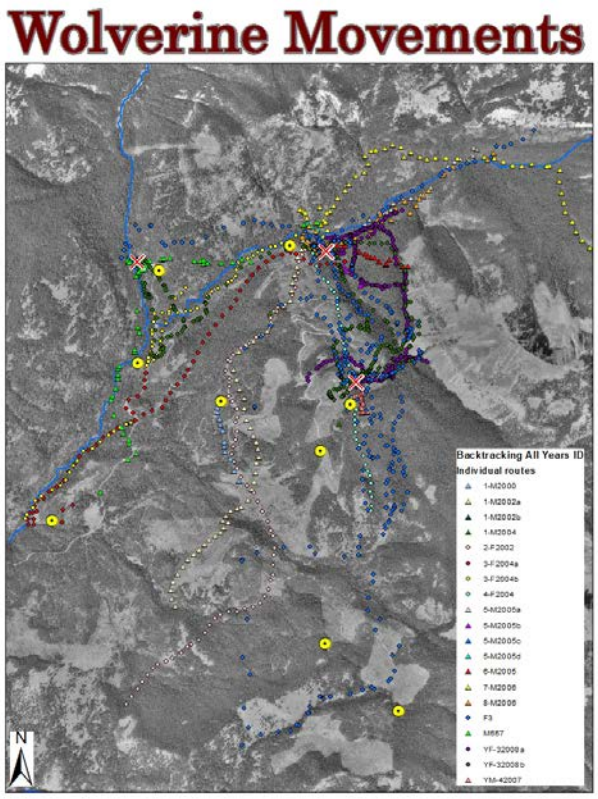

Figure 5: Wolverine Movements in the study area displayed by individual.

Ordinary Least Square

The Multiple R^2 values for the model with all explanatory variables included is 0.0042. The remainder of the results of the OLS regression analysis are reported in this order of explanatory variables; roads, clear-cut edge, slope, aspect. Coefficient values are 329, 169, 27, 0.7. VIF values are 1.009, 1.007, 1.012, 1.004. The following are values that reflect upon the overall model while considering all the explanatory variables in the regression. The AIC values are 57,154. The Joint F statistic is 3.13. The Joint Wald statistic is 8.31. Koenker statistic is 11.66 and the Jarque-Bera statistic is 92125.06.

Geographically Weighted Regression

The following are the results of the GWR for the four explanatory variables:

- Roads: Residual Squares = 2,511

  AIC = 8,060

  R^2 = 0.63

- Clear-Cut Edge: Residual Squares = 23,386,431

AIC = 14,841

R^2 = 0.45

- Slope: Residual Squares = 43,148,634

AIC = 38,005

R^2 = 0.52

- Aspect: Residual Squares = 37,018,444

AIC = 36,852

R^2 = 0.58

The condition number exceeded the suggested value of 30 in a small portion of instances. The only case where the explanatory variable had no condition numbers greater than 30 was with the slope regression results. Those above 30 are not reliable regression analysis values. The R^2 values range from 0.44 for edges and 0.63 for roads with slope having 0.52 and aspect with a 0.58. These should be considered as percentages (44%, 63%, 52%, 58%) and understanding that this explains an approximately percentage of the variation in the dependent variable. The spatial autocorrelation test

indicated that the exploratory variable aspect and slope had a spatially random distribution where as roads and clear-cut edges were significantly clustered implying less reliability.

Summary

This wasn't a model that cannot recognize a relationship among wolverine locations and habitat type based on the model's parameters. There are patterns and trends among the variables though. The following is a summary of the percentage of wolverine locations in each habitat variable analyzed

Comment[SH3]: Rephrase

The following is the breakdown of habitat selection based on the four 'explanatory' variables used in the analysis. Even though the relationship among these variables cannot be defined using this regression model the summary of this analysis does provide some insight. Figures 6-9 is pie charts displaying the percentage of locations in each habitat type used for analysis.

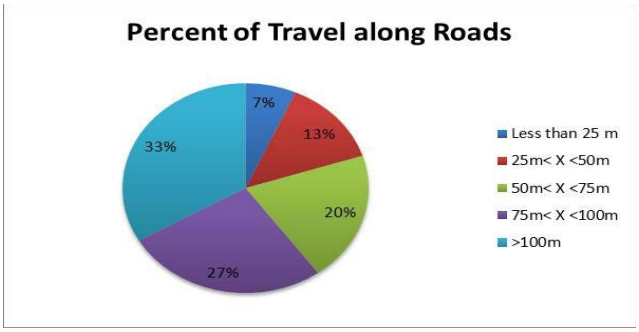

Figure 6: Percent of Travel Along Roads

Figure 6 displays that there is in fact a trend in the data with respect to travel along or near roads. The buffers used were created at 25, 50, 75 and 100 meters. The significant numbers to point out are the predominant portions of wolverine movements are more than 50 meters from the road. Specifically, 33% are more than 100 meters from a road, 27% are less than 100 meters but greater than 75 meters, and 20% are at least 50 meters but less than 75 meters from a road. A total of 20% of the wolverine locations were within 50 meters of a road.

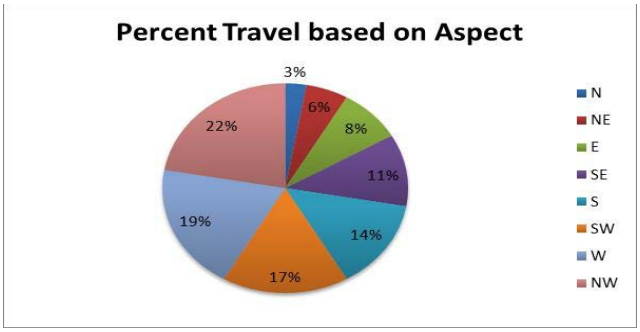

Figure 7: Percent Travel Based on Aspect

There are a higher proportion of wolverine locations on west facing aspects. However, the predominant aspect of the study area is more westerly so this is no surprise. They seem to show a slightly higher selection for southern facing slopes but most of the bait stations and traps sites were on southern facing slopes so this isn't terribly surprising.

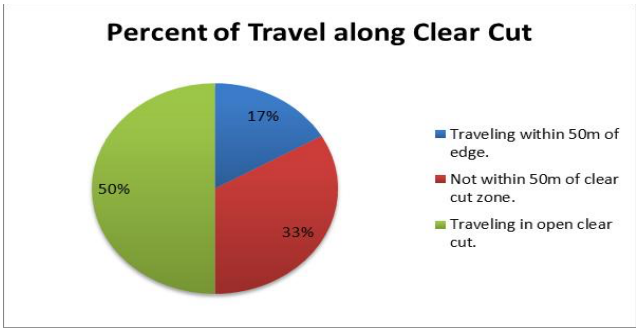

Figure 8: Percent Travel Along Clear Cut

Wolverine locations were located in clear-cut zones 50% of the time, with the least amount of travel along the 50-meter edge at 17%. 33% of the wolverine locations were located in the forest.

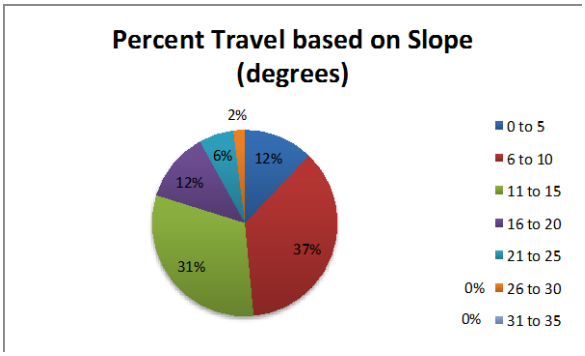

Figure 9: Percent Travel based on Slope

Figure 9 displays that the predominate slopes used in the study area is 6 to 10 ° with 37% of the locations and 11 to 15 ° with 31% of the locations.

Discussion

The OLS values indicate all positive relationships with varying degrees with the strength of the relationship. While there are varying strengths among the relationships between wolverine movements and the explanatory variables, values needed to be considered. The multiple R^2 is one of the first strong indicators that the OLS model is not the most suitable model for this data. As the multiple R^2 measures model performance higher values are desired. The VIF results indicate that there is no redundancy within the data. The high AIC value implies that this model is performing poorly and reliability is a concern. While the Koenker statistic is significant this suggest that there is nonstationarity and/or heteroscedasticity. Models that reflect statistically significant nonstationarity are commonly good candidates for GWR analysis. It is clear for many reasons why the OLS analysis is not a good fit model. This is most likely due to the fact that it is a global model. It is not a good fit because this dataset is not at a global scale.

The AIC results of comparing the GWR model to the Ordinary Least Squares (OLS) model indicates in every application of the analysis that the GWR is a more fitting model for this dataset. The reason for this is most likely due to

the fact that OLS is a global model whereas GWR is a local regression model. With a study area that is slightly smaller that 12 km^2 a local model is more fitting. However, the residual squares results were significantly higher than preferred which indicates that the GWR model is not the best fitting model, maybe not even a good fit. The R^2 values indicate a decent goodness of fit with higher values, closer to 1.0 being preferred as it assesses how well the local regression model fits the observed values.

In conclusion, based from this analysis there does not seem to be significant evidence supporting the hypothesis presented in this report and must be rejected. Wolverines do not seem to show any sort of preference or selection towards roads or clear cuts with respect to movements in this study area. Based on the analysis they do not seem to avoid them and at times utilize them. There is most definitely a trend or pattern with respect topography features and wolverine movement but there doesn't appear to be a relationship based on this model. The research in this study does not indicate that wolverines have any sort of selection, or preference, regarding slope or aspect during movements based on this analysis.

This analysis provides a foundational starting point for further analysis. While the regression analysis presented here is fitting for this application it may not be the best fit. Although the GWR was a more suitable model than the OLS model there is still a need to develop a more improved, complex and fitted model with respect to this dataset. The GWR regression model most definitely provides valuable information regarding the data as well as areas where the model isn't the best fit for the dataset.

The knowledge of wolverine ecology is absolutely crucial for the survival of the species. We must continue our efforts to study and document wolverine behavior, ecology and demographics. As the data becomes more abundant analyses become more reliable and conservation strategies are more effective. While each and every study is important many of the studies only represent a few individuals of the entire population or the analysis is conducted on a smaller local geographic scale. It is vital that we continue our research on various geographic areas as well as increase our sample size and/or study areas if possible in order to present the most substantial and reliable results.

Areas for Further Research

In general there are many more areas for wolverine research that is needed for conservation and management of the species and the ecosystems it inhabits. This research provided an abundance of valuable data, beyond the scope of this analysis that can be further analyzed allowing a significant insight to the ecology of wolverines in the GYE, specifically, a DNA analysis component. Is there a means to retrieve DNA to determine species and/or individual (scat, hair, urine)? What is the success rate of DNA retrieval based from scat, hair, or urine? By utilizing the back tracking data, how difficult was it to retrieve DNA. Or how far did field crews have to travel to collect sign that provides DNA (DNA retrieved/ km traveled)? That information can be compared and assessed to other wolverine studies and other studies that utilized similar methodology. The backtracking data can also aid in a comparative analysis to live-capture with respect to population estimates and demographics. Is there a less-invasive way to get reliable data? Additionally, this data would be a reliable dataset to utilize more applicable statistical models that are more fitted to explain the trends and patterns observed. One example would be to pursue a Resource Selection

Function (RSF) that models predictions of habitat use. Other habitat selections models would also be effective for analysis on this dataset.

Wonderful work. Great use of geostatistical tools to complete your work.

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Your external reviewer makes good points re. scale.

Your summary and discussion and page 42 are exemplary. Rejecting our hypotheses opens the door to further research in new directions that we might not have originally thought of. You do have great foundational work here.

Cheers.

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Appendices

Gantt Chart of Project Plan

	Phase	Task	Start Date	Completed By	# of days
1.)	1a.	Kick-Off	11/15/14	11/15/15	< 1
	1b.	Follow up kick-off	2/10/15	2/10/15	< 1
2.)	2a.	Data Exchange	2/12/15	6/15/15	117
	2b.	Additional Data Needed if necessary	6/15/15	7/15/15	30
3.)	3a.	Preliminary Analysis Begins	6/15/15	7/1/15	15
	3b.	Primary Analysis Initiated	7/1/15	11/1/15	90
	3c.	Additional Analysis?	8/1/15	11/1/15	60
4.)	4a.	Preliminary Research	2/12/15	6/1/15	120
	4b.	Thorough Research Initiated	6/1/15	8/1/15	60
5.)	5a.	Outline of report provided	7/1/15	7/1/15	1
	5b.	First steps of report completed	7/10/15	7/17/15	7
	5c.	Middle Sections of report	7/17/15	8/1/15	13
	5d.	Final sections of report	8/1/15	9/1/15	30
6.)	6a.	Client First Review	9/1/15	10/1/15	30
	6b.	Additional peer review	10/1/15	11/1/15	30
7.)	7a.	Finalization and Corrections	11/1/15	11/20/15	30
	7b.	Submission	11/20/15		

Metadata of Study Area

NAD_1983_UTM_Zone_12N X

WKID: 26912 Authority: EPSG

Projection: Transverse_Mercator

false_easting: 500000.0

false_northing: 0.0

central_meridian: -111.0

scale_factor: 0.9996

latitude_of_origin: 0.0

Linear Unit: Meter (1.0)