PREDICTING POTENTIAL HABITAT AND DISPERSAL CORRIDORS FOR COUGARS IN MIDWESTERN NORTH AMERICA

by

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Since 1990, >130 confirmations (e.g., carcasses and photographs) of cougars (*Puma concolor*) have been recorded in midwestern North America. I created a model of potential cougar habitat in 9 midwestern states using geospatial data, expert-opinion surveys, and a GIS. Based on matrices of pair-wise comparisons involving habitat layers, 11 expert biologists were surveyed to rank habitat factors of importance to potential cougar habitat in the Midwest. I then used a GIS to analyze data and create a map of potential cougar habitat. I further determined potential dispersal corridors for cougars using least-cost path methods. About 8% of the study region contained highly suitable habitat (≥ 75% suitability) for cougars. I identified 6 large, contiguous areas of highly suitable habitat for cougars (≥ 2,500 km^2 in size with ≥75% habitat suitability). The most likely least-cost path started in western Texas and branched to areas of suitable habitat in the Ouachita and Ozark National Forests.

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CHAPTER 1

POTENTIAL HABITAT FOR COUGARS IN MIDWESTERN NORTH AMERICA

INTRODUCTION

Cougars (*Puma concolor*) have historically occupied most of the western hemisphere, ranging from the Atlantic to Pacific Oceans and from northern British Columbia to southern Chile (Sunquist and Sunquist 2002). By the early 1900s, these top predators were extirpated from eastern and midwestern North America because of habitat loss and intentional killing due to concerns about human safety, ungulate populations, and livestock depredation (Sunquist and Sunquist 2002). Distributions were restricted to the rugged topography and remoteness of western North America, where cougars remained a bountied animal until the 1960s (Desimone et al. 2005). Cougars were then reclassified and managed as a big game species in most western states (Desimone et al. 2005, Nadeau 2005, Whittaker 2005). Increased protection, along with growing elk (*Cervus elaphus*) and deer (*Odocoileus spp.*) populations, has since allowed for a rebound in numbers across the West (Nadeau 2005).

Within the past 15 years, cougar confirmations (i.e., carcasses, DNA, photographs, and video) in midwestern North America have increased dramatically (Nielsen et al. 2006). Many carcasses have been of young males, which are the primary dispersers in cougar populations (Sweanor et al. 2000). The Cougar Network, a non-profit organization dedicated to studying cougar-habitat relationships, reports >130 cougar confirmations in the Midwest since 1990; in Nebraska alone there have been 31 cougar confirmations during this period (Cougar Network 2006). Before 1990, evidence for cougar presence in the Midwest was exceedingly rare. Given the increasing number and sex/age composition of cougar confirmations and their long-distance dispersal capability (up to 1,067 km for males, Sweanor et al. 2000, Thompson and Jenks 2005; and 1,328 km for females, Cougar Network 2006), it is possible that cougars may be starting to recolonize the Midwest via dispersal of juveniles. There is a plentiful source of dispersers in the Black Hills, South Dakota, as evidenced by at least 8 radiocollared sub-adult males and one radiocollared sub-adult female dispersing from the area during the last 5 years (D. Thompson, South Dakota State University, personal communication).

Because cougar confirmations have been increasing and because other large carnivores have successfully recolonized the Midwest, eventual inhabitation of the region by cougars seems possible. For example, gray wolves (*Canis lupus*) were extirpated from the Lower and Upper Peninsulas of Michigan by the 1950s (Gehring and Potter 2005) and Wisconsin by 1960 (Thiel 1985, Wydeven et al. 1995). Since 1985, the wolf population in Wisconsin has risen to >250 wolves in 66 packs (Wydeven et al. 2001). The Upper Peninsula of Michigan has also observed a steady increase in wolves since the 1990s, due to natural recolonization of the area through long-distance dispersal from populations in northern Minnesota (Mech et al. 1995, Gehring and Potter 2005). The potential for similar recolonization by cougars and the increasing number of confirmations has made cougars a species of significant concern among wildlife biologists and the public in the Midwest (Bolgiano et al. 2000, Tischendorf 2003, Nielsen et al. 2006).

Large-scale habitat models have been created for many carnivore species using animal location information, remotely sensed data, multivariate statistics, and GIS (Clark et al. 1993, Carroll et al. 1999, Mace et al. 1999, Nielsen and Woolf 2002, Treves et al. 2004). These models are created by statistically evaluating relationships between species occurrences and landscape characteristics (Store and Kangas 2001); such analyses typically rely upon empirical data regarding species occurrence. However, empirical data may not be available, especially in the case of rare species such as cougars in the Midwest. Expert-opinion surveys can be used in lieu of empirical data to obtain information regarding habitat needs (Pearce et al. 2001, Clevenger et al. 2002, Martin et al. 2004). Store and Kangas (2001) describe a technique in which GIS, spatial analysis, and decision analysis techniques are used to develop large-scale habitat models. Expert opinion and multi-criteria analysis, specifically the analytical hierarchy process (AHP; Saaty 1980), transform expert knowledge regarding wildlife habitat needs into numerical form. Applications of geographic information systems are then used to produce cartographic maps by combining the expert-assisted data and spatial analysis of existing landscape information.

Expert-opinion models have been used and evaluated by biologists studying potential habitat of large carnivores. Clevenger et al. (2002) compared empirical data with literature and expert-assistance in the assessment of habitat linkages for black bears (*Ursus americanus*). Literature and expert opinion reflected data gathered by radiotelemetry, displaying the applicability of these methods. In separate studies, Thatcher et al. (2006) and Singleton et al. (2002) used expert-opinion surveys in conjunction with GIS and multivariate statistical techniques to model potential reintroduction sites for the Florida panther (*Puma concolor coryi*) and least-cost paths for large carnivores in Washington, respectively.

Although a few researchers have discussed the recent confirmations of cougars in the Midwest (Tischendorf 2003, Nielsen et al. 2006), no research has been conducted regarding potential habitat suitability for cougars in North America's interior. The goal of my study was to develop a spatially-explicit model of potential habitat for cougars in the Midwest, using expert-opinion surveys, multi-criteria analysis, and a GIS. In a conservation context, I wished to identify midwestern landscapes suitable for cougars. This analysis could promote further investigation and establish awareness to future presence of cougars and potential conflicts between humans and cougars.

STUDY AREA

The study area covered 1,659,710 km^2 of the midwestern United States, including the states of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Arkansas, Missouri, Iowa, and Minnesota (Figure 1). This region was selected because of the increasing numbers of cougar confirmations in the area (Figure 1), its proximity to western cougar populations, the likelihood of potential dispersal corridors, and the scarcity of cougar confirmations east of the Mississippi River (Nielsen et al. 2006). Therefore, I chose a conservative approach by modeling cougar habitat in North America in a region with the highest potential for re-colonization.

The study area was dominated by agriculture and grasslands; approximately half (49%) of the area was used for agricultural purposes and 25% is composed of grasslands (United States Geological Survey 1992). Statewide proportions of agriculture ranged from 36% in Arkansas to 81% in Iowa. Conversely, forest cover only composed 15% of the land cover of the study area; Arkansas contained the largest proportion of forest cover (51%).

Human densities ranged from <1 persons/km^2 in remote areas of North Dakota and South Dakota to >10,500 persons/km^2 in Minneapolis and St. Paul, Minnesota (United States Census Bureau 2000). Road densities ranged from 65 m/km^2 to 189 m/km^2 (Bureau of Transportation Statistics 2000). Stream densities were lowest in South Dakota and Oklahoma (64 m/km^2) and highest in Arkansas (114 m/km^2).

The region was mainly characterized by rolling plains and local changes in elevation were typically minor. However, the Ozark Mountains in southeastern Missouri, northwestern Arkansas, and eastern Oklahoma were characterized by steep topography, reaching elevations of >762 m above sea level (National Oceanic and Atmospheric Administration 2006). The Black Hills in South Dakota were also characterized by rugged terrain, with elevational changes of 914 m. Regional climate was continental and mean annual temperatures ranged from 2º C in Minnesota to 17º C in Oklahoma. Extreme temperatures can reach -57º C in the north to >43º C in the south. Average precipitation ranged from 89 cm of rain and 178 cm of snow in the north to 142 cm of rain in the south.

METHODS

Modeling Approach

My approach to identify potentially suitable habitat was similar to that of Thatcher et al. (2006) and was based on an assessment of biological and anthropogenic influences that could have significant effects on potential habitat for cougars in the Midwest. I emphasized expert knowledge, decision-making techniques, geospatial data, and a GIS to model potential habitat. I created a survey to obtain expert opinion regarding factors potentially affecting cougar habitat. Completed surveys were analyzed using the AHP (Saaty 1980), which is a decision-making technique used to identify the relative importance of specific factors in question. Results from the surveys were then combined with geospatial data in a GIS to create a model of suitable habitat for cougars in the Midwest. Additional detail on my modeling process can be found in LaRue and Nielsen (2006).

Expert-Opinion Surveys

To create a habitat model, which commonly relies upon empirical data from animal space-use studies, it was first necessary to identify specific habitat requirements for cougars (Clark et al. 1993, Clevenger et al. 2002, Nielsen and Woolf 2002). However, because cougar presence in the Midwest is relatively scant and potential habitat in this region has not been identified, acquisition of empirical data regarding habitat needs for cougars was not possible. Therefore, I used an expert-opinion survey to obtain information to rank variables for my habitat model (Store and Kangas 2001, Clevenger et al. 2002). My survey was approved by the Human Subjects Committee at Southern Illinois University Carbondale (protocol #06028).

I created an expert-opinion survey (Appendix A) by first researching cougar literature and soliciting information from cougar biologists. I identified habitat factors and ecological requirements for cougars, which included cover type, distance to roads, distance to water, slope, and human density (Table 1, Appendix B). With the assistance of two cougar experts (H. Shaw, The Juniper Institute; C. Anderson, Wyoming Game and Fish Department), I developed a survey consisting of several questions regarding pair-wise comparisons of the aforementioned habitat factors. The survey asked expert participants to score habitat variables in order of potential importance to cougars in the Midwest, based upon personal experience and knowledge of cougar ecology. The survey was then sent to 29 wildlife biologists who study cougars or furbearer biologists who work for state or federal agencies in the Midwest.

Geospatial Data

I created geospatial datasets to represent midwestern landscapes by downloading 30-m digital elevation model (DEM) data and land cover from http://seamless.usgs.gov (United States Geological Survey 1992). Human density data were obtained from 2000 U.S. Census Bureau (United States Census Bureau 2000) and road information was 2000 TIGER line data from the Bureau of Transportation Statistics (Bureau of Transportation Statistics 2000). All geospatial data were processed in ArcGIS 9.0 (Environmental Systems Research Institute 2004).

Digital elevation model data were mosaiced and clipped for each state in the study area by using extensions in ArcToolbox for ArcGIS 9.0 (Environmental Systems Research Institute 2004). I then resampled the mosaics to 90 m. Slope was calculated as percent rise and I classified slope based on categories in the expert-opinion survey (Table 1). I further used the statewide 90-m DEM data and the Hydrology tool to create stream shapefiles by filling the DEM, calculating flow direction, and calculating flow accumulation. The stream shapefiles were buffered based on distances identified in the expert-opinion survey (Table 1).

The 1992 National Land Cover Dataset contained 21 classes, but similar types were grouped together into 8 different categories: barren/developed and open water, deciduous forest, mixed forest, evergreen forest, grasslands, agricultural, wetlands, and shrublands (Table 1, Appendix B). I then resampled all mosaics to 90 m.

Roads data, which included all major highways and interstates, were clipped by state extensions in ArcToolbox for ArcGIS 9.0 (Environmental Systems Research Institute 2004). A multiple ring buffer was applied to all roads, according to the distances identified in the survey. All layers were then converted to raster and reclassified into categories consistent with the expert survey (Table 1).

Analytical Hierarchy Process

Because not all habitat variables are equally important in the characterization of potential habitat for cougars, I needed to determine the relative importance of each variable by surveying experts in the field. A popular technique for the development of relative weights is a decision-making method called the AHP (Saaty 1980). The AHP is a flexible, structured method that enables individuals to derive a solution to a problem based on past experience (Kovacs et al. 2004). This process utilizes pair-wise comparison matrices, that clarify the relative importance of two criteria involved in determining habitat suitability. Experts then compare every possible pairing and enter ratings, which are based on a continuous scale (Figure 2), into the matrix (Table 2).

Eleven expert-opinion surveys were returned and subsequently analyzed using the AHP. Matrices of pair-wise comparisons were completed and preferences were then summarized to assign each element a relative importance value (Kovacs et al. 2004). This is a two-step process, which first involved normalizing the data, where a_{ij} was the pair-wise rating for attributes i and j:

$$a_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij}, \text{ for all } j = 1,2,\ldots, n.$$

Weights were then calculated as follows, where w is the computed weight of an attribute (e.g., deciduous forest) within variable (e.g., cover type):

$$w_i = \sum_{j=1}^{n} a_{ij}, \text{ for all } i = 1,2,\ldots, n.$$

I carried out the AHP in Microsoft Excel®. All attribute and variable responses were combined and averaged. I then ranked attributes and assigned the averaged weights to variables.

Raster Modeling

The final step in the modeling process was to create a map of potential habitat for cougars in the Midwest. I reclassified all data layers based on the rankings calculated from the AHP and then assigned the averaged weights for the variables with Map Algebra within ArcToolbox in ArcGIS 9.0 (Environmental Systems Research Institute 2004) for each 90-m^2 pixel. Raw scores were transformed to percentages, where 100% indicated the highest suitable habitat. I also wished to define a cut-off percentage for defining the “highest suitable” habitat for cougars. Rather than choosing a completely arbitrary percentage for this purpose, I used the Black Hills region of South Dakota as a guide. Specifically, I determined the average percentage of all pixels within the Black Hills, where an established population of 127-149 cougars already exists (Fecske 2003, Thompson and Jenks 2005). The average habitat percentage in the Black Hills region was 75%, thus, I considered pixels with a suitability score of ≥ 75% as the highest suitable habitat for cougars throughout the Midwest.

Following Thatcher et al. (2006), I determined the largest areas of highly suitable habitat for cougars in the region. A grid was overlaid on the habitat suitability map; the grid cell size of 75 km^2 was based upon the smallest female home range in the Black Hills population (Fecske 2003). I then identified grids that contained ≥ 50% of the area in ≥ 75% suitable habitat and delineated areas of contiguous habitat of this percentage that were ≥ 2,500 km^2 in size. This area is in concordance with Beier (1993), which suggested that cougars need areas of 1,100-2,200 km^2 to persist in the absence of immigration; and Thatcher et al. (2006), who indicated that Florida panthers required areas ≥ 2,590 km^2 for population viability.

Model Validation

I validated the accuracy of my habitat model using 66 cougar confirmation locations from North Dakota (n = 46), Nebraska (n = 12), and Missouri (n = 8) collected during 1990-2006. I chose to not build the model with cougar confirmation locations because of the low number of confirmations relative to the large study area. Cougar confirmations existed as carcasses, verified tracks, or photographs recorded at exact coordinate locations and were obtained from the Cougar Network website (Cougar

Network 2006, Nielsen et al. 2006). I overlaid cougar confirmations onto the habitat model and determined the mean percentage of habitat suitability at the section (259 ha) associated with each confirmation.

RESULTS

Relative Importance of Variables

Land cover was the most important variable for predicting potential habitat for cougars in the Midwest (Table 3). Within the land cover variable, forest cover (i.e., mixed, deciduous, and evergreen) was the most suitable for cougars (Table 4). Developed and cultivated lands were the least suitable cover types, being ≤ 15% as critical as forest cover.

Human density was 66% as important as land cover in determining potential cougar habitat (Table 3). Within this variable, low density (<5 people/km^2) was ranked best for cougars (Table 4). High density of people (>20 people/km^2) was only 11% as significant as low densities.

Distance to paved roads was moderately important to potential cougar habitat in the Midwest, and only about half as critical as land cover (Table 3). Long distances from roads (>5 km) were ranked most crucial, being about twice as important as short distances from roads (<0.3 km) (Table 4).

Slope was of relatively minor importance in predicting potential cougar habitat in the Midwest (Table 3). Within the slope variable, steep (>15%) and moderate slopes (5-15%) were of equal rank (Table 4); gentle slopes (<5%) were considered only about half as significant (Table 4). Distance to water was the least important variable in predicting potential cougar habitat (Table 3). Short distances to water (≤ 1 km) were approximately twice as important as moderate distances (1-5 km) and three times as important as long distances from water (≥ 5 km) (Table 4).

Habitat Model

About 8% of the Midwest contained highly suitable habitat (≥75% suitability) for cougars (Table 5, Figure 3). The states with the largest proportion of suitable habitat were Arkansas (19%), Missouri (16%) and Minnesota (11%); all other states contained <6% suitable habitat (Table 5).

I identified 6 large sites (≥ 2,500 km^2) of contiguous, highly suitable habitat for cougars: Ouachita National Forest, Ozark National Forest, Mark Twain National Forest, Black Hills, Badlands, and northeastern Minnesota (Table 6; Figure 3). The Ouachita National Forest was the largest area of contiguous cougar habitat (15,000 km^2 between two states; Table 6), containing approximately 90% forest cover and low amounts of developed and agricultural land (Table 7). The Mark Twain National Forest was the second largest area of contiguous cougar habitat, with an average human density of 16.0 persons/km^2 and large proportions of forest cover (88%; Table 7). Northeastern Minnesota contained 11,100 km^2 of highly suitable habitat that was low in human density (Tables 6 and 7). Road density and agriculture land use was lowest in this area compared to the other sites (Table 7).

The Ozark National Forest (9,000 km^2; Table 6) contained much forest cover and low percentages of developed areas (Table 7). However, this area of habitat had the highest road density (167 m/km^2) and a moderate human density (Table 7). The 2 smallest sites of contiguous habitat for cougars were in the Badlands and the Black Hills (Table 6). The Badlands contained the lowest human density (0.5 persons/km^2) and the lowest percentage of forest cover compared to the other sites (Table 7). The Black Hills was the smallest area of contiguous habitat (Table 6), containing the highest human density due to the nearby presence of Rapid City (Table 7). This site contained relatively low percentages of agriculture and developed land, and high proportions of forest cover (Table 7).

Model Validation

Average potential habitat suitability in the 66 sections containing cougar confirmations was 68%. The model appeared most accurate in North Dakota; average habitat suitability for sections containing cougar confirmations in that state was 74%. Average habitat suitability was lower for Missouri (61%) and Nebraska sections (56%) with cougar locations, respectively.

DISCUSSION

Amount and Distribution of Habitat

I provide the first large-scale assessment of potential cougar habitat east of their established range in North America. Approximately 8% of the Midwest was considered highly suitable habitat for cougars; however, large, contiguous areas of highly suitable habitat only represented 3% of the region. Smaller areas of suitable habitat occur and are patchily distributed throughout the region. Because these areas are likely not large enough to maintain a viable population (Beier 1993, Thatcher et al. 2006), but are still suitable for cougars, these may serve as suitable dispersal habitat for cougars traveling through the Midwest. Much of this potential dispersal habitat runs along major rivers in the region (e.g., Missouri River, Platte River) and it is well known that cougars use river corridors for travel (Beier 1993, Beier 1995).

My analysis indicated 6 large areas of highly suitable cougar habitat ranging in size from 2,500 km^2 in the Black Hills to 15,000 km^2 in the Ouachita National Forest. Unlike Thatcher et al. (2006), my goal was not to rank these areas for any purpose; this task is more suited for predicting potential reintroduction sites. I also did not account for distances from potential sources of dispersing animals, nor did I indicate probability of recolonization for particular areas in the study region. However, given that there are breeding populations in the 2 smallest identified areas of potentially suitable habitat for cougars (i.e., the Black Hills [Fecske 2003] and North Dakota Badlands [Feckse 2006]), I assume the additional 4 large regions of high habitat suitability delineated in this study may be sufficient to potentially contain a breeding population of cougars. Portions of Missouri, Arkansas, and southeastern Oklahoma appear to be very promising potential cougar habitat because of rugged topography, thick forest cover, and relatively low human densities. Arkansas was the only state of overlap between Thatcher et al. (2006) and my study; both studies found the Ozark National Forest and Ouachita National Forest to be highly suitable for *Puma*.

Habitat Variables

Cougars are well known as habitat generalists throughout their range (Sunquist and Sunquist 2002, Pierce and Bleich 2003), and my challenge was to base the habitat model on variables considered to be potentially important for cougars in the Midwest. I included 5 habitat variables in my model. Their categorizations were based on assistance from 2 expert cougar biologists and scientific literature regarding cougars and other wide-ranging carnivores (Wydeven et al. 2001, Clevenger et al. 2002, Dickson et al. 2005, Thatcher et al. 2006). Of these variables, 3 were of primary importance: land cover, human density, and distance to roads. Land cover was chosen because of the importance of forest and hindrance of agriculture and developed areas to cougars (Sunquist and Sunquist 2002, Pierce and Bleich 2003). Presence of forest cover was specifically critical for cougars because of prey availability and the hunting, stalking, and denning cover that forests provide (Lindzey 1987, Sunquist and Sunquist 2002, Pierce and Bleich 2003). Low human density was favorable because cougars generally prefer areas further from human disturbance (Van Dyke et al. 1986). Long distances from roads were more suitable for cougars, which is also empirically true (Dickson and Beier 2002).

Model Accuracy

My habitat model appeared relatively accurate when validated with an independent set of cougar confirmation locations. Percent suitable habitat of cougar validation locations in the corresponded with the minimum threshold I considered to be highly favorable habitat. The Badlands has recently been confirmed to contain a breeding population of cougars (Fecske 2006), which likely explains the high model accuracy in this area.

The model did not perform as well in Nebraska and Missouri, however, these results do not negate my model. Several cougar confirmations in Nebraska and Missouri were carcasses of juvenile males, which were likely dispersing animals moving between patches of suitable habitat in a mostly unsuitable matrix. This is certainly true in Nebraska, where no large areas of contiguous, highly-suitable habitat existed for cougars.

Potential Limitations to My Approach

I recognize limitations to expert- and GIS-based habitat models and that other abiotic and biotic factors excluded from my survey could contribute to habitat suitability for cougars. First, the geospatial data sources I used could not reveal fine-scale habitat information, such as vegetation structure used by prey or as stalking cover for cougars. Second, there was no existing reliable regional dataset regarding prey abundance (e.g., white-tailed deer [*Odocoileus virginianus*]) or competing predators (e.g., gray wolves) available for use in the model. Although forest cover was a likely surrogate for prey abundance, such that more forest cover results in higher deer abundance (Roseberry and Woolf 1998), I am aware of 1 instance in my study region where this is not the case. Highly forested northeastern Minnesota was identified as containing much suitable cougar habitat; however, competition with wolves and low densities of deer may preclude successful persistence of a cougar population in that area. The wintering deer population in a portion of northeastern Minnesota coincident with the area of suitable habitat for cougars has been decimated for >30 years (Nelson and Mech 2006). Few deer have recolonized the area, likely due to wolf predation and forest maturation (Nelson and Mech 2006). Deer would be the primary prey for cougars in Minnesota, but because prey resources in the area are limited, exploitative and interference competition could occur between cougars and wolves (Kunkel et al. 1999). Therefore, potential inhabitation of northeastern Minnesota by cougars may be affected by wolf presence and lack of primary prey.

Conservation Implications

The primary conservation utility of my model is to predict areas where cougars may ultimately exist in the Midwest if recolonization occurs. The model is useful for understanding the potential proximity of cougars to humans, livestock, and other wildlife populations, thereby providing an educational and planning tool to proactively address human-cougar conflicts. For example, a serious implication of cougar presence in the Midwest is the fear of attacks on humans (Beier 1991, Kadesky et al. 1998, McKee 2003). Although cougar attacks are relatively rare (Beier 1991, Conrad 1992, Rollins and Spencer 1995), knowledge of potential cougar distribution throughout the Midwest could alleviate fears by educating citizens of possible cougar whereabouts in the future. Second, apprehension about potential cougar depredation of livestock (Torres et al. 1996) could be addressed with the assistance of my model. The Midwest is an area of considerable cattle, swine, sheep, and horse production, and agriculturalists in the region are already worried about cougar depredation of livestock. Finally, state and federal wildlife agencies are concerned about potential cougar impacts on deer populations and the potential for cougar conflicts with established carnivores in the Midwest (e.g., gray wolves, coyotes [*Canis latrans*], and bobcats [*Lynx rufus*]). In this respect, my model indicates areas where wildlife agencies should be watching for cougars in the future.

CHAPTER 2

PREDICTING DISPERSAL CORRIDORS FOR COUGARS IN MIDWESTERN NORTH AMERICA

INTRODUCTION

The possibility that cougars could re-colonize previously extirpated areas in midwestern North America is provocative and exciting, as its implications for conservation and management of large carnivores are far-reaching (Tischendorf 2003). While considered extirpated for >100 years, cougars have been reported in the Midwest consistently since 1990, with >130 confirmations (e.g., tracks, photographs, or carcasses) reported by the Cougar Network (2006); one-third of these confirmations are of carcasses of juvenile male cougars killed by vehicles or hunters. Since similar re-colonization events have occurred in other carnivore populations, such as wolves (*Canis lupus*) in Wisconsin and Michigan (Mech et al. 1995, Gehring and Potter 2005), cougar presence in the Midwest is a phenomenon that warrants attention and further investigation.

Given the paucity of research regarding cougar presence in the Midwest, reasons for increasing confirmations are still unknown. Several theories exist as to the reason for this phenomenon, including escaped captive animals or the possibility of small remnant populations in the region. These theories lack supporting evidence, as most necropsied carcasses had eaten wild game and lacked tattoos or tags associated with captivity (Cougar Network 2006). Also, there have been no records of kittens, which would be indicative of remnant populations (Cougar Network 2006). However, one theory remains valid: since most carcass confirmations have been of juvenile males, the most plausible explanation is that juveniles are dispersing from established populations in the west.

Dispersal is a permanent movement away from a natal home range to a place where it reproduces or would have reproduced if it had survived or and found a mate (Howard 1960, Greenwood and Harvey 1982). In cougar populations, dispersal occurs between the ages of 10-33 months (Hemker et al. 1984, Maehr et al. 1991, Lindzey et al. 1994, Logan et al. 1996) and consistent with polygynous mammals, juvenile males are the primary dispersers (Anderson et al. 1992, Sweanor et al. 2000). Cougars are capable of dispersing long distances (Murphy et al. 1999, Logan and Sweanor 2001, Thompson and Jenks 2005); long distance dispersal is important in cougar populations, as recruitment often occurs because of immigration of juveniles from adjacent populations (Beier 1995, Sweanor et al. 2000). Furthermore, dispersal enables cougars to expand their distributional range and can lead to gene flow between populations and re-colonization of unoccupied areas (Beier 1995, Penrod et al. 2006). Vacant habitats may become re-colonized if they are linked geographically to populations that could provide sources of immigrants (Murphy et al. 1999).

Since the 1960s, cougar populations in the west have increased dramatically, primarily because of proper management that has protected the species from indiscriminate killing (Nadeau 2005) and because of increasing ungulate populations throughout cougar range (Berger and Weyhausen 1991). There also appears to be healthy gene flow between several western populations, indicating that western populations are somewhat interconnected (Anderson et al. 2004). Elevated cougar populations in the west may be pushing juvenile dispersers into the Midwest in search of available habitat to establish home ranges, as only a few vacancies may exist within western cougar range. Indeed, genetic studies of populations in Wyoming discovered high migration rates across open and unsuitable habitat, as male dispersal has presumably maintained connectivity between populations (Anderson et al. 2004). Effective cougar population size in Wyoming was estimated to be 500 individuals and actual size of these populations well exceeded the minimum at nearly 4,500 individuals (Anderson et al. 2004). Another study found that the age structure of cougar populations in Wyoming were primarily sub-adults (Anderson and Lindzey 2005), which constitute most of dispersers (Anderson et al. 1992, Sweanor et al. 2000).

Populations on the edge of western distributions exist as potential sources of cougar dispersal into the Midwest. For instance, the Black Hills, South Dakota, contains a cougar population with approximately 150 individuals (Fecske 2003), and sub-adult dispersal has been frequently documented within the past 5 years (D. Thompson, South Dakota State University, personal communication; Cougar Network 2006). One particular male was recorded traveling 1,067 km during dispersal (Thompson and Jenks 2005) and several others have dispersed >400 km (D. Thompson, South Dakota State University, personal communication; Cougar Network 2006). Also, populations in Texas appear to be expanding eastward, as the eastern-most counties within current distributions have recently reported the highest cougar presence of any county in the state (Harveson et al. 2003).

Because there is a distinct possibility that cougar range may expand into the Midwest, an investigation of potential paths of dispersal is warranted. A useful method of determining dispersal corridors is through the development of least-cost paths (Meegan and Maehr 2002, Schad et al. 2002, Larkin et al. 2004, Kautz et al. 2006, Penrod et al. 2006). This technique models the relative cost for an animal to move between 2 areas of suitable habitat (Penrod et al. 2006). Least-cost path (LCP) analysis is based on how the movement path of an animal may be affected by characteristics of the landscape, such as land cover, human density, roads, or slope (Singleton et al. 2002, Penrod et al. 2006). Within a GIS, each cell in a raster dataset is assigned a value between 0 (least costly for movement) and 1 (most costly). The model creates the most likely travel route by selecting a combination of cells that accrue the least resistance with the shortest distance between 2 areas of suitable habitat (Larkin et al. 2004). Least-cost paths contain the most suitable habitat and fewest movement barriers (Larkin et al. 2004), and therefore, the best potential route for a dispersing animal.

Although a few studies have addressed confirmations of cougars in the Midwest (Tischendorf 2003, Nielsen 2006, Nielsen et al. 2006), no research has been conducted regarding potential dispersal from western populations into the region. My goal was to model LCP for cougars in the Midwest, using the habitat suitability model developed in Chapter 1 as the basis for analysis. I identified corridors through the Midwest where the landscape would facilitate long-distance movement of cougars, which would be useful for understanding landscape permeability for cougars in the Midwest and for monitoring purposes.

METHODS

Study Area and Overall Approach

I used the 9-state Midwest study area outlined in Chapter 1 and added Wyoming, Colorado, New Mexico, and Texas because these states contain the eastern-most distribution of cougar populations (Cougar Network 2006). My approach to modeling potential dispersal corridors for cougars was based on LCP methods and a habitat suitability model for cougars (Chapter 1), where biological and anthropological influences were assessed by cougar experts to determine potential impacts on suitable habitat for cougars in the Midwest. The habitat suitability model for cougars represented the base layer for the LCP analysis (Kautz et al. 2006).

Least-Cost Paths

I created geospatial datasets to represent potential dispersal corridors by obtaining data as in Chapter 1; all geospatial data were manipulated in ArcGIS 9.0 (Environmental Systems Research Institute 2004). I first created a habitat model for cougars in the Midwest using expert opinion, geospatial data, and a GIS (Chapter 1) and added the states of Texas, New Mexico, Colorado, and Wyoming; these states contain resident populations of cougars from which dispersal into the Midwest could occur. I mosaiced the habitat models for the Midwest and the additional states. Map Algebra was used to calculate reciprocal pixel values of the habitat model to create a cost raster that associated favorable habitat with lower pixel values, and thus, lower cost of movement through them.

I obtained information from cougar biologists in Texas (J. Young, Texas Parks and Wildlife Department, personal communication), New Mexico (R. Winslow, New Mexico Department of Game and Fish, personal communication), Colorado (K. Logan, Colorado Division of Wildlife, personal communication), and Wyoming (C. Anderson, Wyoming Game and Fish Department, personal communication), to identify the eastern-most counties that contain cougar populations in each state. The Black Hills, South

Dakota, the Badlands, North Dakota, and counties identified by experts served as the eastern edge of cougar range and as source areas for LCP analysis.

Using ArcToolbox and the cost raster, I created cost-weighted distance and direction rasters for the eastern-most counties of cougar range, as these counties served as the "source" for each LCP. The source for each LCP was the polygon from which all movement began. The "destination" was the point or polygon where all paths ended. Thus, the model created a path that began at the source and ended at the defined destination, using the cost-distance and direction rasters as the environment through which to move. I then ran a LCP from the source polygon (i.e., all eastern-most counties in cougar range) to the destination polygon, which consisted of the areas of contiguous ($\geq$2,500 km^2), highly suitable habitat ($\geq$75% suitability) in Minnesota, Missouri, Arkansas, and Oklahoma (Chapter 1).

Using the same source polygons, and cost direction and cost-weighted distance rasters, I further created LCP to locations of 29 cougar confirmations (Cougar Network 2006) in North Dakota (n=9), Nebraska (n=12), and Missouri (n=8). The destinations in this case were exact coordinate locations of cougar confirmations per state; this analysis was meant to simulate the most likely path through which a cougar could have moved from anywhere in western cougar ranges to the point at which the confirmation was recorded. Confirmations consisted of carcasses, photos, tracks verified by a professional wildlife biologist, or DNA evidence (Cougar Network 2006). None of the cougar confirmations used in this analysis were radio-collared animals associated with any on-going cougar research projects (Feckse 2003, Thompson and Jenks 2005).

I wanted to accurately describe the dispersal paths by which cougars could travel and to determine lengths of each path. First, I buffered all LCP by 1 km, which is a sufficient width for cougar movement through a corridor (Noss 1992, Beier 1995). I then extracted all land cover, streams, and road density data within each buffered LCP and determined the amount of forest, grassland, agriculture, and developed land within each buffered LCP. I also calculated the density of streams and roads contained in each buffered LCP.

Assumptions

I made several assumptions regarding LCP modeling. Dispersing cougars respond to the landscape at several scales (Dickson and Beier 2002, Dickson et al. 2005). My major assumption was that dispersing cougars would be less sensitive to microhabitat characteristics (e.g., vegetation structure) and respond to general suitability of macrohabitat for movement purposes (Walker and Craighead 1997). To model large-scale corridor routes, I further made these assumptions:

1) Favorable corridors were composed of primarily suitable habitat for cougars. Dispersal habitat may contain smaller areas of suitable establishment habitat, and may contain areas of completely unsuitable habitat (e.g., developed lands, agricultural fields) throughout the corridor (Beier 1995, Kautz et al. 2006). Although cougars prefer cover (Lindzey 1987, Belden et al. 1988, Laing 1988, Pierce and Bleich 2003), I assumed that a cougar could move relatively short distances without appropriate cover, as studies have found that cougars can travel over unsuitable terrain (Beier 1995, Logan and Sweanor 2001, Anderson et al. 2004, Dickson et al. 2005, Kautz et al. 2006).

2) The LCP provides a greater probability of survival for a cougar while traversing the entire distance. A dispersing cougar may not choose the most optimum path for movement, as animals are likely unaware of their destination and use of a corridor is dependent on whether travel patterns of a cougar cause it to encounter the entrance (Beier 1995). I recognize that these may not be exact paths used by cougars, due to variability in individual behavior (Walker and Craighead 1997). If a cougar did follow the LCP, it would encounter fewer hazards (e.g., roads), spend less time traveling, and habitat through which it traveled would likely optimize food and cover, thus increasing survival (Walker and Craighead 1997, Larkin et al. 2004, Penrod et al. 2006).

3) Human influences on the landscape are permanent and may hinder movement of cougars. First, human development greatly influences cougar presence in an area, as cougars tend to avoid human disturbance (Van Dyke et al. 1986). Roads, in particular, may pose the greatest threat of mortality for a dispersing cougar (Beier 1995, Murphy et al. 1999); indeed, several confirmations of cougars in the Midwest have been road-killed animals (Cougar Network 2006). Also, because cougars are large, elusive predators and people typically do not understand cougar biology (Casey et al. 2005), innate fear by humans may cause the tendency for direct persecution. Therefore, I assumed that optimal dispersal habitat should tend to avoid human development and disturbance, even though cougars may persist near areas of human development (Beier 1995).

RESULTS

Best Least-Cost Path

The best LCP originated in Kimble County, Texas, and branched to areas in the Ouachita National Forest, the Ozarks National Forest, and Mark Twain National Forest (Figure 4). Path length was 1,113 km and average road density was 79 m/km^2 in buffered LCP. Average stream density was 77 m/km^2. Forest cover represented 45% of buffered LCP and grasslands comprised 20%. Agriculture and developed land represented 15% and 21%, respectively, of buffered LCP.

Least-Cost Paths to Cougar Confirmations

I created 29 LCP to confirmed cougar locations in North Dakota, Nebraska, and Missouri (Figure 5). In North Dakota, LCP lengths ranged from 3 km to 479 km and average LCP length was 200 km. All LCP originated in the Badlands (Table 8). Average road density was 36 m/km^2 and average stream density was 143 m/km^2 in buffered LCP. Grasslands and agriculture represented >80% of buffered LCP (45% and 38%, respectively; Table 8).

There were 12 confirmations in Nebraska; 7 LCP originated in Wyoming and 5 paths started in the Black Hills, South Dakota (Figure 5). The average length of LCP beginning in Wyoming was 68 km (Table 8). Grasslands represented 83% of buffered LCP and only 1% of buffered LCP contained developed land. Five LCP originated in the Black Hills and average path length was 384 km. Buffered LCP contained a stream density of 249 m/km^2 and only 7% forest cover (Table 8).

Seven of the 8 LCP to confirmations in Missouri originated in Kimble County, Texas (Figure 5). The average length of these paths was 1,213 km. Road density was 79 m/km^2 and stream density was 78 m/km^2 in buffered LCP (Table 8). On average, buffered LCP were dominated by forest cover; developed land only represented 2% of buffered LCP. The length of 1 LCP beginning in Colorado was 838 km (Figure 5). Stream density was 187 m/km^2 and grasslands were the dominant land cover type in the buffered LCP (Table 8).

DISCUSSION

Least-Cost Paths

My creation of LCP provides the first description of potential dispersal corridors for cougars, should recolonization of the Midwest occur. The best LCP originated in Kimble County, Texas, and terminated in the Ouachita and Ozark Mountains of Oklahoma, Arkansas, and Missouri. Seven LCP to confirmations in Missouri also partially followed the best LCP. These buffered LCP were typically abundant in forest cover, with relatively high stream density and low amounts of agriculture and developed land. These paths originated in an area of Texas where eastern range expansion has already occurred (Harveson et al. 2003) and therefore, could be a realistic source of dispersers into the area. Further, 12 cougar confirmations have been recorded in eastern Texas and 2 have been recorded in Arkansas (Cougar Network 2006), all of which were relatively close to the best LCP.

My results for the best LCP are consistent with empirical studies suggesting that dispersing cougars travel along riparian zones (Beier and Barrett 1993, Dickson et al.

2005), remain near habitat that provides cover (Beier 1995, Dickson et al. 2005, Kautz et al. 2006), and generally avoid human-influenced landscapes (Beier 1995, Murphy et al. 1999). Road density was slightly higher than stream density, but this may be inconsequential as Dickson et al. (2005) noted that paved roads may constrain movement, but do not prevent movement by cougars. Other studies have shown that cougars do not necessarily avoid roads during travel (Sweanor et al. 2000) and may also disperse through corridors containing unsuitable habitat (Anderson et al. 2004) or unnatural features such as golf courses and housing developments (Beier 1995, Dickson and Beier 2002). However, contact with roads and other human influences increases probability of mortality for cougars (Logan et al. 1986, Maehr et al. 1991, Murphy et al. 1999).

The maximum length of the best LCP was 1,113 km, which is similar to the maximum straight-line distance for a juvenile male cougar during dispersal (Thompson and Jenks 2005); a dispersing juvenile female cougar within western distributions has also been recorded traveling >1,300 km (Cougar Network 2006). Furthermore, lesser dispersal distances of <400 km are commonly reported in the literature (Anderson et al. 1992, Beier 1995, Sweanor et al. 2000, Logan and Sweanor 2001). It is likely that cougars could travel similar distances into the Midwest during dispersal.

Buffered LCP to confirmation locations were similar to the best buffered LCP in that these paths also included low road density ($\leq$ 80 m/km^2), low proportions of developed land ($\leq$ 6%), and terminal locations were within recorded dispersal distances of cougars. However, one major difference between the best buffered LCP and buffered LCP to confirmations was that average forest cover was low (2-7%) and percent grass cover was relatively high (45-88%) in paths to cougar confirmations. Others have found that grasslands may play an important role in cougar movement (Dickson et al. 2005), especially areas devoid of forest cover such as the agricultural Midwest. Dickson et al. (2005) found that grasslands were used during movement and stasis, suggesting that grasslands allow cougars to stalk and pursue prey. A study involving an expert survey found cougar presence in mixed and short-grass plains of western Oklahoma, and that prairie and grassland matrices in Minnesota were suitable habitat for cougars based on occurrences (Hutlet 2005, Cougar Network 2006). Furthermore, cougar populations were once widespread throughout the prairie-dominated Midwest prior to extirpation circa 1900 (Sunquist and Sunquist 2002, Pierce and Bleich 2003). Therefore, the resulting high grassland cover within buffered LCP to confirmations of cougars may in fact allow for movement between forest or riparian areas while dispersing.

The disparity in the amount of forest cover between best LCP and LCP to confirmations was notable, as the best buffered LCP contained higher proportions of forest cover than paths to confirmations. This result was not surprising, given that most of the Midwest contains low amounts of forest cover (<15%). Paths to confirmations generally compensated lack of forest cover with high proportions of grassland and high stream density suitable for cougar dispersal. Stream density (i.e., riparian areas) in buffered LCP to confirmations was much higher (up to 249 m/km^2) than the best LCP for the region. These results were consistent with studies documenting cougar use of riparian corridors for movement (Murphy et al. 1999, Dickson and Beier 2002, Dickson et al. 2005). The resulting high stream density also represents the importance of riparian corridors to cougars in a region where forest is not highly available.

Conservation Implications

There is much utility in modeling LCP for cougars because this analysis allows for the identification of potential dispersal corridors, which is important to long-term management and planning for cougar populations in the Midwest (Sweanor et al. 2000). Identification of areas on the landscape that promote dispersal may better equip agencies to monitor cougar presence in the region. In particular, the most cost-effective and widely used method of determining cougar presence and abundance is track surveys (Smallwood and Fitzhugh 1995, Mason et al. 1999, Choate et al. 2006). Camera traps may be another useful method for monitoring cougar presence as these methods have been effective for monitoring other large, elusive felids such as jaguars (*Panther onca*; Wallace et al. 2003, Silver et al. 2004) and tigers (*Panthera tigris*; Karanth 1995, Karanth and Nichols 1998) that typically occur at low densities. Because paths of travel for cougars through the Midwest are not yet known empirically, agencies could use the LCP created in this study as a guide for placement of track surveys or camera traps. Focusing efforts in areas where cougar presence has already been noted (Cougar Network 2006) may also be useful from a management perspective.

Table 1. Habitat variables and attributes within each variable to be considered by experts when developing weights for the model of potential habitat suitability for cougars in midwestern North America.

Cover type	Distance to roads	Distance to water	Human density	Slope
Developed, barren, and open water	Long (>5 km)	Long (>5 km)	High (≥ 20 people/ km^2)	Steep (>15°)
Deciduous forest	Medium (0.3-5 km)	Medium (1-5 km)	Medium-High (11-19 people/ km^2)	Moderate (5-15°)
Evergreen forest	Short (<0.3 km)	Short (<1 km)	Medium-Low (6-10 people/ km^2)	Gentle (<5°)
Mixed forest			Low (<5 people/ km^2)	
Agricultural				
Wetlands				
Shrublands				
Grasslands				

Table 2. Example of a pair-wise comparison matrix for assessing the relative importance of human density classes within the variable "human density", using the analytical hierarchy process (Saaty 1980). Values inside the matrix indicate the relative importance to potential cougar habitat of the row variable compared to variables in the columns.

Human Density				
	Low	Medium-Low	Medium-High	High
Low (<5 people/km^2)	1			
Medium-Low (6-10 people/km^2)	1/3	1		
Medium-High (11-19 people/km^2)	1/5	1/3	1	
High (>20 people/km^2)	1/7	1/5	1/3	1

Table 3. Weights for variables used in development of the model of potential habitat suitability model for cougars in midwestern North America.

Variable	Weights[a]	Standard deviation	Percent importance from land cover
Land cover	1.84	0.59	100
Human density	1.22	0.82	66
Distance to paved roads	0.86	0.45	47
Slope	0.61	0.56	33
Distance to water	0.47	0.26	26

[a]Weights were calculated using the Analytical Hierarchy Process (Saaty 1980) and represent the averaged, relative scores of importance of each variable to potential cougar habitat suitability in midwestern North America.

Table 4. Weights for land cover, distance to paved roads, distance to water, human density, and slope variables used in the development of the model of potential habitat suitability for cougars in midwestern North America.

Variable	Attribute	Weight	Standard deviation	Percent importance from highest ranking variable
Land cover	Mixed Forest	1.92	0.51	100
	Deciduous Forest	1.61	0.37	84
	Evergreen Forest	1.59	0.62	83
	Shrublands	1.12	0.85	58
	Wetlands	0.67	0.29	35
	Grasslands	0.61	0.47	32
	Agricultural	0.28	0.17	15
	Barren/Developed	0.19	0.05	10
Distance to paved roads	Long	1.43	0.71	100
	Medium	0.88	0.34	62
	Short	0.69	0.73	48

Table 4. Continued.

Variable	Attribute	Weight	Standard deviation	Percent importance from highest ranking variable
Distance to water	Short	1.57	0.41	100
	Medium	0.92	0.27	59
	Long	0.52	0.27	33
Human density	Low	2.28	0.39	100
	Medium-Low	1.00	0.18	44
	Medium-High	0.46	0.27	20
	High	0.25	0.07	11
Slope	Steep	1.17	0.54	100
	Moderate	1.17	0.41	100
	Gentle	0.66	0.53	56

Table 5. Percent and total area of highly suitable potential habitat (≥ 75% suitability) for cougars in each state in midwestern North America.

State	Percent (%) of highest suitable habitat	Total area of the state (km^2)
Arkansas	19.0	26,029
Missouri	16.0	28,928
Minnesota	11.0	24,071
North Dakota	5.6	10,267
Oklahoma	5.1	9,243
South Dakota	4.8	9,913
Nebraska	4.3	8,609
Kansas	3.6	7,661
Iowa	2.6	3,787
Entire Midwest region	7.7	128,608

Table 6. Summary statistics for large areas of contiguous, highly suitable potential habitat for cougars in midwestern North America.

Label [a]	Location	Area (km^2) [b]	Percent (%) of state area [b]
A	Badlands, ND	3,825	2.1
B	Northeastern Minnesota, MN	11,100	5.1
C	Black Hills, SD	2,625	1.3
D	Mark Twain National Forest, MO	12,150	6.7
E	Ozark National Forest, AR	9,000	6.6
F	Ouachita National Forest, AR and OK	15,000	5.5 (AR); 4.1 (OK)
	Entire Midwest region	53,700	3.2

[a]Defined in Figure 3.
[b]Amount of area of contiguous (≥ 2,500 km^2), highest suitable (≥75%) habitat for cougars in midwestern North America.

Table 7. Mean values of habitat variables used in the model of potential habitat suitability for cougars in midwestern North America.

Label [a]	Location	Human density (persons/km^2)	Road density (m/km^2)	Forest (%)	Agriculture (%)	Developed (%)
A	Badlands, ND	0.5	37.4	36.0	3.7	0.1
B	Northeastern Minnesota, MN	3.5	20.3	68.9	0.6	0.1
C	Black Hills, SD	21.8	65.2	87.5	2.0	0.2
D	Mark Twain National Forest, MO	16.0	106.0	88.2	9.8	0.1
E	Ozark National Forest, AR	10.7	167.0	88.5	9.9	0.1
F	Ouachita National Forest, AR and OK	9.3	112.0	89.1	7.2	0.1

[a]Defined in Figure 3.

Table 8. Summary statistics for 29 least-cost paths from source area (i.e., eastern-most areas in current western cougar ranges containing known breeding populations) to cougar confirmations in North Dakota, Nebraska, and Missouri.

Source Location[a]	Paths *n*	Path length (km) ±SE (range)	Road density (m/km^2) ±SE	Stream density (m/km^2) ±SE	% Forest ±SE	% Grasslands ±SE	% Agriculture ±SE	% Developed ±SE
A	9	201 ±59 (3- 479 km)	36 ±6	143 ±29	2 ±1	45 ±6	38 ±5	6 ±1
B	5	384 ±55 (267-522 km)	39 ±2	249 ±24	7 ±1	83 ±0.4	7 ±1	2 ±0.2
C	7	68 ±12 (13-108 km)	77 ±49	60 ±24	6 ±4	83 ±3	8 ±2	1 ±0.5
D	1	838	80	187	5	58	29	4
E	7	1,213 ±52 (1,015- 1,455 km)	79 ±1	78 ±2	57 ±1	13 ±0.5	16 ±1	2 ±0.1

[a]Defined in Figure 2.

Figure 1. Study area for modeling potential cougar habitat suitability in midwestern North America. Cougar confirmations in the region from 1990 to the present are shown (Cougar Network 2006, Nielsen et al. 2006). Confirmations within the Black Hills and Badlands are not shown for clarity. Class I confirmations are carcasses, photos, or DNA verified by wildlife professionals. Class II confirmations are tracks verified by wildlife professionals.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT **MORE IMPORTANT**

Figure 2. Nine-point continuous rating scale for pair-wise comparisons of habitat variables in the analytical hierarchy process (Saaty 1980) used to model potential cougar habitat in midwestern North America.

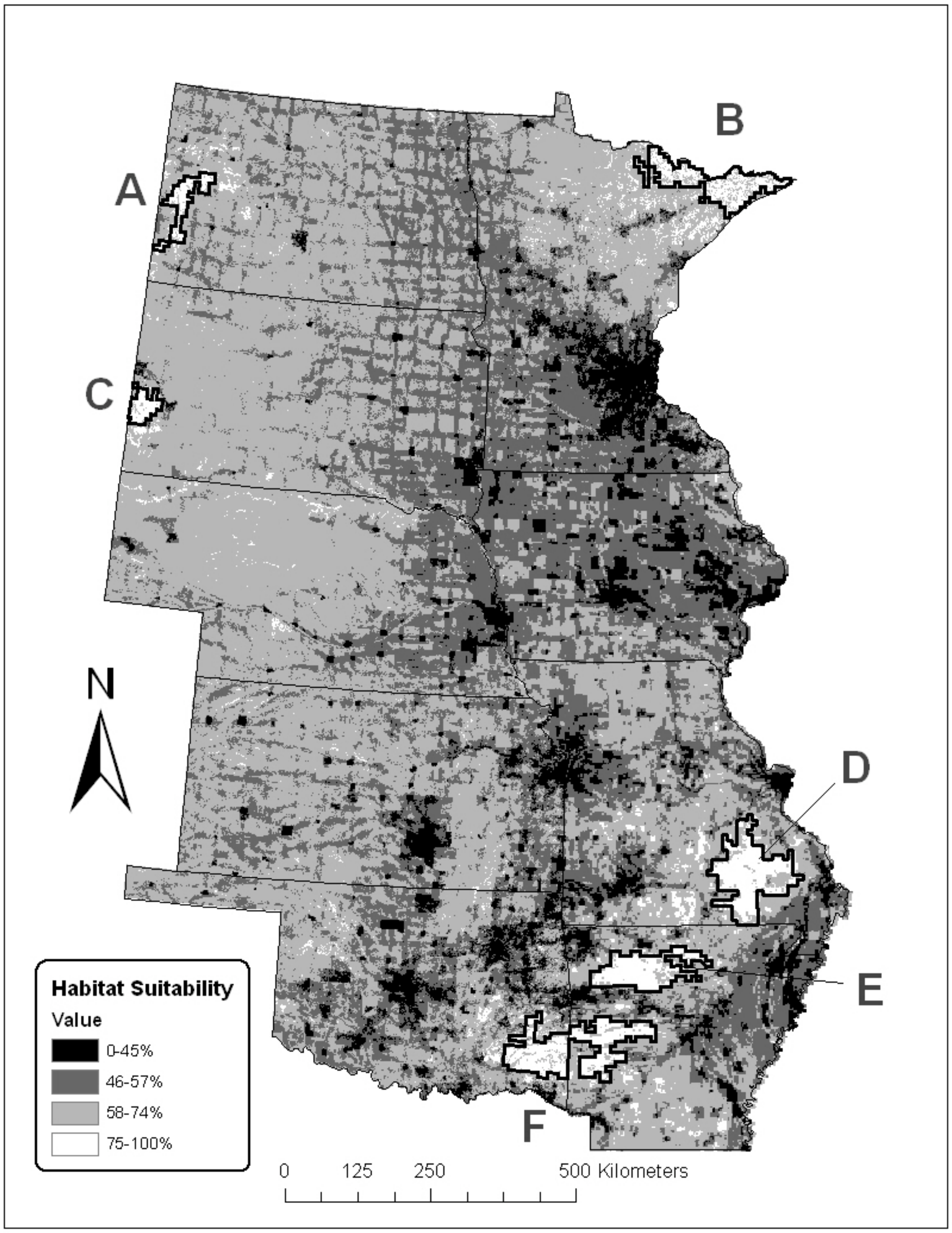

Figure 3. Potentially suitable habitat for cougars in midwestern North America. Six large areas of contiguous, highly suitable habitat were identified: A. North Dakota Badlands region, ND; B. Northeastern Minnesota region, MN; C. Black Hills region, SD; D. Mark Twain National Forest region, MO; E. Ozark National Forest region, AR; F. Ouachita National Forest region, AR and OK.

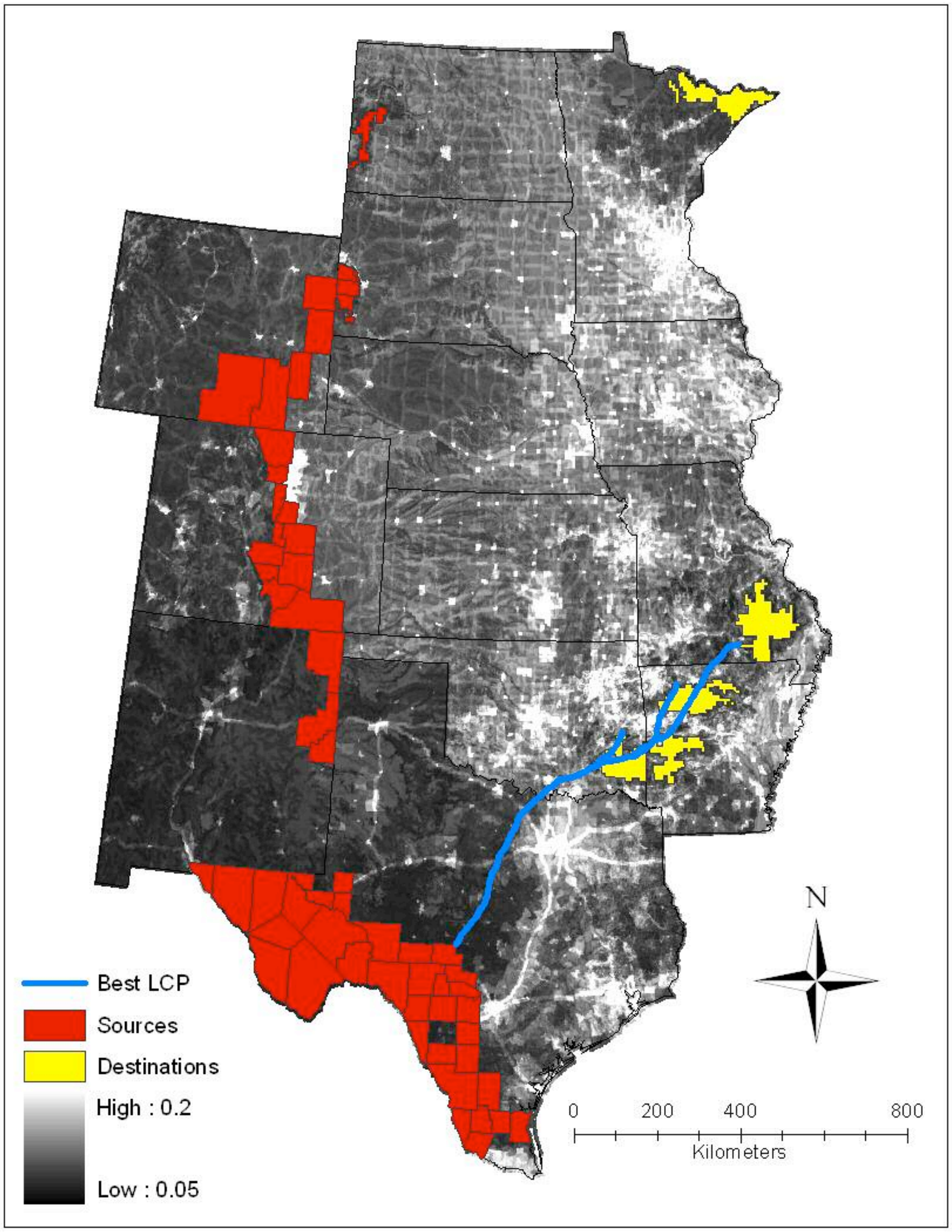

Figure 4. Best least-cost paths from source area (i.e., easternmost areas in current western cougar ranges containing known breeding populations) to areas of suitable habitat in midwestern North America.

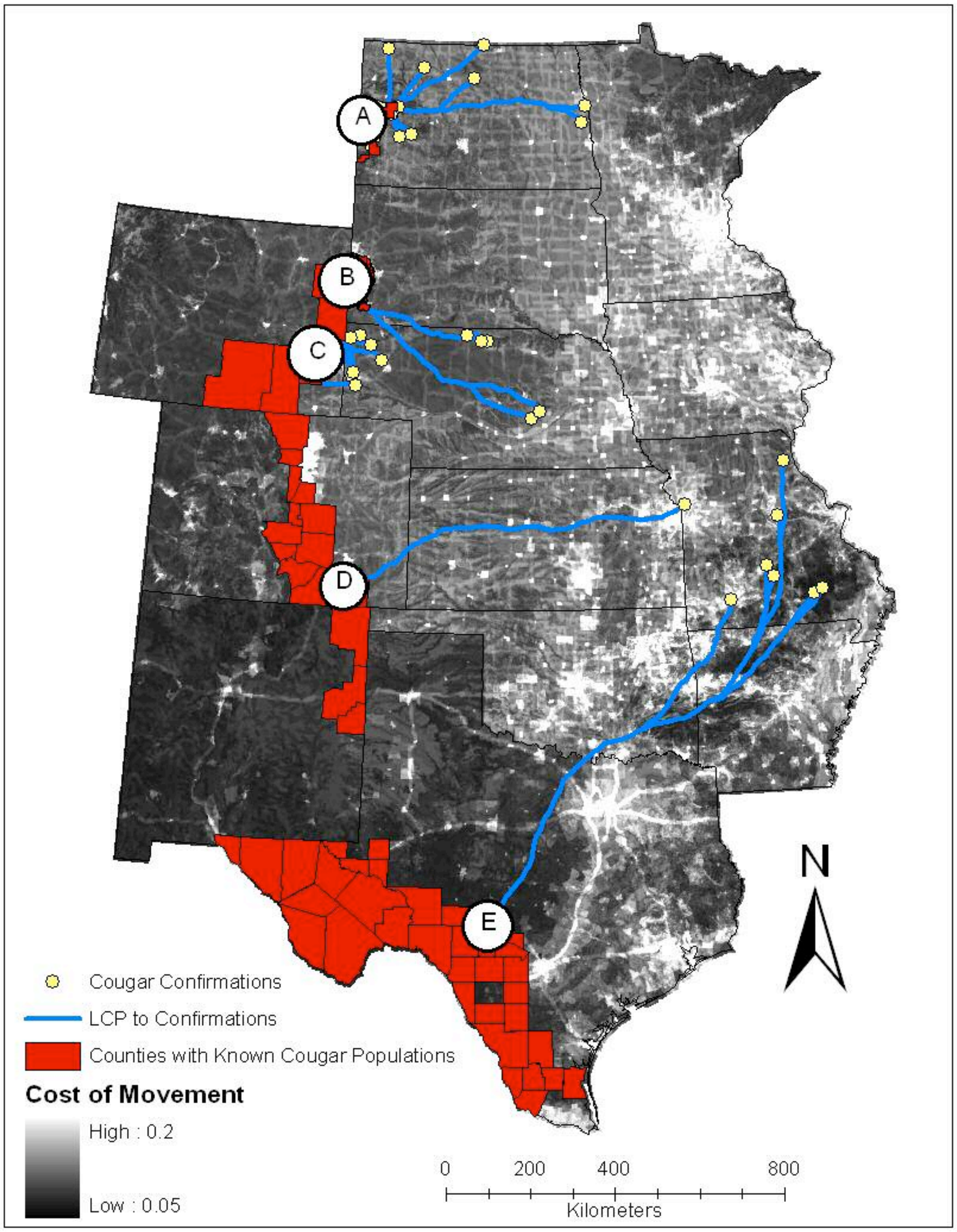

Figure 5. Least-cost paths from source area (i.e., easternmost areas in current western cougar ranges containing known breeding populations) to cougar confirmations in North Dakota, Nebraska, and Missouri. Starting points for least-cost paths were: A. Badlands, ND; B. Black Hills, SD; C. Platte and Niobrara Counties, WY; D. Las Animas County, CO; E. Kimble County, TX. Dates of confirmations range from 1990-2006 and confirmations are exact coordinate locations of cougars.

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APPENDICES

APPENDIX A

Dear Dr. Smith,

During the past decade, cougar confirmations (i.e., verified carcasses, photos, and DNA evidence) have increased dramatically in Midwestern North America. Since cougars have been extirpated from this region for a century, their potential presence in the area is of considerable interest to many wildlife biologists and the public. Hence, it is time to conduct preliminary scientific analyses into the phenomenon to provide wildlife biologists with management information.

I am conducting a graduate research project to predict potential cougar habitat and dispersal corridors in Midwestern North America (i.e., generally the states between the Rockies and the Mississippi River and Manitoba/Saskatchewan). I am working under the advisement of Dr. Clay Nielsen at the Cooperative Wildlife Research Laboratory at Southern Illinois University Carbondale, and in conjunction with the Cougar Network. Because no definitively breeding cougar populations exist in the Midwest outside of the Black Hills, acquisition of empirical data to investigate habitat use is not possible. Thus, I will be using expert opinion to help develop a geographic information system (GIS) model of potential cougar habitat.

I am requesting your participation in this survey because of your expertise in the area of cougar biology and/or Midwestern carnivores. The enclosed survey contains matrices of pair-wise comparisons regarding factors important to potential cougar habitat in the Midwest. Each set of comparisons has an associated set of definitions to refer to while scoring the habitat factors. Land cover data were obtained from the National Land Cover Dataset provided by the United States Geological Survey; all other data were obtained from *www.usgs.gov*. Prey densities (e.g., white-tailed deer) will be assumed to be correlated with land cover, as such datasets are not available for all states.

Participation in this survey is completely voluntary and your individual responses will remain confidential. However, to create a valid and accurate map of potential habitat suitability, it is necessary to have as large a number of responses as possible. Thus, I encourage your participation and thank you in advance for your time. This model will not be used for any political purpose whatsoever; my goal is simply to produce a map of cougar habitat potential using the best science possible.

Please complete and return this survey in the stamped envelope provided by April 15. If you have any questions or concerns, I can be contacted toll-free at 866-401-5673. I can also be e-mailed at *mlarue@siu.edu*. Thanks again for your participation.
Sincerely,

Michelle LaRue
Graduate Research Assistant
Cooperative Wildlife Research Laboratory

Southern Illinois University Carbondale
Carbondale, IL 62901
Phone: 866-401-5673
Email: mlarue@siu.edu

This project has been reviewed and approved by the SIUC Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research Development and Administration, SIUC, Carbondale, IL 62901-4709. Phone (618) 453-4533. E-mail: siuhsc@siu.edu.

Survey: Potential Cougar Habitat in Midwestern North America

Background Information

Recently, the cougar has resurfaced as a topic of discussion among wildlife biologists and the general public due to the possibility of cougar dispersal east of their current geographic range. Confirmed cougar carcasses, scat, and tracks in Midwestern states have increased dramatically in the past decade suggesting eastward movement of at least a limited number of individuals into the human-dominated landscape of the Midwest.

I wish to identify potential habitat for cougars in Midwestern North America, which includes Oklahoma, Arkansas, Missouri, Kansas, Nebraska, Iowa, Minnesota, South Dakota, North Dakota, Wisconsin, the Upper Peninsula of Michigan, and the Canadian provinces of Saskatchewan and Manitoba. To do this, it is necessary to understand the foremost factors determining cougar habitat suitability. Five habitat variables were identified (cover type, distance to roads, distance to water, human density, and slope) and will be ranked in order of importance by experts in cougar ecology. These surveys will be analyzed at the Cooperative Wildlife Research Laboratory at Southern Illinois University Carbondale using multi-criteria evaluation (Saaty 1980) and implemented into a GIS, where a map of potential habitat suitability for cougars in the Midwest will be produced.

Objective

The objective of this survey is to gather expert opinion about cougar habitat in the Midwest by asking wildlife biologists to rank certain factors important to cougar habitat. Experts will be using pair-wise comparisons and analytical hierarchy process (AHP) (Saaty 1980) to make these comparisons.

Model Structure

Table 1 displays all variables to be ranked in order of importance to potential habitat suitability for cougars in the Midwest. Variables will be scored within each habitat factor as well as among each factor (i.e., variables within "cover type" will be scored against each other and "cover type" itself will subsequently be scored against the other 4 factors: distance to roads, distance to water, human density, and slope). Upon reception of all completed surveys, investigators will determine the average weight of each factor, using multi-criteria evaluation (Saaty 1980; Clevenger et al. 2002). These calculated weights will be applied in a GIS to produce a map of potential habitat suitability for cougars in the Midwest.

Table 1. Habitat factors and variables within each factor to be considered for cougar habitat model.

Cover Type	**Distance to Roads**	**Distance to Water**	**Human Density**	**Slope**
Developed/Barren and Open Water	Long	Long	High	Steep
Deciduous Forest	Medium	Medium	Medium-High	Moderate
Evergreen Forest	Short	Short	Medium-Low	Gentle
Mixed Forest			Low	
Planted				
Wetlands				
Shrublands				
Grasslands				

Survey Instructions

On a scale of 1/9 to 9, as a pair-wise comparison of variables, rank the importance of each variable relative to another. You can think of each comparison in terms of two 30m x 30m pixels, comparing the two pixels relative to their importance to cougar habitat in the Midwest.

Scoring Scheme:

1/9	1/7	1/5	1/3	**1**	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	**Equally**	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT **MORE IMPORTANT**

EXAMPLE:

The tables below represent an example scoring scheme using the Saaty (1980) pairwise comparison matrix method (Clevenger 2002). These tables show an example of the progression of filling out a *hypothetical* survey regarding habitat suitability for cougars in the Midwest. Pair-wise comparisons are made by working your way across rows, comparing the importance of the variable in a given row to the variable in the associated column. A variable in comparison to itself receives a score of 1, meaning it is equally important (i.e. "Open" compared relatively to "Open" is equally important).

To begin, the expert starts on the column titled "Deciduous" and compares the importance of a 30 m^2 tract of deciduous cover type relative to a 30 m^2 tract of "Open" cover type, which may be 5 (strongly more important). In other words, "Deciduous" is *strongly more important,* or 5 times as important as "Open".

	Open	Deciduous	Coniferous	Agriculture	Grasslands
Open	1				
Deciduous	**5**	1			
Coniferous			1		
Agriculture				1	
Grasslands					1

The expert next works down to the row titled "Coniferous" and compares this cover type to "Open" (**A**, below), using the continuous scale above.

	Open	Deciduous	Coniferous	Agriculture	Grasslands
Open	1				
Deciduous	5	1			
Coniferous	**A**		1		
Agriculture				1	
Grasslands					1

Moving across the "Coniferous" row, the expert next compares "Coniferous" to "Deciduous" (**B**, below), again using the aforementioned scoring scheme.

	Open	**Deciduous**	Coniferous	Agriculture	Grasslands
Open	1				
Deciduous	5	1			
Coniferous	A	**B**	1		
Agriculture				1	
Grasslands					1

The expert will continue in this fashion until the lower portion of the matrix is complete. An example of a completed survey may look like this:

	Open	Deciduous	Coniferous	Agriculture	Grasslands
Open	1				
Deciduous	5	1			
Coniferous	7	3	1		
Agriculture	3	1/5	1/7	1	
Grasslands	3	1/3	1/5	3	1

The matrix is symmetric, so only the lower half needs to be filled in; the upper half will contain reciprocals of the lower half. *Note that comparisons between two *different* variables may also be given a score of 1 (meaning they are equally important relative to each other).

Now, please begin the survey. Again, if you have any questions or concerns, call toll-free (866-401-5673) or email mlarue@siu.edu.

Expert Survey on Cougar Habitat
Part 1 of 2

Scoring Scheme:

1/9	1/7	1/5	1/3	**1**	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	**Equally**	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT **MORE IMPORTANT**

1. Cover Type- Please score these variables according to relative importance to potential cougar habitat in the Midwest. Use the land cover definitions attached and the scoring scheme identified above. Think of the importance of the cover types to a cougar in a 30 meter block of this habitat. This land cover data will be analyzed using a raster (pixel-based) dataset, with resolution of 30 meters.

	Barren/Developed and Open Water	**Deciduous Forest**	**Evergreen Forest**	**Mixed Forest**	**Cultivated**	**Wetlands**	**Shrublands**	**Grasslands**
Barren/Developed and Open Water	1							
Deciduous Forest		1						
Evergreen Forest			1					
Mixed Forest				1				
Cultivated					1			
Wetlands						1		
Shrublands							1	
Grasslands								1

Scoring Scheme:

1/9	1/7	1/5	1/3	**1**	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	**Equally**	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT **MORE IMPORTANT**

2. Human Density (persons/km^2)- Please score these variables according to relative importance to potential cougar habitat in the Midwest. The divisions were determined from analysis of the source data. Use the scoring scheme identified above.

Definitions:

High: $\geq$ 20 persons/km^2 **Medium-High:** 11-19 persons/km^2

Medium-Low: 6-10 persons/km^2 **Low:** $\leq$ 5 persons/km^2

	High	**Medium-High**	**Medium-Low**	**Low**
High	1			
Medium-High		1		
Medium-Low			1	
Low				1

3. Distance to Paved Roads (km)- Please score these variables according to relative importance to cougar habitat in the Midwest. These divisions were determined from the source data and literature. Use the scoring scheme identified above.

Definitions:

Long: > 5 km **Medium:** 0.3 km- 5 km **Short:** < 0.3 km

	Long	**Medium**	**Short**
Long	1		
Medium		1	
Short			1

Scoring Scheme:

1/9	1/7	1/5	1/3	**1**	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	**Equally**	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT **MORE IMPORTANT**

4. Distance to Water (km)- Please score these variables according to relative importance to potential cougar habitat in the Midwest. The divisions were determined by the investigators. Use the scoring scheme identified above.

Definitions:
Long: > 5 km **Medium:** 1 km-5 km **Short:** < 1 km

	Long	**Medium**	**Short**
Long	1		
Medium		1	
Short			1

5. Slope (in degrees)- Please score these variables according to relative importance to cougar habitat in the Midwest. These divisions were determined by the literature. Use the scoring scheme identified above.

Definitions:
Steep: >15 degrees **Moderate:** 5-15 degrees **Gentle:** 0-5 degrees

	Steep	**Moderate**	**Gentle**
Steep	1		
Moderate		1	
Gentle			1

Expert Survey on Cougar Habitat
Part 2 of 2

Scoring Scheme:

1/9	1/7	1/5	1/3	**1**	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	**Equally**	Moderately	Strongly	Very Strongly	Extremely

LESS IMPORTANT **MORE IMPORTANT**

6. Score Among Variables- Now, please score each habitat factor to the others in relation to its importance to potential cougar habitat in the Midwest, using the same scoring scheme as above.

	Cover Type	**Distance to Roads**	**Distance to Water**	**Human Density**	**Slope**
Cover Type	1				
Distance to Roads		1			
Distance to Water			1		
Human Density				1	
Slope					1

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Land Cover (Cover Type) Class Definitions:

These are the definitions you will use when evaluating differences between cover types. These data were obtained from the United States Geological Survey (USGS) (http://landcover.usgs.gov/classes.asp) and represent reclassifications of land cover provided by the USGS. Data are from 1992 satellite imagery and resolution to be analyzed will be 30 meters.

Barren/Developed and Open Water: Areas characterized by a high percentage (≥ 30%) of constructed materials or areas characterized by bare rock, gravel, sand, with relatively little or no "green" vegetation present. Also, all areas of open water with < 25% vegetation.

Deciduous Forest: Areas dominated by trees where ≥ 75% of trees lose foliage simultaneously in response to seasonal change.

Evergreen Forest: Areas dominated by trees where ≥ 75% of trees retain their leaves all year. Canopy is never without green foliage.

Mixed Forest: Areas dominated by trees where neither deciduous nor evergreen species represent > 75% of the cover present.

Planted: Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber. Herbaceous vegetation accounts for 75-100% of the cover.

Wetlands: Areas where the soil or substrate is periodically saturated with or covered with water. These areas have forest or shrubland vegetation accounting for 25-100% of the cover or have perennial herbaceous vegetation accounting for 75-100% of the cover.

Shrublands: Areas dominated by non-natural vegetation (i.e. areas planted or maintained for production of fruits, nuts or berries) generally < 6 meters tall. Shrubland accounts for 25-100% of the cover.

Grasslands: Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is < 25%, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

APPENDIX B

Land Cover Types

1). Barren/Developed and Open Water: These were reclassified together because they are virtually unusable to cougars as habitat, or for movement corridors.

2). Deciduous Forest: This was not reclassified from its original definition. It was decided that this cover type may be essential to cougar habitat and is different from any other land cover classification.

3). Evergreen Forest: This was not reclassified from its original definition.

4). Mixed Forest: This was not reclassified from its original definition.

5). Planted: This classification includes row crops, small grains, pasture, fallow, and urban grasses. These were all considered to have the same expected effect on cougar habitat suitability and were thus combined.

6). Wetlands: The original 2 classes of wetlands were categorized together under this classification because of their similarity in regards to habitat suitability to cougars.

7). Shrublands: Shrublands and non-natural woody vegetation was included in this category because of similarities in vegetation structure.

8). Grasslands: This was not reclassified from its original definition.

Human Density Classifications (persons/km^2)

1). Low: 0-5 persons/km^2

-This constitutes 310 counties out of 857 in the study area; this is 36% of the counties to be analyzed.

-Covers mostly western ND, SD, NE, KS, and OK

-Also, much of northern MN

2). Low-Medium: 6-10 persons/km^2

-This constitutes 196 out of 857 counties; this is 23% of the counties to be analyzed

-Northern MN, much of IA, southern AR, and southern MO

3). Medium-High: 11-19 persons/km^2

-This constitutes 177 out of 857 counties; this is 21% of the counties to be analyzed

4). High: ≥ 20 persons/km^2

-This constitutes 166 out of 857 counties; this is 19% of the counties to be analyzed

-Includes large cities and their metro areas: Twin Cities, Kansas City, St. Louis, Oklahoma City, Little Rock, Des Moines

Distance to Paved Roads (km)

1). Long: 5 km

2). Medium: 0.3 km-5 km

3). Short: < 0.3 km

-This division was based upon Dickson et al. 2005. It was found that cougar kills were not any closer than 300 meters from a road. I assumed that suitable stalking, hunting, and general movements would be no closer than 300 meters from a paved road.

Distance to Water (km)

1). Long: > 5 km

2). Medium: 1 km- 5 km

3). Short: > 1 km

-This division is based upon an assumption that cougars will likely travel up to 1000 meters to come in contact with water.

Slope (degrees)

1). Steep: > 15 degrees

-These definitions will be based upon the source digital elevation model (DEM) data for the study area from the National Elevation Dataset (http://seamless.usgs.gov).

2). Moderate: 5-15 degrees

3). Gentle: < 5 degrees

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