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Habitat Suitability Analysis for Mountain Lions (*Puma Concolor*) Recolonization/ Reintroduction in Minnesota

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ABSTRACT

The mountain lion range once extended throughout the state of Minnesota. The breeding population has been greatly reduced with time, new roads, and timber harvesting, which have broken large tracts of contiguous forest into isolated patches that are too small and no longer suitable for the breeding mountain lion population. The objective of this study is to use suitability analysis to determine the most suitable habitat to conserve mountain lion populations threatened by habitat fragmentation. To attain our objective, we created three sub models that contribute to the overarching goal of the suitability model. A habitat sub model was developed for finding the best habitat, a food sub model for access to the maximum amount of food needed, and a security sub model focusing on the distance from houses, roads, and urban development. Using the Weighted Sum tool, the three sub models were combined to produce a suitability surface based on the trade-off of the preferences of the goals represented by each sub model. Our suitability model shows large areas of high-quality mountain lion habitat in the northern and north-eastern sections of the state. These areas contain favourable locations for mountain lion habitat, such as forested land cover, low-density populations, steep slopes, short distances to streams, and area unimpeded by major roads. The southern and western parts of the state are characterized by lower slopes, more agricultural land, grassland, developed land, and higher population density, which results in lower quality habitat. The twin cities have the worst mountain lion habitat.

KEYWORDS

Suitability analysis, mountain lion, model builder, food model, security model, habitat model

INTRODUCTION

One of the greatest threats to biodiversity worldwide is habitat destruction (Wilcove et al. 1998), and this problem is inevitable in areas undergoing rapid urbanization that causes habitat fragmentation (Crooks, 2002). These fragmented landscapes affect carnivores thought to be particularly vulnerable to local extinction due to comparatively big ranges, low numbers, and direct persecution by humans (Noss et al. 1996; Woodroffe & Ginsberg, 1998). The extirpation of top predators from fragmented landscapes generates trophic cascades that modify the ecological community structure (Crooks & Soulé, 1999). The ecology of several carnivore species and their responses to ecological disturbances, such as fragmentation, are often poorly understood (Crooks, 2002). Before colonial settlement, the terrestrial range of mountain lions, or cougars (*Puma concolor L.),* extended almost coast to coast, from the Yukon province in Canada to Southern Chile (Young & Goldman, 1946; Anderson, 1983; Culver et al. 2000). However, prey depletion, urbanization, and deforestation led to its extirpation from nearly the complete eastern U.S. by the 20th century (Logan and Sweanor, 2001). Nowadays, they are restricted to Western North America, as their presence in Eastern North America is limited, as it has been for nearly a century (Wright, 1959; Bolgiano, 1995). This is largely due to the region's large amount of undeveloped or protected land. With continued development and urban growth in the Western U.S., there has been an increase in the number of mountain lions culled by management agencies (Cougar Management Guidelines Working Group, 2005).

The effect of land uses on ecological systems differs comparatively on how broadly natural conditions are changed. Large carnivores like mountain lions are sensitive to habitat fragmentation, which can negatively affect the population, such as through inbreeding depression (Riley et al. 2014). Major roads and freeways are near absolute barriers to the movement of mountain lions and can lead to such habitat fragmentation (Riley et al. 2014). Corridors between fragmented habitat can allow general flow between small populations of mountain lions to prevent inbreeding depression. Previous studies have shown mountain lions use river corridors for travel between fragmented habitats (LaRue & Nielsen, 2011). Once a quality habitat has been located, it is important to assess its connectivity to avoid problems such as inbreeding depression. The result of an increasing population consequently leads to the encroachment of the urban landscape to areas devoted to wildlife (Vitousek et al. 1997) by modifying its natural conditions (Marzluff & Wing 2001; Theobald 2004). It is common knowledge that biodiversity disaster is increased by intensifying human land uses (Jenkins, 2003), and the number of diminishing species seems to be growing. Almost 25% of all extant mammalian species are presently endangered with extinction (Schipper et al. 2008; Burdett et al. 2010). To understand how endangered species respond to both natural and human landscape altercations, efficient conservation strategies are vital (Sanderson et al. 2002).

In the Western United States, land use has typically been associated with agriculture, forestry, and mining; however, industrial and residential development in recent decades has been increasing rapidly, particularly affecting natural landscapes with high amenity values due to scenery, wilderness, and wildlife (Hansen et al. 2002; Leu et al.2008; Burdett et al. 2010). The population of the Western U.S. is growing at a rate three times faster than the rest of the country (Baron et al. 2000; Travis, 2007). With this faster rate of population growth, studies have shown that residential development in rural areas is increasing faster than in the urban landscape at a rate of more than 60% (Theobald, 2003), resulting in disturbance of wildlife habitat. With exurban land use growing up to 10 times more than suburban and urban land use, with an increasing rate of 10–15% a year (Theobald, 2005) in the contiguous U.S., species-habitats are affected, creating a need to determine effective mitigation strategies. Much of Midwestern North America has witnessed a rise in the mountain lion sightings as they re-colonize parts of their former range (Cougar Network, 2007; Rosatte, 2011; LaRue et al. 2012), which also increases human-cougar interactions (Torres et al. 1996; Sweanor and Logan 2010; LaRue et al. 2012). The cougar population has been extirpated for >100 years, and only about 170 confirmed cougar sightings were reported during 1990–2008 across the entire Midwestern U.S. Recolonization warrants attention because mountain lions can help change ecosystem functioning upon their return (LaRue et al. 2012; LaRue & Nielsen, 2016). The recolonization of wolves, such as in Yellowstone (Ripple & Beschta, 2004; Fortin et al. 2005; Callan et al. 2013; LaRue & Nielsen, 2016), has greatly impacted competing carnivore populations through competitive exclusion (LaRue & Nielsen, 2016).

The creation of pre-emptive management and preservation plans for mountain lions in rapidly developing regions of the Western U.S., like Minnesota, requires a profound understanding of the relations among mountain lions, their preferred habitat, and variable intensities of human expansion. An ideal location to study the interactions between puma habitat and human land use is the Northeastern region of Minnesota, USA, since this region still contains relatively large areas of protected wild lands. Mountain lions are found in several of the protected areas in Minnesota, but are harshly threatened by habitat loss and fragmentation, disappearing in habitat fragments that become too small or isolated (Beier, 1993; Crooks, 2002; Hunter et al. 2003). Mountain lion habitat suitability would not only benefit their conservation but also improve the wider protection of biodiversity in Minnesota.

The recolonization of mountain lions in Minnesota will help balance white-tailed deer (*Odocoileius virginiana*) populations (Thompson et al. 2009; LaRue & Nielsen, 2016), and those of other species such as peccaries, wild boars, elk, moose, bighorn sheep, beavers, porcupines, rabbits, ground squirrels, mice, and even skunks (Busch, 2004). Mountain lion recolonization in Minnesota will not only keep prey populations in check, helping to prevent overgrazing of rangelands and shrubs in riparian areas (Busch, 2004, Ripple & Beschta, 2006), but will also play a crucial part in preserving the biodiversity and stability of ecosystem dynamics. The recolonization of mountain lions is already taking place in the Midwestern U.S. and research on this has gained a lot of attention (LaRue et al. 2012; O'Neil et al. 2014; LaRue & Nielsen, 2016). However, this effect is limited to the western sections of the regions using the dispersal method and numerous collared animals have come from the Black Hills, South Dakota (Thompson & Jenks, 2010). Extending the recolonization eastward to the Midwestern U.S. and creating a suitable habitat for this carnivore helps resource management efforts for the ecosystem.

Models have been developed within the emerging discipline of land-change science (Turner et al. 2007). Theobald (2005) developed a spatially-explicit model for the U.S., proficiently forecasting past, current, and future housing densities along a rural to exurban to urban gradient. 'Interfacing this model with a species habitat model allows the effects of intermediate-intensity human development and future-development patterns to be evaluated' (Burdett et al. 2010). Habitat suitability modelling using Geographic Information Systems tools has assumed immense significance and is widely used in natural resource management. Results from these models are usually simple and straightforward and can be used for the valuation of conservational impacts in a timely and cost-effective fashion (Kushwaha et al. 2004; Zarri et al. 2008). For meaningful wildlife conservation effort, habitat suitability evaluation is the first stage (Kushwaha, 2002) in finding out the degree of suitability of the area for a particular species. Geospatial technology has been used in numerous studies of biodiversity, landscape fragmentation, population modelling, and habitat suitability assessment (Cumming, 2000; Lenton et al. 2000; Hortal et al. 2001). Geospatial technology offers accurate data and information for determining the environmental quality (Schamberger & Krohn, 1982). The greatest and common application of GIS in conservation is the species-environment relationship modelling. This relation assumes that the distribution of animals is predicted based on the characteristics of its habitat, which also includes measures of human disruption and prey accessibility (Alexander et al. 2006).

The objective of this study is to use suitability analysis to determine the most suitable habitat to conserve mountain lion populations being threatened by habitat fragmentation and to assess the hypotheses about how natural and anthropogenic features affect the habitat use of mountain lions. As restricted carnivores, mountain lions need territories that offer access to prey, which in North America are often deer (*Odocoileus virginianus, O. hemionus*) and elk (*Cervus elaphus*) (Logan & Irwin 1985; Arundel et al. 2007; Knopff et al. 2009; Bacon et al. 2011). This carnivore prefers rugged terrain with some lateral cover, such as forest, shrub, or rocky outcroppings (Logan & Irwin 1985; Arundel et al. 2007) to facilitate predation. Deer are often associated with edge habitats, selecting ecotone edge as the best habitat (Holmes & Laundre´; 2006, Laundre´ & Loxterman, 2007), which is logical (Alverson et al. 1988). Urban development and fragmented landscapes have caused mountain lions to use human infrastructure corridors like gravel roads and trails (Dickson et al. 2005; Kertson et al. 2011). However, mountain lions are not pliant to all intensities or scales of disturbance (Morrison et al. 2014). Urban development fragments their habitat and causes movement barriers (Maehr et al. 2002; Dickson et al. 2005; Arundel et al. 2007; Kertson et al. 2011), which also displaces the carnivore, thereby creating prey refugia that can result in trophic cascades (Ripple & Beschta, 2006, 2008). To attain our objective, we created three sub models to help simplify the problem and make each sub model contribute to the overarching goal of reaching a suitable model. A habitat sub model was developed to find the best habitat, a food sub model for access to the maximum amount of food, and a security sub model focusing on the distance from houses, roads, and urban development. Using the Weighted Sum approach, the three sub models (Habitat, Food, and Security) were combined to produce the final suitability surface based on the trade-off of the preferences of the goals represented by each sub model to establish a high-quality habitat for mountain lions in Northern Minnesota. Apart from its real-world significance, the result of this study would serve as a baseline for future management planning for the conservation of this wildlife species threatened by habitat fragmentation.

1. MATERIAL AND METHOD

1.1. Study area

Our study area is located in the upper Midwest region of the United States. It is covered by a total surface area of 87,014 square miles (225,370 km^2), and is the 12th largest state in the United States (Figure 1). The natural vegetation of Minnesota is made up of prairie grasslands in the southwestern and western parts of the state, the Big Woods deciduous forest of the southeast, and the northern boreal forest (Minnesota department of natural resources). On average, 0.74 meters of rain falls in Minnesota per year, which is below the US average of 0.99 meters. The state gets an average of 1.14 meters of snowfall, almost double the 0.66 meters a U.S. city gets per year. The state only experiences an average of 195 sunny days per year. The average January low is -16^o C and the average July high is around 27.2^o C (Minnesota climate extremes). Most of Minnesota is made up of gently rolling plains formed when glaciers moved over the area. The northern part of the state is the most rugged, while the northeast subdivision has many rocky ridges and deep lakes, with the area north of Lake Superior being the roughest and most isolated. The highest point in the state – Eagle Mountain – is located north of Lake Superior. The state is home to a variety of wilderness, park, and other open spaces. Minnesota has 72 state parks and recreation areas, 58 state forests covering about four million acres (16,000 km²), and several state wildlife sanctuaries (Minnesota Department of Natural Resources). Although the state has acres of land dedicated to public parks and natural areas, development and other land uses still threaten wildlife habitat in several places.

The mountain lion range once extended throughout the state of Minnesota. With the arrival of Europeans and industrialization of the region, mountain lions were essentially driven out of the state. Mountain lions still occur in Minnesota but in very limited numbers. Currently, there is no known presence of a breeding population in the state. While some areas of the state are no longer suitable for a breeding population, such as the twin city metropolitan area, areas in Minnesota with less development and smaller, more dispersed populations of humans may have habitat able to support a breeding population. Recolonization of mountain lions in Minnesota requires the attention of natural resource managers, given the consequences to conservation and management of big predator populations and their prey (LaRue & Nielsen, 2016). An examination of the spatial responses of mountain lions around people and human-developed habitats is important for mitigating human-mountain lion interactions, both in terms of evaluating risks to public safety and livelihoods and of managing the impacts of human activity on cougars (Arundel et al. 2007; Kertson et al. 2011).

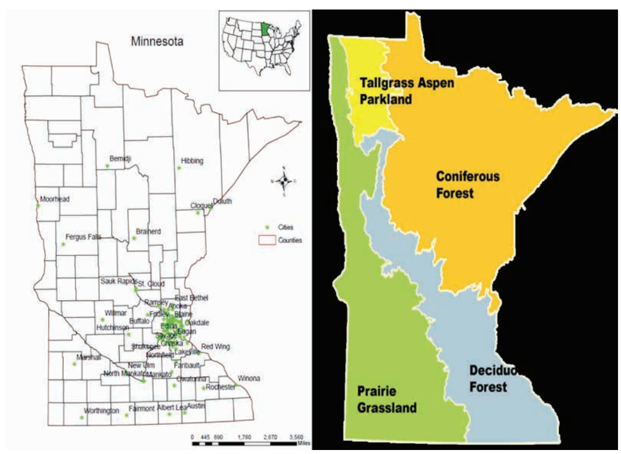

Figure 1: Study area showing cities and natural vegetation cover data adapted from the Minnesota department of Natural resources.

1.2. Data

Several datasets were identified and shown to affect evaluating appropriate habitat for mountain lions (Gilad et al. 2013), like land use (national land cover dataset: https://www.mrlc.gov/finddata.php), national evaluation and slope from 30 m resolution national elevation dataset (NED: https://lta.cr.usgs.gov/NED), roads, highway, and streams data was obtained from the topologically integrated geographic encoding and referencing (TIGER) project of the U.S. Census Bureau (http://www.census.gov/geo/maps-data/data/tiger.html). Building location data was downloaded from Minnesota Geospatial commons (https://gisdata.mn.gov/) and deer density from the Minnesota Department of Natural Resources (http://www.dnr.state.mn.us/mammals/deer/management/statistics.html). Such data is needed because mountain lion suitability requires information on landscape, water disposal, suitable vegetation, food sources, open and unrestricted terrain, and distance from human activities (Singer et al. 2000; Smith, Flinders, & Winn, 1991).

1.3. Habitat Suitability Modelling

The ecological characteristics used in this model are similar to those used in the previous studies modelling the mountain lion habitats (LaRue & Nielsen, 2011; O'Neil et al. 2014). ArcGIS Model Builder was used to create a habitat suitability model based on the ecological characteristics that make up quality mountain lion habitat. We developed three sub models for the habitat selection of mountain lions in Minnesota based on habitat, food, and security. Habitat identifies the most preferred habitat for mountain lions to live within. Food identifies the most likely areas in which mountain lions may find suitable food. Since the mountain lion is an interior species and generally avoids human activity, the security sub model identifies the least human-impacted areas. Each sub model contains criteria relevant to its goal (Figure 2).

The habitat sub model has three criteria: shelter (with forestland being the most preferred), access to water, and terrain features (with steeper slopes being preferred). Here, the natural landscape, vegetation (partitioned into selected, avoided, and all vegetation categories) topography of the human landscape, and protection status is vital. To determine the potential corridors for movement, we located areas with large tracts of surrounding native hardwood forest, as well as areas that mountain lions would be averse to moving through. To do this, we used the land use and land cover layer. Land cover is the most important factor for potential habitat suitability and is reclassified into five classes (Table 1) (LaRue & Nielsen, 2011). First, we grouped the different land use classes into groups based on use, such as managed forestry, residential, institutional, and native hardwood. Digital elevation model (DEM) data was used to generate slope data (Jenness, 2013). The slope was calculated using the slope tool in ArcGIS Model Builder on an elevation raster, and distance from water took the Euclidean distance from water on the study area. The food sub model includes access to the maximum amount of food (with forestland and grassland being preferred, as well as access to prey). Mountain lions primarily prey on large ungulates, such as deer and elk, in their northern (Minnesota) and southern regions (Dennison et al. 2016). Land use and deer density were used as the input for the food security model. Deer reside within several forested lands in the state and travel freely within the surrounding terrain. The native mountain lion population (*Puma concolor*) is a potential predator of deer. The deer population in the study area is monitored by the Minnesota Department of Natural Resources, and catch density was used as one of the variables for the food model. The security sub model focuses on distance from houses, roads, and human development (Figure 2). We calculated distances to roads or highways. All variables were resampled to the North American geographic coordinate system from 1983 with a cell size of 30 * 30 m.

For the mountain lion habitat sub models, land use categories, distance from streams, and slope data was needed to be transformed to a common ratio to represent mountain lion preference. For this sub model, we used the 1–10 scale, where steeper slopes are assigned the highest value of 10. For distance from the stream and land use, the Euclidean distance was used to transform them into the same preference scale. Similarly, with distance to stream transformation, the lowest to the highest values in the study area are transformed to the lowest to highest values in the favourite scale (or vices versa). This has been described as a data dependent transformation. This same process of data transformation was used in all sub models; the habitat, food, and security sub models must identify and place a common scale and criteria before all the three sub models can be combined (O'Neil et al. 2014). After the results from all three models were transformed, a weighted sum approach was used by overlaying all the resulting rasters, then each was multiplied by the determined weight (Table 1). The weights used for the analysis were based on the results obtained using the Analytical Hierarchy Process (Saaty, 1980), which represents the averaged, relative scores of the importance of each variable to potential mountain lion habitat suit-

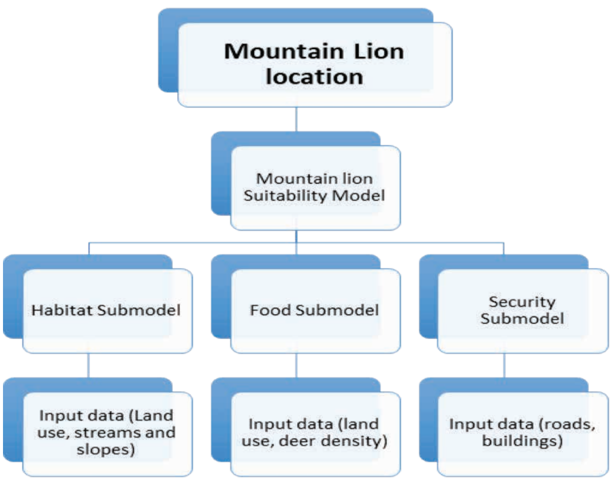

Figure 2: Mountain lion suitability model flow chart

ability in Midwestern North America (LaRue & Nielsen, 2008). This weight estimation approach is a well-thought-out and flexible method that allows people to use past experience to find the solution to a problem (Kovacs et al. 2004) by using pairwise assessment matrices that simplify the significance of the two criteria involved in determining habitat fitness (LaRue & Nielsen, 2008).

Table 2–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 (LaRue, 2007).

This habitat model was the basis for the least-cost path modelling procedures used for predicting dispersal corridors for cougars in the Midwest.

O'Neil et al. (2014), in their study in the upper great lakes region also used weights similar to the ones used by LaRue & Nielsen, (2008). Based on the information presented in Table 2, we combined all weights from the various sub models that included all six of the weighted ecological characteristics from the common scale transformation for a final suitable model for mountain lions (Figure 3). Adding all sub models together, resulting higher values obtained from the weighted sum represented the most suitable locations for habitat for mountain lions based on trade-offs by each sub model where the most suitable locations would be those with the most food and security.

2. RESULTS

Each of our individual sub models were able to identify habitat that could support mountain lions with sufficient food and security. For our habitat model, the DEM was the first data layer, and the most suitable escape terrain was an area of 27–85% slope protected by a 300 m distance from this slope. Areas associated with human activities were considered unsuitable for mountain lions. Conifer-hardwood forest community dominates the northeastern region of the state with spatial vegetation coverage of red pine forest and jack pine forest occurring on dry, fire-prone sites, with white spruce, balsam fir, white cedar, and black spruce. The habitat sub model found an area as described: a forested land with access to water and suitable terrain (ledges and cliffs), making this location an ideal candidate for the habitat sub model's most suitable surface (Figure 3). This was due to large areas of forest mixed with slopes and low densities of humans.

The habitat model was most suitable in the northeastern region of the state, with enough forest land, water, and required landscape for mountain lions to thrive. The food sub model also selected a greater portion of this as being suitable, meeting the suitable prey and access to prey habitat criteria, which from our study was deer density. This location was also less densely populated, which is good because mountain lions have been observed to avoid areas with a human presence (Smith et al. 1991), making the area suitable for the food supply model (Figure 4).

Mountain lions use areas that are farther from both high speed and low speed paved roads, making their home

Table 1: Habitat suitability model variables and weights as per LaRue & Nielsen, (2008) and O'Neil et al. (2014)

Variable	Attribute	Weight (S.E.)	Percent importance from highest ranking variable
Land cover	Mixed forest Deciduous forest Evergreen forest Shrublands Wetlands Grasslands Agricultural Barren/developed	1.92(0.51) 1.61(0.37) 1.59(0.62) 1.12(0.85) 0.67(0.29) 0.61(0.47) 0.28(0.17) 0.19(0.05)	100 84 83 58 35 32 15 10
Distance to paved roads	Long (>5 km) Medium (0.3–5 km) Short (<0.3 km)	1.43(0.71) 0.88(0.34) 0.52(0.27	100 62 48
Distance to water	Short (<1 km) Medium (1–5 km) Long (>5 km)	1.57(0.41) 0.92(0.27) 0.52(0.27)	100 59 33
Human density	Low (<5 persons/km2) Medium-Low (6–10 persons/km2) Medium-High (11–19 persons/km2) High (>20 persons/km2)	2.28(0.39 1.00(0.18) 0.46(0.27) 0.25(0.07)	100 44 20 11
Slope	Steep (>15◦) Moderate (5–15◦) Gentle (<5◦)	1.17(0.54) 1.17(0.41) 0.66(0.53)	100 100 56

range far away from paved roads. Once a home range was established, they avoid using areas close to those roads. Thus, the low urban nature of the north and northeastern parts of the state made it the most suitable area for security (Figure 5). As shown in Figure 5, areas and low-level road networks, as in the northern part of the state, indicated the most suitable levels, while the high-level road network in the southern part of the state, particularly around Minneapolis–St. Paul, had a great influence on suitability levels. With the permanent influence of human activities on the landscape, this hinders the movement of mountain lions as they tend to avoid human disturbance. The results reveal that human disturbances contribute pointedly to habitat suitability; therefore, the relatively high weights assigned to the human factors were realistic. The northern part of the state, with sparse population density, showed a great level of varied suitability distribution on the map in areas with low roads; areas with many roads cause great fragmentation of the landscape for mountain lions.

Variables like habitat conditions, distance to disturbances or other avoided areas, physical barriers, and topography were spatially explicit, and each factor had its own heterogeneity in the study region. As local communities and roads facilitate human activities, they have 'barrier' and 'fragmentation' effects on mountain lion habitat. Although mountain lions have a strong moving ability, the barrier effect of high-level roads is evident. Roads constitute the utmost risk for mountain lion disappearance, as several mountain lion deaths related to road-kill has been reported by the 2006 Cougar Network. The best location for the security model is in the northern and

Table 2: Weights for variables used in the development of the model for potential habitat suitability for mountain lions in Minnesota

Factor	Weight
Land cover	1.84
Slope	0.61
Distance to water	0.47
Distance to Building	1.22
Distance to road	0.86

Adopted Weights from LaRue & Nielsen, 2008 based on the Analytical hierarchy process (Saaty, 1980)

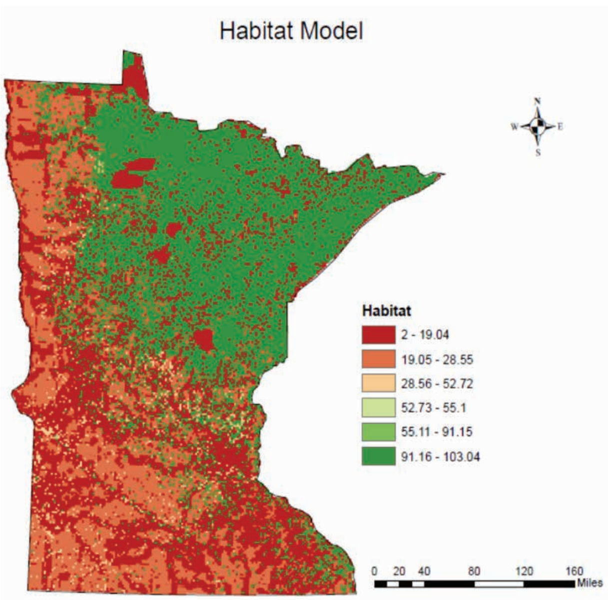

Figure 3: Areas of highly suitable potential mountain lion habitat in Minnesota. The areas selected as the best habitat considered the vegetation type, access to rivers, and suitable topography or slope.

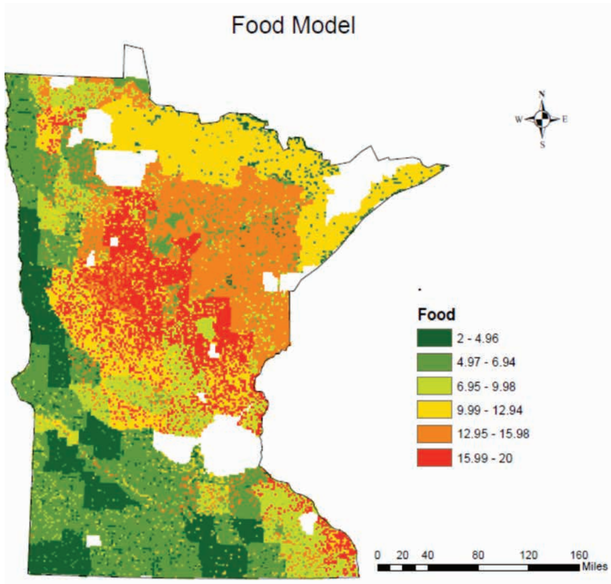

Figure 4: Food Sub Model. The locations selected were based on the availability of prey; in our case, deer catch density was used as a measure of the prey for mountain lions in Minnesota.

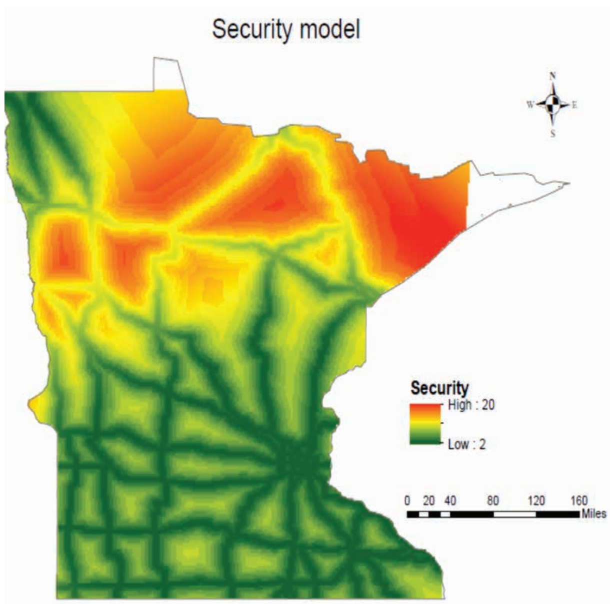

Figure 5: Security sub model. The best location is selected based on the urban development attributes.

northeastern parts of the state, with less urban development and transportation networks (Figure 5).

The combined weights of all three models produced the final suitable model, which could be identified as a safe ground for mountain lions. Using suitability modelling, three areas in northern Minnesota were located with large amounts of high-quality habitat that could potentially support a breeding population of mountain lions (Figure 6). Suitable habitat parcels for the final model were also compared to the historically protected parts of the state (Figure 7), identified as safe ground for mountain lions. These areas contained the favourable ecological characteristics of mountain lion habitat, such as forested land cover, low density human populations, steep slopes, short distances to streams, and area unimpeded by major roads.

3. DISCUSSION

Habitat fragmentation by road construction is one vital factor disturbing biodiversity determination (Gray et al. 2016; Liu et al. 2017). Road construction has a great effect on animal movement and is of great concern to wildlife biologists (ˇCervinka et al. 2013; Switalski & Nelson, 2011). Switalski & Nelson (2011) indicated in their study that road removal could be a strategy for restoring black bear (*Ursus americanus*) frequency and habitat, and the level of landscape permeability for pumas (*Puma concolor*) could be measured by distance to roads and housing density (Gray et al. 2016; Liu et al. 2017). As a matter of fact, the behaviour of animals has also proven to vary with different degrees of human trails, reflected by roads and other disturbed areas (Stewart et al. 2016). The effects of road construction undermines the decrease of habitat quality. This study showed that the suitability distribution is uneven and highly fragmented, as shown in Figure 6. High levels of road construction, especially in the southern part of the state, associated with high levels of urbanization, can result in significant harm to habitat suitability and connectivity. Roads and highway planning have commonly reflected a one-dimensional, linear zone along the highway. Therefore, design dimensions have been the main concern of planners. But the ecological effects of roads are many times wider than the road itself and can be vast and persistent (Forman & Alexander 1998; Trombulak & Frissell, 2000). Because of the broad landscape context of road structures, it is vital to include landscape designs and processes into planning and building processes (Forman, 1987).

The southern and western parts of the state are characterized by lower slopes, more agricultural land, grassland, developed land, and higher population density, which results in lower quality habitat, with the twin cities having the worst mountain lion habitat. The harassment of mountain lions in the Midwest, exploitation of their prey, and habitat loss across their historic range have relegated this species to habitats in the western states and southern Florida (Anderson, 1983). The vegetation and features of these regions provide habitat for prey and cover for cub rearing, hunting, and stalking prey (Logan & Irwin 1985; Laing, 1988; Koehler & Hornocker 1991; Beier et al. 1995; Williams et al. 1995). In Minnesota, an understanding of the mountain lion distribution and habitat selection is pertinent to managing the impact of hunting and trapping of mountain lions (Torres et al. 1996), cougar attacks on humans (Beier, 1991), and habitat fragmentation (Beier, 1993). Results from this study showed that it is very important to include different human factors into region-wide habitat management, so as to avoid incorrect estimations of suitable habitat. Minimal human interaction has a considerable impact on suitability levels. Mountain lion reintroduction sites could be found farther away from roads and buildings, given that the sub-reserves are currently separated by just a few miles from one another. Po-

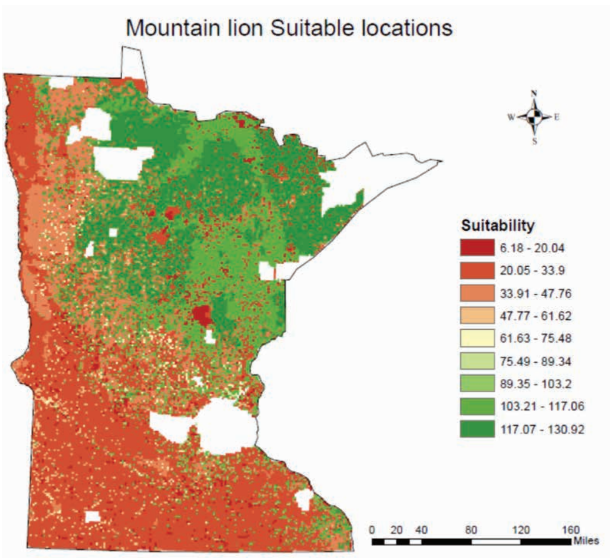

Figure 6: Potential cougar recolonization sites

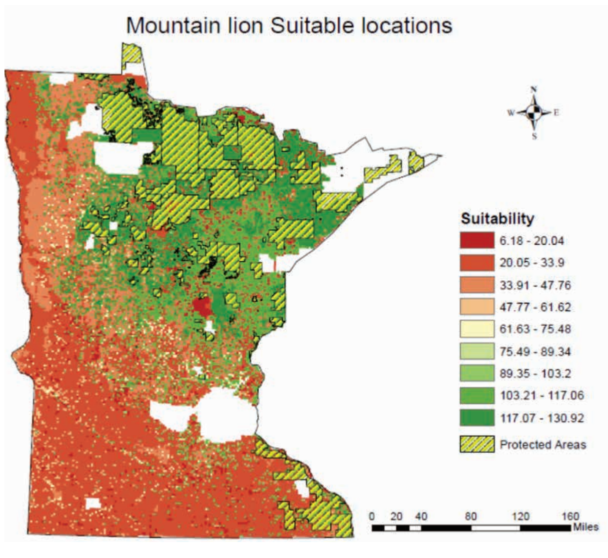

Figure 7: Suitable landscapes and protected areas

tential corridors linking the separated sub-reserves are urgently needed to protect the mountain lions and local biodiversity levels.

4. CONCLUSION

We produced spatially-explicit maps of mountain lion habitat to examine the implications of including exurban development in a mountain lion habitat model and evaluated the future distribution and introduction of mountain lions in Minnesota. First, we estimated the effect of incorporating the response of mountain lions to forest land by looking at how land-use changes, access to water, and suitable terrain affect the distribution of mountain lion habitat in Minnesota. Second, we estimated food availability using deer density and suitable habitat availability. Third, using housing density and distance to roads, we estimated how continuing development would affect the future distribution of suitable mountain lion habitat in Minnesota. Finally, we combined all weighted models into a suitability model for mountain lions in the state of Minnesota. Our suitability model shows large areas of high-quality mountain lion habitat in the northeastern region of the state. These areas contain the favourable locations of mountain lion habitat, such as forested land cover, low-density populations, steep slopes, short distances to streams, and area unimpeded by major roads. Human development and road construction will remain of major ecological importance, functioning as channel, habitat, basis, and sink; yet there is growing universal concern in viable transport systems (Clevenger et al. 2002). Transportation networks and mitigation passages will certainly play a critical part in safeguarding landscape patterns and processes so they can be conserved, reinstated, and even improved (Forman, 1998). Mitigation preparation will deliver an outstanding occasion to incorporate ecological processes and flows into the larger fabric of human land use. Our study took advantage of the suitability method to design potential sites for the movement and reintroduction of mountain lions between detached nature reserves based on seven influencing factors (land use, streams, slope, deer density, roads, and building locations). Potential sites were located between different nature reserves, which have also been greatly fragmented by human activities. The most suitable sites identified here are just a stepping stone for mountain lion reintroduction in Minnesota, as large road construction and its effects on landscapes will continue to impede mountain lion movement within the identified sites. Therefore, building mitigation measures at the suitable sites will make management strategies feasible. Unlike previous studies that considered the entire Midwest, our study modelled the locations where the mountain lions could be recolonized in Minnesota. This study provides detailed statewide information from which local, state, and federal agencies can pool information before making decisions, as the growing population of mountain lion prey may pose as an ecosystem biodiversity imbalance challenge in the region.

To mitigate fragmentation as a result of anthropogenic effects, linkages between the different fragmented habitats (Beier & Noss, 1998; Haddad et al. 2003) can solve biodiversity issues. This situation creates environments where wildlife can move free and unhindered (Keeley et al. 2016), and the least cost analysis can be modelled to attain this objective (Noss & Daly, 2006). When the potential linkages are not constrained by urban development, this approach becomes very important. However, many linkage policies are void of the transparency needed for a modelling approach (Keeley et al. 2016). Further work on potential reintroduction sites needs to be conducted. Monitoring procedures should be carried out to improve the information of new sites and to determine when and how location enables the species to move through the landscape. Also, in the management procedure, current mountain lion habitat projects should be evaluated. Upgraded living conditions offering the best suitable location should guarantee long-lasting solutions to the new mountain lion introduction sites as a means of passage of mountain lions and other wildlife. Finally, greater cooperation among the various stakeholders is needed on the issues related to mountain lion conservation and reintroduction in Minnesota.

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