Risk Analysis of the Timber Rattlesnake (*Crotalus horridus*) in Great River Bluffs State Park, Minnesota

Matt Randerson
Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987

Keywords: Rattlesnake, *Crotalus horridus*, GIS, Habitat Suitability, Visitor Use, Risk Analysis

Abstract

The timber rattlesnake (*Crotalus horridus*) is a threatened species in the state of Minnesota. In order to protect this species, it is important to know where they live. Geographic information systems (GIS) can be a useful tool in helping us understand the habitat of these animals. Negative encounters with humans may cause stress to timber rattlesnakes, potentially altering their behavior and habitat. While it is important to preserve the habitat of this species, it is also important to keep the public safe. The timber rattlesnake is a venomous snake and while a bite from this snake is not typically fatal, it is often severe enough to require hospitalization. This study attempts to determine the areas that are at greatest risk for rattlesnake encounters using Great River Bluffs State Park, Minnesota as a study area. To accomplish this, a habitat suitability map for timber rattlesnakes and a visitor use map showing where humans are most likely to be present were created and overlaid with one another. Areas were then given a risk rating based on habitat suitability and the likelihood of human presence to determine which areas possess the greatest risk of rattlesnake encounters.

Introduction

While timber rattlesnake (*Crotalus horridus*) encounters are typically not a common occurrence in Minnesota, they have been seen by people in public places, such as state parks. These snakes are threatened in the State of Minnesota and are in need of protection in order to thrive as a species. They may also pose a threat to park visitors due to their venomous bite. To ensure the safety of both timber rattlesnakes and park visitors, it may be beneficial for park managers to create risk assessment maps to determine the areas most likely for rattlesnake encounters to occur. This study attempts to identify areas that are at the greatest risk for rattlesnake encounters using Great River Bluffs State Park in Minnesota as a study area.

Species Profile

Physical Description

Timber rattlesnakes are venomous snakes with keeled scales (Minnesota Department of Natural Resources [MNDNR], 2009). They generally range from 80 to 122 cm (31.5 to 48 in) in length (excluding the rattle). They have a wide, triangular-shaped head with vertically elliptical pupils. The dorsal coloration varies and may be yellow, tan, brown, reddish brown, or occasionally gray. Dark brown or black chevron-shaped bands run along the dorsal surface of the snake. The ventral coloration of the snake is yellowish tan or light grey (MNDNR, 2009). The behavior of the snake can be described as shy or docile (MNDNR, 2009; Rubio and Keyler, 2013).

Randerson, Matt. 2016. Risk Analysis of the Timber Rattlesnake (*Crotalus Horridus*) in Great River Bluffs State Park, Minnesota. Volume 19, Papers in Resource Analysis. 13 pp. Saint Mary's University of Minnesota Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu

Historical Range

Timber rattlesnakes were historically present in eight Minnesota counties. Figure 1 shows the current, historical, and peripheral range of the timber rattlesnake (MNDNR, 2009).

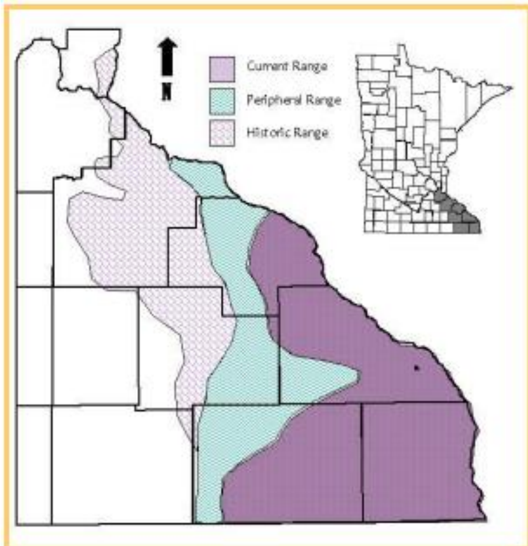

Figure 1. Current, historical, and peripheral range of the timber rattlesnake in southeastern Minnesota. Figure obtained from MNDNR (2009).

Historical Population Decline

The timber rattlesnake is currently listed as a threatened species in Minnesota (MNDNR, 2009). Populations have been drastically reduced and the species have even been extirpated from certain areas of Minnesota. This decline was primarily caused by humans. In 1909, a bounty on timber rattlesnakes was put into effect driven by fear of the animal. Less significant causes of population decline include habitat destruction, road mortality, and collection for the pet trade. In 1984, the timber rattlesnake was listed as a species of special concern in Minnesota. Five years later, the bounty on timber rattlesnakes was repealed. In 1996, the timber rattlesnake was listed as a threatened species in Minnesota (MNDNR, 2009).

Habitat

The timber rattlesnake is present in 30 states across the United States. Ideal habitat for timber rattlesnakes in Minnesota includes forested bluffs, rock outcrops, and bluff prairies (MNDNR, 2009). Brown (1993) recommends caution in interpreting habitat descriptions within existing literature as each timber rattlesnake area has its own distinctive characteristics. Habitat varies depending on the time of year, including summer habitat, winter habitat (or hibernaculum), and transient habitat (Brown, 1993; MNDNR, 2009).

Summer Habitat

Forested bluffs act mainly as summer foraging areas for the timber rattlesnake. Cultivated row crops, old fields, and grasslands may also be utilized as foraging areas (Ernst and Ernst, 2012). Tree species associated with forested bluffs may include oak, maple, basswood, elm, and hickory (Oldfield and Keyler, 1989). The timber rattlesnake will generally be found in forests of greater than 50% canopy closure, though gravid females tend to be found in forests with less than 25% canopy closure. These gravid females require a rookery and basking area which could be a den entrance itself or a rock or grouping of rocks near the den (MNDNR, 2009).

Winter Habitat

Rock outcrops and bluff prairies are used by timber rattlesnakes during the winter as den sites (Oldfield and Keyler, 1989). Plants typically associated with these areas could include cedar, oak, birch, cottonwood, hackberry, sumac species, poison ivy, wild grape, bittersweet, columbine, harebell, puccoon, violet, wood sorrel, and various grasses. Rock outcrops or bluffs of limestone, sandstone, or dolomite with a southern aspect and ample sun exposure are necessary for thermoregulation (Oldfield and Keyler, 1989). Timber rattlesnakes tend to use the same den year after year (Brown, 1993).

Transient Habitat

Transient habitat is the area between the summer and winter habitat. This is an area that is close to the den, usually within 200 meters (MNDNR, 2009). This area tends to have rough topography and rocky terrain in close proximity to the den site and contains open woodland with exposed clearings and shelter rocks. These shelter rocks, or "snake rocks," will often be utilized by a single snake year after year. Adult females rely on this transient habitat during their reproductive years (Brown, 1993).

Movement

Timber rattlesnakes have seasonal migrations that occur in spring (out-migrations) and autumn (in-migrations). The distance travelled from the den of the snake is important in predicting where snakes may occur. Gravid females preparing to give birth tend to move less than other snakes. While the average maximum migratory distance from a den for males is 4.07 km (2.5 mi), the maximum distance documented for a single snake is 7.2 km (4.5 mi; Brown, 1993).

Susceptibility to Disturbance

Timber rattlesnakes are susceptible to human disturbance (Brown, 1993). Snake rocks are rocks or aggregations of rocks that are used by snakes annually, though these may be abandoned if disturbed. After a few disturbances, a snake may no longer bask on the surface of these snake rocks. The effect of disturbance by humans is controversial, as some researchers feel that human observers merely elicit brief curiosity. Some researchers even believe that capture and release have little impact on the behavioral patterns of the snakes. In personal communication with timber rattlesnake researchers in Minnesota, Oldfield and Keyler (1991), Brown (1993) notes Oldfield and Keyler believe field processing causes the animal significant psychological stress. Upon release at the capture site, the snake will often leave within a day or two and may not return to the area for months or even years (Brown, 1993).

Snakebite Side Effects

Timber rattlesnakes are included in the 15% of the species of snakes that are considered dangerous to humans (Gold, Dart, and Barish, 2002). Their venom is very toxic and can deliver large enough doses to cause fatalities, though envenomations are rare as timber rattlesnakes are rather docile, slow to assume defensive posture, and encountered infrequently (Rubio and Keyler, 2013). Though their bite is not typically fatal, it is severe enough to cause hospitalization.

In a case study involving 36 rattlesnake bites in southeastern Minnesota, western Wisconsin, and northeastern Iowa, 27 snakebites were inflicted by timber rattlesnakes (Keyler, 2008). These 27 snakebites occurred over a period of 20 years (1982-2002). Of these 27 snakebite victims, 11 patients (41%) were released from the hospital after four to 12 hours of observation with little or no evidence of envenomation. Three patients (11%) signed out of the hospital against medical advice. A single pediatric case of a two year old boy developed no symptoms but was monitored for 24 hours as a precautionary measure. A fatality was recorded as a result of intravenous envenomation of a 16 year old girl, which was complicated by an extensive delay in interstate transport from a rural area. The remaining 11 patients remained in the hospital for two to 12 days due to symptoms of pain, progressive edema (swelling), ecchymosis (bruising), unfavorable changes in their laboratory coagulation parameters, hypotension (low blood pressure), and in two cases, surgical interventions. The predominant blood abnormality in all 11 patients was thrombocytopenia (low blood platelet count). Antivenom therapy with Antivenin (Crotalidae) Polyvalent was administered to each of these patients, with up to 20 vials administered in a severe case (Keyler, 2008).

Maintenance of Secrecy

Den locations should never be revealed to anyone in order to prevent the taking or killing of timber rattlesnakes, except for valid reasons (e.g., research or protection). Specific den locations have been given in past literature and these sites have been subsequently visited by snake collectors, many times causing extirpation of timber rattlesnakes in the area (Brown, 1993). In order to ensure the safety of the timber rattlesnake population at Great River Bluffs State Park, certain elements have been excluded from this document that may compromise the locations of the snakes.

Study Area

Great River Bluffs State Park is located in Winona County in southeastern Minnesota USA (Figure 2).

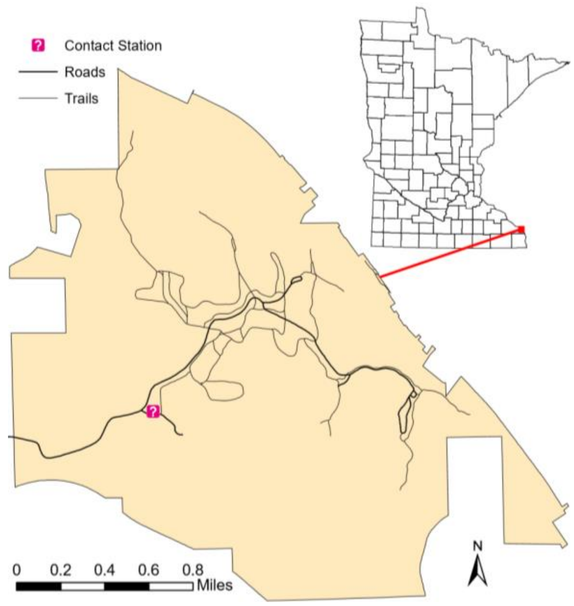

Figure 2. Great River Bluffs State Park.

The 11.27 square kilometer (4.35 square mile) park is a suitable study area because it contains viable populations of timber rattlesnakes with known denning sites (Keyler, 2015). While rattlesnake encounters within the park are relatively infrequent, there have been recorded sightings of timber rattlesnakes by park staff and visitors. Keyler and Oldfield (1992) noted many specimens in a survey were found in Winona County near hiking trails and observation points.

Purpose

Developing a risk assessment map that shows locations where timber rattlesnake encounters are most likely may be beneficial to park managers. This map may help keep visitors safe while also protecting the threatened timber rattlesnake from harm or even stress from an encounter.

Methods

In order to assess the risk of timber rattlesnake encounters throughout Great River Bluffs State Park, a visitor use layer and a habitat suitability layer were required. Ideally, these maps would illustrate where humans and timber rattlesnakes are most commonly found within the park.

Data Acquisition

Data acquired for this study included elevation, land cover, canopy cover, forest cover type, soil type, timber rattlesnake locations, and park roads, trails, and boundaries. All data, with the exception of timber rattlesnake location data, were acquired through the Minnesota Geospatial Commons website. Because the timber rattlesnake is a threatened species, this data was not publicly available. It was acquired through a license agreement with the Minnesota Department of Natural Resources (MNDNR).

The timber rattlesnake data provided by the Minnesota DNR contained a multipart polygon of rattlesnake records. Each record contained information about the rattlesnake sighting, including locational uncertainty, whether or not it was confirmed by a reliable individual, comments, and other information. Records that were not confirmed by a reliable individual were excluded from analysis. The remaining records were inspected to determine if they should be used to model suitable habitat. Records were retained based on snake density (if a single snake was recorded in a small polygon or a large number of snakes were recorded in a larger polygon). Once the appropriate polygons were selected, a set of 100 random points were created in ArcMap 10.2 to represent a sample of timber rattlesnakes since actual GPS data were not available. These points were required for the habitat suitability analysis described below.

All data in this research utilized the North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) Zone 15N projection. All raster data utilized in this study have a spatial resolution of 1 meter with the exception of the land cover and canopy cover data of the National Land Cover Dataset (NLCD) 2011, which have a spatial resolution of 30 meters.

Visitor Use

A visitor use model was created by calculating the one-way travel time for an average visitor to any point in the park, similar to Theobald, Norman, and Newman (2010). This model assumes visitors will travel to areas in the park most accessible to them. While this may not be the most accurate method to depict where humans will be present within the park, it is a way of mapping visitor use without the need of park survey and monitoring data.

The first step in creating the accessibility map was to identify all park entrances. Great River Bluffs State Park has only one official entrance and its location was mapped based on the park road and park boundary shapefiles. Because a visitor use layer was created for the entire park, this model assumes that visitors can travel anywhere in the park, with the exception of areas that are too steep. Had the study area contained more than one entrance, weights would be applied to each entrance to account for the popularity of each particular entrance.

Next, a travel speed was assigned to all roads within the park. This model assumes visitors will travel along roads at the posted speed limit of 32 kilometers per hour (20 miles per hour) for the entire park. This layer was integrated with the hiking velocity layer to create a park wide travel speed layer.

An average person will hike at approximately 5 km/hour on flat terrain, but speed diminishes on steeper terrain. To account for this change in travel speed, the following hiking velocity equation from Tobler (1993) was used:

$$h = 6 * e^{(-3.5*|tan(\theta)+0.05|)}$$

where θ is the slope in degrees. This equation was modified to work in Esri's ArcMap 10.2 by converting degrees to radians, resulting in the following formula:

$$h = 6 * e^{\left(-3.5*\left|tan\left(\frac{\theta}{57.29578}\right)+0.05\right|\right)}$$

The resulting layer consisted of hiking speed values from zero to five km/hour. Due to the extreme slopes in some areas of the park, slopes of greater than 31 degrees were excluded from the calculation. This value is considered to be the maximum slope safe for roofers and is further supported by Kinsella-Shaw, Shaw, and Turvey; 1992, as cited by Frakes, Sherrill, and Flowe (2014). Upon creation of the hiking velocity layer, a travel speed layer was created by combining the travel speed of the roads and the hiking speed layers for the entirety of the park.

While the initial travel speed layer accounted for a decrease in hiking speed due to slope, it did not account for the decrease in speed due to off-trail hiking. Travel speed off-trail was assumed to be the same as on-trail with a decrease in velocity based on landcover type to account for the difficulty of moving through vegetation. This layer was created based on the NLCD 2011 data. Percent of maximum travel speed (PMTS) values used for landcover types were based on a travel time cost surface model (TTCSM) developed by the National Park Service (NPS) and can be found in Table 1 (Frakes *et al.*, 2014).

Table 1. Percent of maximum travel speed values based on NLCD cover classes as defined by Frakes *et al.* (2014).

NLCD Cover Class	**PMTS (% of normal)**
Developed, Open Space	90
Developed, Low Intensity	90
Developed, Medium Intensity	90
Deciduous Forest	70
Evergreen Forest	65
Shrub/Scrub	75
Grassland/Herbaceous	80
Pasture/Hay	80
Cultivated Crops	80
Emergent Herbaceous Wetlands	25

All roads and trails within the park were assigned a PMTS value of 1.00 (100%), because travel speed in these areas is unhindered by vegetation. The PMTS layer and the travel speed layer were combined to create the final velocity layer measured in km/h (Figure 3).

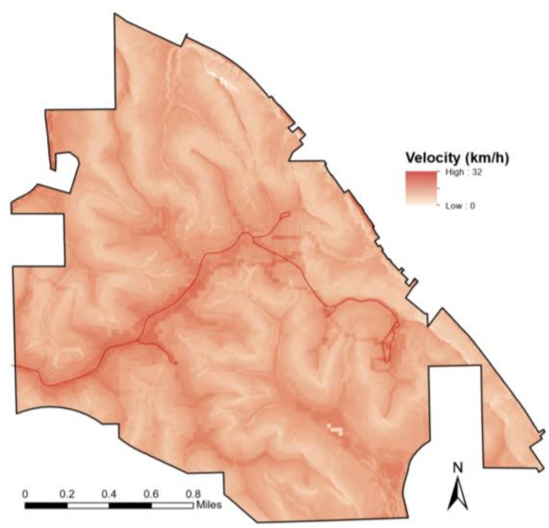

Figure 3. Velocity layer in Great River Bluffs State Park based on posted speed limits, NLCD 2011 landcover, and Tobler's hiking velocity equation (1993).

Once the velocity layer was created, the km/h units were converted into seconds per meter to be used as an impedance layer for cost distance analysis within ArcMap 10.2. The park entrance was used with this impedance layer to calculate the least accumulated cost distance for every output cell location, showing the amount of time it takes to reach each cell (in seconds; Figure 4).

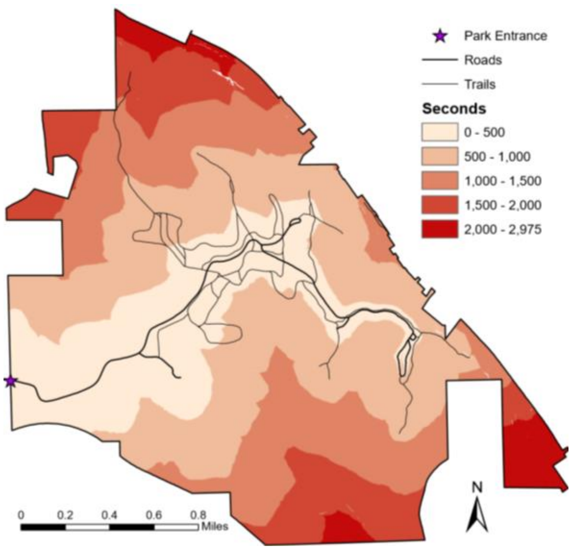

Figure 4. Travel time from the park entrance to every area in the park. Areas with no data signify a slope of greater than 31 degrees.

Areas were manually classified based on the amount of time required to travel to the end of roads and trails for the first two classes and approximate equal park area for the remaining classes. Based on the classification shown in Figure 4, travel times were reclassified into five categories to predict visitor use, which were then used in conjunction with a habitat suitability map for risk assessment.

Habitat Suitability

Environmental Variables

Because timber rattlesnakes have such a large distribution across North America, it was somewhat difficult to determine which variables were relevant for the study area. The accuracy of the habitat suitability model relies on identifying appropriate variables (i.e., leaving no important variables out, and not including any unimportant variables; Rottenberry, Preston, and Knick, 2006).

While most environmental variables used in this model are intuitive, sun index may not be. Sun index is a function of aspect and slope and can be used to identify the most optimal areas for sun exposure and solar radiation (Schantz, 2009). Categorical data (land cover, main cover type, and soil type) were divided into sub-rasters relevant to the study area representing the percentage of a particular categorical value within a 100 meter radius (i.e., percent developed/open space, percent deciduous forest, percent evergreen forest, etc.). These variable rasters were calculated using a 100 meter radius circular neighborhood operation. A number of environmental variables were chosen based on a literature review (Table 2).

Mahalanobis Distance (D^2)

A number of habitat suitability models that predict wildlife habitat require both presence and absence data. Absence data can be problematic because failure to detect an animal does not necessarily mean that it is not present. This can lead to misclassification of presence and absence data which can skew the results of the model (Browning, Beaupré, and Duncan, 2005).

Mahalanobis Distance Statistic is a multivariate statistical method that can be used to predict the habitats of plants and wildlife through the use of only presence data. Mahalanobis D^2 is the squared, standardized distance between a set of

Table 2. Environmental variables used in the principal component analysis.

Environmental Variables	Units
Elevation	meters
Slope	degrees
Aspect	degrees from north
Canopy cover	percent
Sun Index	cos(aspect)*tan(slope)*100
Distance to roads	meters
Distance to trails	meters
Distance to dens	meters
Land cover – 5 variables	percent based on 100 meter neighborhood
Main cover type – 7 variables	percent based on 100 meter neighborhood
Soil type – 9 variables	percent based on 100 meter neighborhood

environmental variables for any given point and the mean values of those same variables where a species was detected (Browning *et al.*, 2005; Rottenberry *et al.*, 2006). Mahalanobis distances are calculated using the formula:

$$D^2 = (x - m)^T C^{-1}(x - m)$$

where x is a vector of data, m is the vector of mean values of independent variables, C^{-1} is the inverse covariance matrix of independent variables, and T indicates that the vector should be transposed (Jenness, Brost, and Beier, 2013a). For the purposes of GIS, each rasterized cell or pixel within the study area is compared to the average environmental conditions where species are present. More suitable habitat is a shorter distance from the average environmental conditions for the species, and as such, is indicated by smaller D^2 values.

Partitioned Mahalanobis D^2(k) Distance

When selecting suitable environmental conditions for Mahalanobis Distance analysis, it is important to extract what each site has in common from the presence data, excluding the variability that makes these sites different (Browning *et al.*, 2005). The purpose of partitioned Mahalanobis D^2(k) is to select a more informative set of principal components that correspond to species requirements. Traditionally, the highest eigenvalues are selected from a principal component analysis (PCA) because these account for the most variability in the data. However, for partitioned D^2(k), principal components with the smallest eigenvalues are retained, as these indicate how sites vary the least (Browning *et al.*, 2005). These values are emphasized because they identify constant relationships with a species' distribution. Environmental variables with a wide range of values will tend to have larger eigenvalues and will be less likely to identify these constant relationships (Rottenberry *et al.*, 2006).

Principal Component Analysis

The results of the principal component analysis are shown in Figure 5 and Table 3. Deciding which components to retain from principal component analysis is somewhat subjective. One way to choose how many components to retain is by using a scree plot to see if there is a point on the graph (often called the elbow) where the slope of graph goes from "steep" to "flat" (Abdi and Williams,

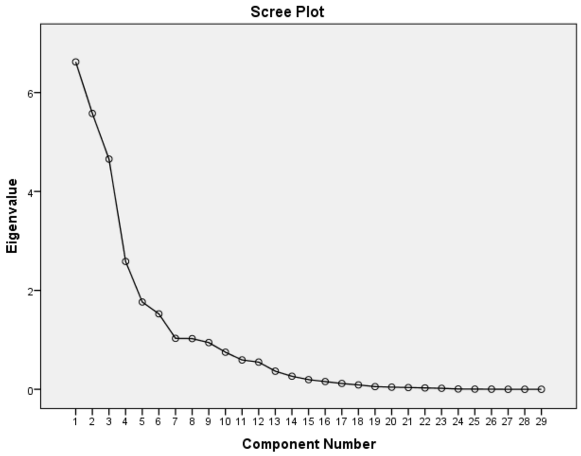

Figure 5. Scree plot of the principal component analysis.

2010). The most drastic change in slope on the scree plot is component 7. If this method were used, all nonzero eigenvalues over 7 would be excluded from the Mahalanobis D^2 calculation.

Another method of choosing which components to retain is by excluding all components whose eigenvalue is larger than the average eigenvalue (Abdi and Williams, 2010). For a correlation PCA, this means following the standard advice to exclude the eigenvalues larger than 1. Using this method, all components above the 9th component are excluded. This method was used to avoid the subjectivity necessary when interpreting scree plots.

Mapping Suitable Habitat

Suitable habitat was mapped using all components with nonzero eigenvalues less than one, retaining components nine through 26. A separate layer was created in ArcMap 10.2 for each principal component based on the eigenvectors of the component matrix. Because all environmental layers are publically available data, the component matrix was intentionally left out of this document to protect timber rattlesnakes by ensuring that the habitat suitability map is not recreated.

Table 3. Results of the principal component analysis.

	Initial Eigenvalues		
Component	**Total**	**% of Variance**	**Cumulative %**
1	6.620	22.828	22.828
2	5.577	19.232	42.060
3	4.656	16.054	58.114
4	2.585	8.914	67.027
5	1.765	6.087	73.115
6	1.525	5.258	78.373
7	1.029	3.549	81.922
8	1.025	3.534	85.456
9	0.945	3.259	88.715
10	0.750	2.585	91.300
11	0.594	2.047	93.347
12	0.551	1.899	95.246
13	0.366	1.261	96.507
14	0.264	0.909	97.416
15	0.196	0.674	98.091
16	0.156	0.540	98.630
17	0.118	0.406	99.036
18	0.088	0.304	99.340
19	0.054	0.185	99.525
20	0.043	0.148	99.673
21	0.035	0.122	99.795
22	0.028	0.096	99.891
23	0.020	0.068	99.959
24	0.006	0.021	99.981
25	0.004	0.012	99.993
26	0.002	0.007	100.000
27	0.000	0.000	100.000
28	0.000	0.000	100.000
29	0.000	0.000	100.000

The raster layer of Mahalanobis $D^2(k)$ was calculated using the Land Facet Corridor Designer v. 1.2.884 developed by Jenness Enterprises. The “Mahalanobis Distances – Create Raster Surface” tool used the sample of rattlesnake data and the 18 (k) principal components as inputs to create the habitat suitability raster (Jenness, Brost, and Beier, 2013b). This raster was manually classified into five classes based on the sample of rattlesnake points for the first class and approximate equal park area for the remaining classes. The habitat suitability raster was intentionally left out of this document to protect the timber rattlesnakes of Great River Bluffs State Park.

Risk Assessment

Once the visitor use layer and habitat suitability layer were created, these layers were reclassified on a scale of one to five to show areas where humans and timber rattlesnakes are most likely to be present (five being the highest, one being the lowest; Figure 6).

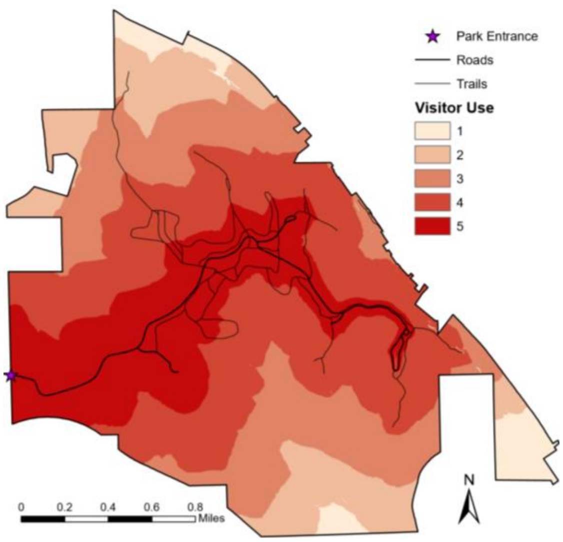

Figure 6. Reclassified visitor use map (five being the highest, one being the lowest).

After reclassifying each map, the values were multiplied by one another to produce the final risk assessment map. Multiplying the values of each map rather than adding them puts more weight on higher values to avoid relatively high risk ratings in areas with low probability of human or rattlesnake presence.

Results

The final risk assessment map was intentionally excluded from this document to protect the timber rattlesnakes of Great River Bluffs State Park. The map was reclassified on a one to five scale based on results of multiplying the habitat suitability raster and the visitor use raster. The total park area by risk rating, calculated from the risk assessment map, can be found in Table 4.

Table 4. Total park area by risk rating (five being the highest and one being the lowest).

Risk Rating	Park Area (%)
1	21.7%
2	53.1%
3	12.3%
4	4.4%
5	8.5%

A small portion of the park contained no data for each of the maps due to large slopes (>31%) and data gaps in the main cover type variable.

While the risk assessment map rates areas within the park on a scale of one to five, it is important to note that a value of five does not mean that rattlesnake encounters in these areas are likely. Rather, the range of values of this map should be interpreted on a range of "least likely" to "most likely. Timber rattlesnakes are secretive creatures that camouflage rather well with their surroundings, so these values are relative to the rest of the park.

Discussion

Visitor Use Map

While more accurate methods exist to model visitor use, the method used in this study uses publically available data that can easily be applied to any study area. More accurate visitor use maps can be created by using park survey and monitoring data if they exist. However, parks may avoid examining the spatial patterns and trends of their visitors due to lack of funding and lack of personnel time (Theobald *et al.*, 2010).

The visitor use map created in this study is likely somewhat inaccurate. Because a portion of King's Bluff trail is so far from the road, it was given a high travel time and, in turn, a low visitor use rating. This caused a section of the trail to be assigned a value of two for visitor use, even though this particular area is likely one of the more popular areas in the park with its scenic vista of Queen's Bluff and the Mississippi River.

Habitat Suitability Map

In the creation of the habitat suitability map, data gaps exist in the DNR forest inventory data. If these areas were inventoried by the DNR, the risk assessment would cover the entire study area with the exception of areas with steep slopes.

The habitat suitability map could also be improved with more accurate timber rattlesnake data. The data provided by the DNR did not contain GPS locations of each snake sighting. Accurate GPS locations are essential in defining their suitable habitat. Random points were created in the general areas where timber rattlesnakes reside, and while these areas are likely similar to their primary habitat, more accurate points would likely generate a more accurate habitat suitability map.

When deciding which principle components to retain from the principle component analysis, bootstrapping and cross validation techniques can be used to further reduce the number of principle components. This can potentially reduce additional variability in the results, giving a more specific output for suitable habitat.

Conclusion

Timber rattlesnake encounters should be avoided as often as possible for the safety of both visitors and rattlesnakes. The methods proposed in this paper are intended to identify areas that are most at risk for rattlesnake encounters. This information can be used by park managers to ensure that no trails or development are created where rattlesnakes are most likely to occur. Additionally, signs could be installed at locations that are at the greatest risk of rattlesnake encounters, similar to the sign in Figure 7.

Figure 7. Timber rattlesnake public awareness sign installed at King's Bluff trailhead at Great River Bluffs State Park.

Acknowledgments

I would like to thank my advisor, Greta Poser, for helping me with many aspects of this study. I would also like to thank my family; none of this would have been possible without all of your love and support.

References

Abdi, H., and Williams, L. J. 2010. Principal Component Analysis. *Wiley Interdisciplinary Reviews: Computational Statistics*, 2, 4, 433-459.

Brown, W. S. 1993. Biology, Status, and Management of the Timber Rattlesnake (*Crotalus horridus*): A Guide for Conservation. Society for the Study of Amphibians and Reptiles. *Herpetology Circulation*, 22, 1-78.

Browning, D. M., Beaupré, S. J., and Duncan, L. 2005. Using Partitioned Mahalanobis $D^2(k)$ to Formulate a GIS-Based Model of Timber Rattlesnake Hibernacula. *Journal of Wildlife Management*, 69, 1, 33-44.

Ernst, C. H., and Ernst, E. M. 2012. Venomous Reptiles of the United States, Canada, and Northern Mexico: Crotalus (Vol. 2). Baltimore, Maryland: JHU Press.

Frakes, B., Sherrill, K. R., and Flowe, T. 2014. National Park Service Travel Time Cost Surface Model (TTCSM): User Guide. *Natural Resource Report NPS/NRSS/NRR—2014/838*. Fort Collins, CO.

Gold, B. S., Dart, R. C., and Barish, R. A. 2002. Bites of Venomous Snakes. *New England Journal of Medicine*, 347, 5, 347-356.

Jenness, J., Brost, B., and Beier, P. 2013a. Land Facet Corridor Designer. Jenness Enterprises, Flagstaff, AZ.

Jenness, J., Brost, B., and Beier, P. 2013b. Land Facet Corridor Designer: Extension for ArcGIS. Jenness Enterprises. Available at: http://www.jennessent.com /arcgis/land_facets.htm.

Keyler, D. E. 2008. Timber Rattlesnake (*Crotalus horridus*) Envenomations in the Upper Mississippi River Valley. In W. K. Hayes, K. R. Beaman, M. D. Cardwell, and S. P. Bush (Eds.), The Biology of Rattlesnakes, 569-580. Loma Linda, CA: Loma Linda University Press.

Keyler, D. E. 2015. [Personal communication]. Winona, MN.

Keyler, D. E., and Oldfield, B. L. 1992. Timber Rattlesnake *Crotalus horridus* Field survey on Southeastern Minnesota State Lands. Minnesota Department of Natural Resources.

Kinsella-Shaw, J. M., Shaw, B., and Turvey, M. T. 1992. Perceiving ‘Walk-on-able’ Slopes. *Ecological Psychology*, 4, 4, 223-239.

Minnesota Department of Natural Resources (MNDNR). 2009. Timber Rattlesnake Recovery Plan. Retrieved 12/14/2015 from http://files.dnr.state.mn.us/eco/nongame/projects/tr_recovery_plan_final2009.pdf.

Oldfield, B. L., and Keyler, D. E. 1989. Survey of Timber Rattlesnake (*Crotalus horridus*) Distribution along the Mississippi River in Western Wisconsin. *Wisconsin Academy of Sciences, Arts, and Letters*, 77, 27-34.

Rottenberry, J. T., Preston, K. L., and Knick, S. T. 2006. GIS-Based Niche Modeling for Mapping Species’ Habitat. *Ecology*, 87, 6, 1458-1464.

Rubio, M., and Keyler, D. E. 2013. Venomous Snakebite in the Western United States. ECO Herpetological Publishing and Distribution.

Schantz, K. A. 2009. Characterization of Landscape-Scale Habitat Use by Timber Rattlesnakes (*Crotalus Horridus*) within the Ridge and Valley and Highlands Regions of New Jersey. Doctoral Dissertation, Rutgers, The State University of New Jersey.

Theobald, D. M., Norman, J. B., and Newman, P. 2010. Estimating Visitor Use of Protected Areas by Modeling Accessibility: A Case Study in Rocky Mountain National Park, Colorado. *Journal of Conservation Planning*, 6, 1-20.

Tobler, W. R. 1993. Three Presentations on Geographic Analysis and Modeling. National Center for Geographic Information and Analysis, University of California.