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Case Study

Landscape characteristics predict locations for potential human–wildlife interactions with timber rattlesnakes in Minnesota, USA

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Abstract: While management measures cannot eliminate human–wildlife conflicts, they have the potential to minimize the damage done to both parties, especially if areas where the nature of the potential interaction can be predicted before an encounter occurs. The timber rattlesnake (*Crotalus horridus*) represents a wildlife species associated with public misconceptions that may foster unwarranted fears and retribution. This species is native to the eastern and southern regions of the United States, including a small population remnant in the southeastern region of Minnesota. To gain a better understanding of the environmental predictors relevant to human–snake encounters in Minnesota (that require action such as relocation), we studied point locations of human–snake interactions requiring human intervention in Winona County in southeastern Minnesota over a 13-year period between 2006 and 2019. We used the points to create a model to predict areas of increased potential for human–snake interactions. Our analysis identified areas with high potential for such contact between humans and rattlesnakes. This research highlighted environmental factors favorable to timber rattlesnake encounters with humans and may serve as a guide for management efforts to mitigate human–snake conflicts.

Key words: conflict mitigation, conservation, *Crotalus horridus*, human–snake interaction, human–wildlife conflicts, MaxEnt, Minnesota, timber rattlesnake

The nature of the relationship between humans and wildlife can become strained when humans and animals come into close contact (Messmer 2000, Yue et al. 2019). In general, wildlife species that humans consider dangerous or less similar to humans tend to be perceived more negatively (Messmer et al. 1999, Batt 2009). In many of these cases, human misperceptions may contribute to species extirpation and extinction (Woodroffe et al. 2005, Clark et al. 2011).

Increased intentional and incidental human interactions with wildlife can increase human health and safety risks (Conover 2019). Many people have been hurt or even killed while trying to manage the damage caused by wildlife (Yue et al. 2019). Where livestock, pets, or small children are present, this risk of human injury may increase (Woodroffe et al. 2005, Conover 2019). With this in mind, wildlife managers and conservation planners have shifted their focus from managing individual problem animals and species to identifying and mitigating the factors contributing to increased human–wildlife conflicts (Messmer 2000, Woodroffe et al. 2005).

Concomitantly, human fear of animals (Christoffel 2007) can ultimately affect public perceptions regarding their management and conservation (Messmer et al. 1999, Castillo-Huitrón et al. 2020). However, the removal of these species can result in long-term negative environmental effects that often outweigh the immediate public risks (Reinert and Rupert 1999, Beschta 2003). As a result, conservation efforts in the past decades have been aimed at finding alternative solutions to negatively perceived human–wildlife interactions (Messmer 2000, Woodroffe et al. 2005).

One example of a species caught in this intersection of human encounter (e.g., with per-

Figure 1. Adult timber rattlesnakes (*Crotalus horridus*) with neonates, Winona, Minnesota, USA, September 16, 2004 (*photo courtesy of P. Cochran*).

ceived threat) and conservation is the timber rattlesnake (*Crotalus horridus*) in Minnesota, USA (Figure 1). The timber rattlesnake is a venomous pit viper native to the eastern and southern regions of the United States, including small remnant populations in the southeastern region of Minnesota (Minnesota Department of Natural Resources [MNDNR] 2009).

Female snakes give live birth to young in the late summer or early autumn; neonates spend most of the remaining active season close to the den and begin hibernation along with other timber rattlesnakes in autumn (Cobb et al. 2005). Hibernacula, or winter den sites, are most often found in areas with moderate to high elevation and slopes coupled with a south or southwest aspect (Keyler and Oldfield 1992, Browning et al. 2005). During the active season, which extends from April to October, timber rattlesnakes will forage throughout a 2- to 5-km range depending on age and sex (Petersen et al. 2019). Timber rattlesnakes are ambush hunters but are generally not aggressive toward humans or large animals unless disturbed (Furman 2007).

Once numerous, the timber rattlesnake in Minnesota has been reduced to only a fraction of its former range and population (Keyler and Oldfield 1992). Several counties in the state had bounties on timber rattlesnakes until 1989 (Keyler and Cochran 2005). During that time, people would locate dens, kill as many snakes as possible, and destroy the hibernacula to reduce the snake population and the perceived threat to humans (Keyler and Fuller 1999). Rattles of killed snakes would then be turned in for a small reward. In 1996, timber rattlesnakes were designated as a threatened species in Minnesota (Keyler and Cochran 2005). Thirty years later, timber rattlesnake populations remain low, with few signs of improvement.

Many anthropogenic factors continue to contribute to the decline of timber rattlesnakes in Minnesota. Through the process of development, much of this snake's habitat has been altered, and snakes have been removed from much of their former range (Keyler and Fuller 1999). Habitat loss may only be a small part of a larger mosaic of human-related impacts that continue to threaten populations of this species throughout its range (Clark et al. 2011). Cobb et al. (2005) reported the distance from birth site to den location for neonates was found to be <400 m. This means that young rattlesnakes have an extremely small range and are especially imperiled where people live, work, or recreate near den locations. Management efforts must be aimed at limiting the encounters between humans and snakes to address this issue.

Roads are often the first source of disturbance that affect rattlesnakes in areas undergoing anthropogenic development. Paths and roads break up what was once continuous snake habitat, change migration routes, disrupt dispersal, and directly cause many deaths in timber rattlesnake populations (Clark et al. 2010). Roads provide an ideal place for reptiles such as snakes to thermoregulate, which only adds to the problem. Many cases of intentional killing of snakes on roadways have been reported (MNDNR 2009). Beyond the effect of roads on timber rattlesnakes, few environmental factors have been identified as contributing to the issue, and management efforts are in need of more detailed information. In particular, the ability to identify and understand features of the environment that increase human–rattlesnake interaction could be particularly useful in targeting efforts to limit conflict.

In 2019, we studied environmental factors that were associated with human–snake encounters that required human intervention to determine if they could be used to predict these types of human–snake encounters and identify high encounter areas. This information could be used to guide management practices toward a proactive approach in the recovery of timber rattlesnake populations throughout their range.

Study area

Our study area consisted of Winona County in southeastern Minnesota, which spans over 1,660 km^2 (Figure 2). We selected this county as our study area because it is inhabited by viable populations of timber rattlesnakes, and thus the potential for human–rattlesnake interaction is higher in this area than elsewhere in the state. Entirely within the Driftless Region, the geography of this area consists of bluffs and forests that provide excellent shelter for the study species (Browning et al. 2005). Cities of varying size were also located in the study area with many rural areas in between to create a wide array of habitat types for potential encounters.

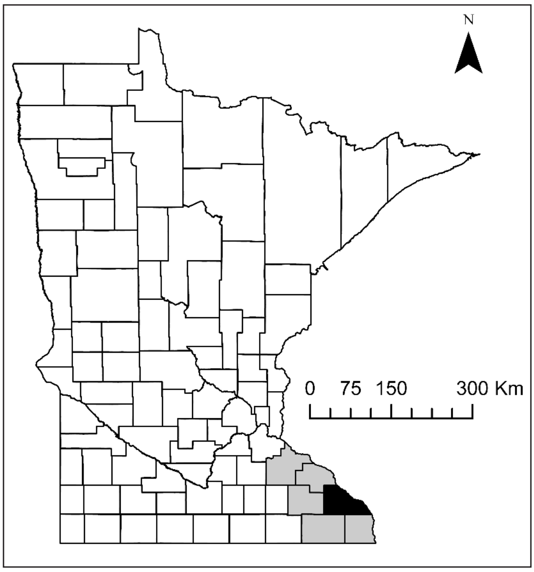

Figure 2. Winona County was the study area and is represented in black shown within a map of the state of Minnesota, USA (1,660 km^2). Other Minnesota counties with current documented timber rattlesnake (*Crotalus horridus*) populations are shaded in gray (Minnesota Department of Natural Resources 2009).

Methods

Data collection

The location data for human encounters with timber rattlesnakes that required human intervention that we used in our study were collected over a 13-year period between 2006 and 2019 by MNDNR volunteer responders. In Winona County, when rattlesnakes are encountered, citizens can call the Winona County Non-Emergency Dispatch and have a rattlesnake responder remove and release the snake nearby but away from homes. During this process, responders record information including the location of the recorded snake. These data were used to create point locations for human–rattlesnake interaction.

To protect the privacy of the citizen reporters, addresses were given to the block-level, and that number was used for all of the snake encounters within that particular block (e.g., 1308 1st Avenue would have been entered as 1300 1st Avenue). The coordinates for these addresses were entered into Google Maps® and converted into point locations in ArcMap 10.5 (ESRI, Redlands, California, USA).

Environmental factors

We selected 7 environmental factors as potential predictors of human–snake interactions. Elevation, aspect, and slope were selected based on the timber rattlesnakes' preference to den in and around bluffs. These factors were also used in a study conducted by Browning et al. (2005) and showed predictive potential. Because encounter sites are dependent on the presence of humans and may be impacted by human environmental factors, we also included predictors of human development in our analysis (Clark et al. 2010). Specifically, we used the percent of the area that was development (based on land cover data) within a 1-km radius and land cover type to model human development. A 1-km radius was chosen as it approximates the maximum home range size and distance timber rattlesnakes travel from a den site (Adams 2005). Distances to the nearest mapped body of water and soil type (by particle size) were modeled as potential predictors for both human development and snake habitat.

For each environmental factor, we produced a map covering the entirety of the study area using ArcMap 10.5 with 10 x 10 m resolution. These were made using datasets retrieved from the Geospatial Data Gateway run by the National Resources Conservation Service under the U.S. Department of Agriculture (datagateway.nrcs.usda.gov). These maps were used as layers in creating MaxEnt models.

MaxEnt analysis

We analyzed point locations and environmental factor maps using a maximum entropy modeling approach in MaxEnt v.3.3.3k (Phillips et al. 2006, 2017). This program takes known presence locations along with potential environmental predictors and identifies similarities in predictors across presence locations that differ from those of the study area generally. From that, each predictor received a measure of importance, a response curve for the effect of that predictor variable on the habitat suitability for the study species, and a continuous predictive map of suitability for the species across the study area. In most applications, MaxEnt is used to model habitat suitability across a region for a study species (e.g., Kalboussi and Achour 2018, Santos et al. 2019). In this research, the "study species" modeled was human–rattlesnake interactions that required human intervention rather than rattlesnakes themselves.

The most appropriate model parameterization in MaxEnt was found in an iterative manner (Svancara et al. 2019). Full models using all environmental predictors were created with all possible combinations from a set of candidate regularization parameters (0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 6, 7, 8, 9, 10, 12.5, 15, 17.5, 20), a value that penalizes for model complexity, and feature types (linear, quadratic, product, threshold, hinge, and interactions), the forms that parameter response curves may take, using the "enmSdm" package in R 3.6.3 (R Development Core Team 2016). Each model was run with 10-fold cross-validation, and the best-supported model among the candidate pool was chosen as that with the lowest sample-size corrected Akaike Information Criteria (AIC_c). From this model, individual environmental predictors were ranked based on their permutation importance. If the lowest ranking variable had an importance value below 1%, it was removed, and the model was run again without that predictor. This process was repeated until all predictors had a variable importance value of at least 2%. No predictor variables in the model had correlation values large enough to require their removal (Pearson correlation $>|0.70|$).

We used cross-validation to test the predictive ability of the final model using test data not used to build or train the model. We ran 10 replicates, withholding 10% of the points for each replicate. This was done within MaxEnt by randomly assigning each point location as a "test" point for 1 of the 10 replicates so that each point was used to build 9 models and independently assess 1. For each model, response curves were created for each predictor variable, and these values were used to observe variability in parameter estimates. The accuracy of the model was determined by the ability of the model to differentiate between sample and random points based on the environmental factors at that location as measured by the area under the curve (AUC) of the receiver operating characteristic. A model no better than random would have an AUC value of 0.5, and a model with perfect predictive ability would have an AUC of 1 (Poor et al. 2012).

We averaged the test data AUC values over all 10 replicates to determine an overall AUC value for the aggregate model. In addition, the impact of each environmental factor in the creation of the model was calculated as the minimum, maximum, and average suitability for every value within the observed range of predictor variables for the 10 replicate models. These outputs appeared as response curves illustrating the suitability of a location on a spectrum or across categories of environmental variables. All of these together were used to create a comprehensive model on the suitability of Winona County for human–snake interaction.

Results

We used 81 encounter locations in Winona County from 2006 to 2019 in our analysis. The optimal model identifying human–snake interactions that required human intervention within Winona County had a regularization multiplier value of 2.5 and included a combination of linear, quadratic, hinge, and threshold feature types. The overall accuracy of the model produced was very high, with an AUC value of 0.946. The primary variable contributing to the model was the proportion of developed land within a 1-km radius followed in order by land cover, slope, and elevation. Aspect, soil particle size, and distance to water were not included in the final model, as they were removed during the optimization process.

The proportion of developed land within a 1-km radius contributed much more to the model than other predictors (44.9%). The areas with highest suitability for human–snake interaction were at 10% development and above (Figure 3A). At highly developed areas, the suitability dropped slightly, but not substantially. The second highest contributing factor was

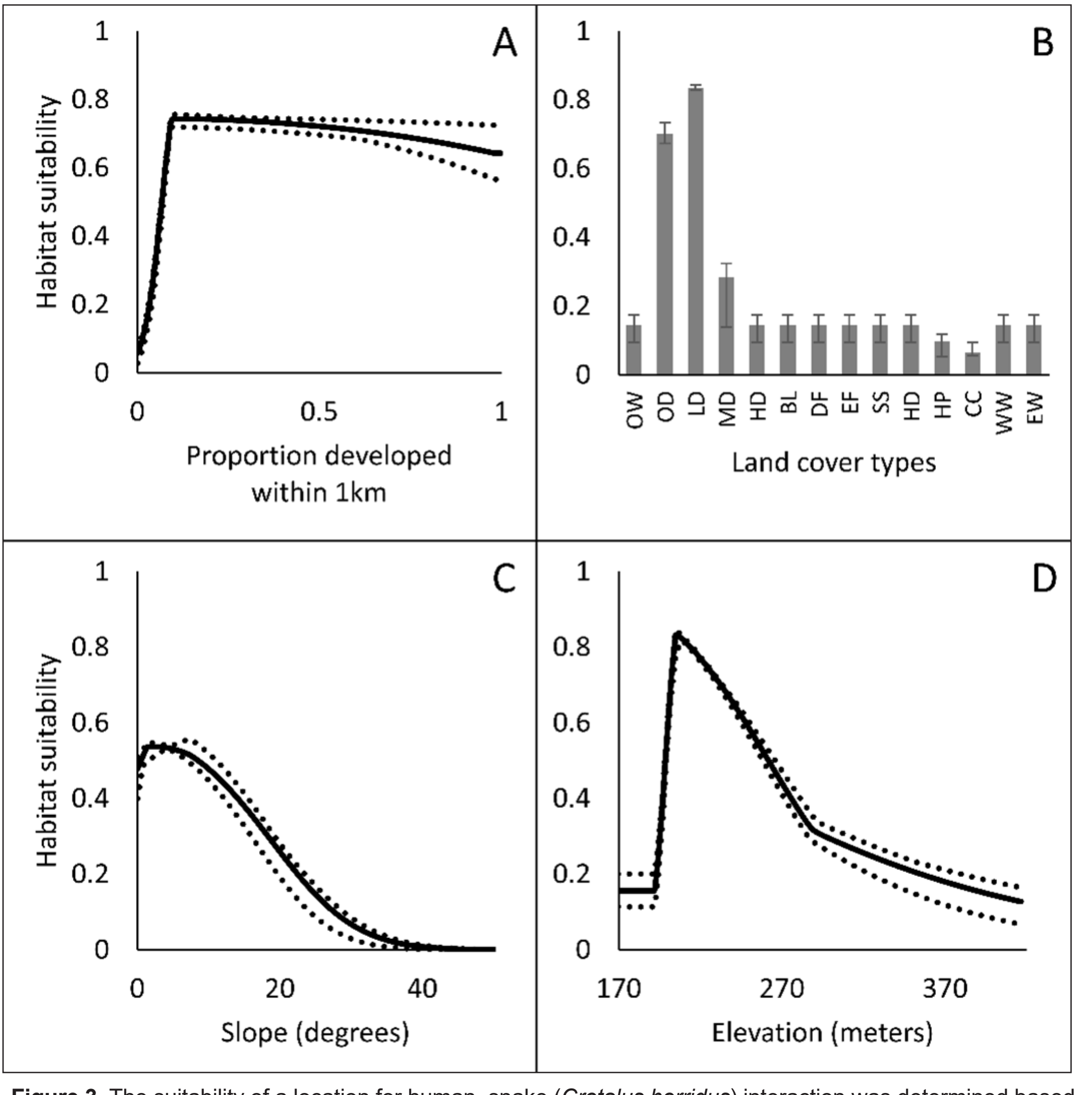

Figure 3. The suitability of a location for human–snake (*Crotalus horridus*) interaction was determined based on (A) proportion of the surrounding area developed within a 1-km radius, (B) land cover type, (C) slope, and (D) elevation. For land cover types, the abbreviations are: open water (OW), open developed (OD), light development (LD), medium development (MD), heavy development (HD), barren land (BL), deciduous forest (DF), evergreen forest (EF), mixed forest (MF), shrub/scrub (SS), herbaceous (H), hay/pasture (HP), cultivated crops (CC), wetland (WW), and emergent herbaceous wetland (EW). For the line graphs, the average of all 10 replicates appears in solid black, and dotted lines represent the minimum and maximum values for all 10 replicates. For the bar graph, the columns are the average of the 10 replicate models, and the error bars represent the minimum and maximum results from the 10 models.

land cover (25.8%). Lightly developed areas and open developed spaces showed the highest likelihood of encounter (Figure 3B). Fields and pastures exhibited the least potential for interaction. The next most important variable was slope (15.0%), followed closely by elevation (14.3%). For slope, 0–5° was the most conducive to encounters (Figure 3C). An elevation just over 200 m was the most suitable for human–snake interaction (Figure 3D). All of these environmental factors were used together in the creation of a final model that predicted the suitability of areas throughout Winona County for human–snake interaction (Figure 4).

Discussion

Conflict between humans and rattlesnakes can be detrimental to both parties involved, but especially to snakes (Furman 2007). Our study produced an accurate model, which identified

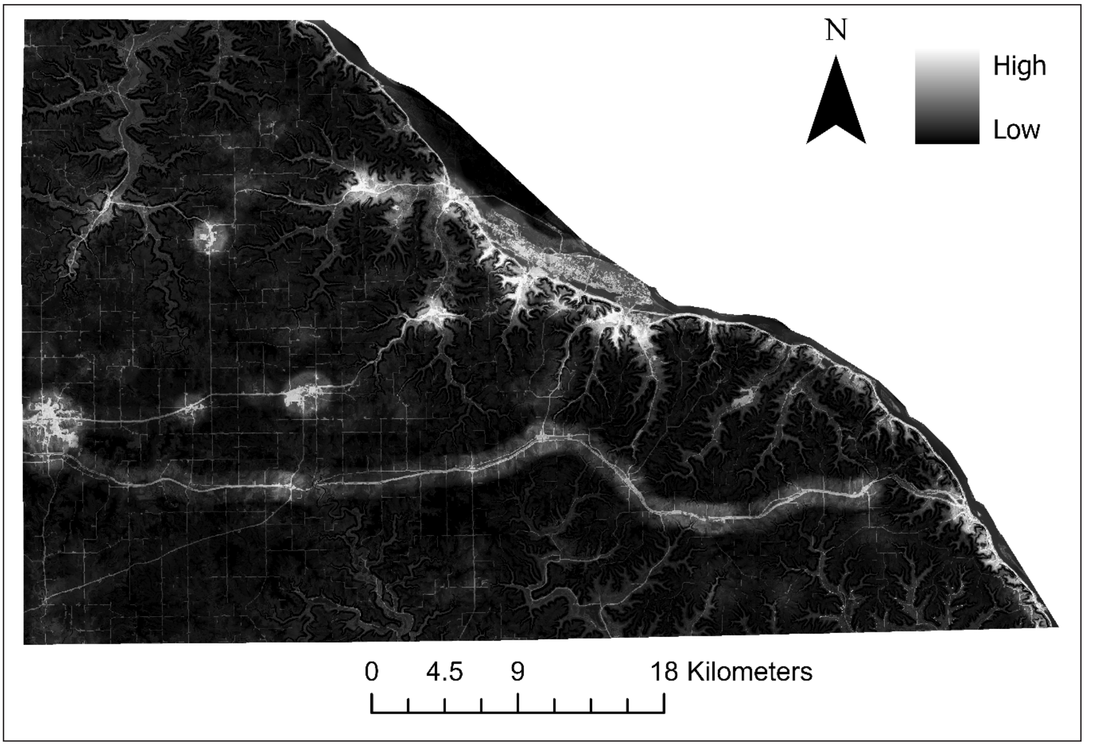

Figure 4. The final averaged predictive model of human–rattlesnake (*Crotalus horridus*) interaction suitability mapped across the entire study area of Winona County, Minnesota, USA. Areas in white have the highest suitability for human–snake interaction while darker areas have lower suitability.

the environmental factors that may predispose a location to higher potential for human–snake interactions that would require action or intervention by humans. From this, management efforts may be tailored to fit the needs of both humans and rattlesnakes with a more focused approach to areas of greatest need. Examining the proportion of development in a 1-km radius, land cover, elevation, and slope could be particularly useful since these 4 factors were the most important to the creation of the predictive model.

The most important variable in predicting these human–snake interactions, the proportion of developed land, suggested that any area containing even moderate amounts of development was at risk for encounters with rattlesnakes. Ten percent development and above within a 1-km radius showed a relatively similar suitability in the model. This may be explained by the fact that preferred habitat for timber rattlesnakes occurred in both developed and undeveloped areas within the study area (Browning et al. 2005). This finding further implies that rural and urban areas must both be targeted in resolving this situation. In areas where no development has taken place, encounter suitability was very low. This suggests that snakes and humans were not having interactions in these areas, or the encounters were not those that lead to conflict. It could be that snakes encountered in such low developed areas were seen as less of a threat and, therefore, did not warrant a call for relocation.

Model results related to land cover suggested similar trends to the proportion of developed land with some additional insight. The 2 most suitable types of land cover for interaction were lightly developed and open developed spaces. Highly urbanized areas likely received less incidents between humans and rattlesnakes, as they are heavily developed. The least suitable land cover types for interaction were hay or pasture and cultivated crops. This was consistent with the first factor, which showed that completely undeveloped areas would have the least potential for interaction. When considering the most and least suitable cover types together, some interesting implications arose. Where the land was open with development, encounters occurred. On the other hand, where the land was open and undeveloped, there were very few issues between humans and snakes. This could suggest that open areas that underwent development were particularly problematic for creating new areas of interaction.

The third factor, elevation, suggested that human–snake interaction occurred most often at relatively low elevations at an altitude of approximately 200 m. This could be explained by both the terrain of Winona County and snake behavior. In hot weather, timber rattlesnakes tend to leave the highest parts of the bluffs and move to lower elevations to escape the heat (Waldron et al. 2006). This movement may have caused snakes to encounter people as they passed through yards and roads on their route. A second wave of interactions may have occurred as these snakes returned to the higher elevations when temperatures decreased. This type of encounter was essentially unavoidable because snakes initiated the interaction. However, the model could help to predict where these issues will occur, which managers and homeowners can use to limit the susceptibility to human–snake interaction.

Slope was the final of the 4 major contributing environmental factors to the model produced. The response curve for this variable showed a slope of 0–5° to be the most suitable for human–snake interaction. Based on the previous factors, this was relatively unsurprising. In order for people to develop land, a flat or nearly flat surface was necessary. The highest suitability for interaction appeared in developed areas, which also included areas with minimal slope.

The remaining factors (distance to water, aspect, and soil type) were not included in the final model and, therefore, played a small role, if any, in the suitability of an area for human–snake interaction. While aspect is a major factor in hibernacula selection among timber rattlesnakes, it did not appear to be an influencing factor in human encounters, which primarily took place during the summer months (Browning et al. 2005). During the summer, snakes stay away from the den site for extended periods of time and likely follow prey species, which could have explained the relative unimportance of soil, aspect, and distance to water in our model (Petersen et al. 2019).

While the accuracy of the model developed was high, caution should be taken in extending the model predictions to other areas. The environmental predictors of human–rattlesnake interaction may have been location-specific, and the predictors for Winona County may not apply elsewhere. In particular, our study area was in the Driftless Region where the topography of bluffs and coulees differs starkly from other parts of the Midwest (and regions further away). Also, because our study was conducted in a somewhat rural county with only small cities, it may not be directly applicable to areas of greater human density. In addition, because multiple years of data were pooled, inter-year variation in the spatial patterns of encounter were not assessed. Finally, because location data were derived from rattlesnake responder deployment, these locations represent only a subset of human–rattlesnake encounters in this area and may have been biased toward those locations where people were more predisposed to calling the rattlesnake responder program.

Because the model we created in this study was effective in predicting locations of human–snake interactions that require human intervention, the potential for utility in guiding conservation efforts is high. Up to this point, recovery efforts have been focused on reducing the human impact on timber rattlesnakes so that the species will have time to reestablish (MNDNR 2009). Nonetheless, encounters between snakes and people have remained common. If the population of snakes is to remain viable, management efforts could be aimed at the areas with the highest suitability for human–snake interaction. In this way, both humans and snakes can benefit from the implementation of this model. Further research could expand to include more demographic information on snakes encountered, human dimensions data on the reporters of snakes, and more analysis of patterns of encounters over time (both intra- and inter-annually).

Management implications

The strength of our model was its ability to identify specific areas that are likely to be problematic based upon previous incidents of encounter. Because much of the management for conflict with timber rattlesnakes involves public education, in areas where interaction is expected, wildlife managers can tailor their efforts to be most effective. For instance, homeowners in such areas might be provided with additional materials on what to do in the event of a snake that needs to be moved. If a population of timber rattlesnakes exists in an area where little human–snake conflict is anticipated, the population could be a center of greater conservation efforts to maximize benefits to the snake population while minimizing the potential for encounter with humans. Where populations are present in high-encounter areas, greater care must be taken to avoid conflicts, especially those leading to rattlesnake fatalities. Further research into the trends of human–snake interaction based on other factors such as weather patterns and time periods could help to create a fuller picture of the relationship between timber rattlesnakes and humans. Finally, the approach used in this study is not restricted to just human–snake interactions. Any human–wildlife interaction with documented locations could be used to identify the environmental characteristics that predispose a location to such an interaction. We encourage ecological modelers and wildlife managers to collaborate in the construction of predictive models of human–wildlife interactions so that managers can target management and education where they would be most effective.

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