Distribution, Habitat Analysis, and Conservation of the Timber Rattlesnake in Virginia

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Abstract

The timber rattlesnake (*Crotalus horridus*) is a forest dwelling terrestrial pit viper that utilizes several types of habitat within the forest environment. One type of habitat crucial to the species' survival in mountainous regions and at more northern latitudes is basking habitat, which typically is an exposed rocky area used by gravid females for gestation, and by other timber rattlesnakes for shedding, mating, and digesting. Understanding the range of the timber rattlesnake in Virginia will enable biologists and land managers to better manage the landscape in a way conducive to the survival and persistence of timber rattlesnakes. To improve our ability to identify and locate areas potentially containing timber rattlesnake basking habitat, I used 5 landscape-level habitat variables with logistic regression and geographic information systems (GIS) to model and map areas of western Virginia potentially containing timber rattlesnake basking habitat. Models were ranked using Akaike's Information Criterion (AIC) and were crossvalidated using the methods of Fielding and Bell (1997). Aspect, slope, elevation, landform index, and percentage of forest cover values were derived using GIS for 217 known basking sites in western Virginia. I then used data derived for the 217 known basking sites to create 22 *a priori* models. The best model used the variables of aspect, slope, landform index and percentage of forest cover. When I crossvalidated the top model, the kappa value, a measure of the proportion of specific agreement, and was 0.804. During field tests the predictive model was used to find timber rattlesnakes at 3 of 15 (20%) of the test sites in the Goshen Wildlife Management Area in southwestern Virginia. My predictive model has proven to be an effective tool that could be used by biologists and land managers to locate and protect timber rattlesnake basking habitat. The historic and current ranges for the timber rattlesnake in Virginia were determined using literature records, database records, place names, personal interviews, and site surveys. Historically, the timber rattlesnake ranged over the entire state. Currently, the timber rattlesnake is restricted to the mountainous regions of Virginia (not including the coastal plain population of the timber rattlesnake). The biology of *Crotalus horridus* and regulations and management practices used by other states within the range of the species were used to create a set of management recommendations to the Virginia Department of Game and Inland Fisheries. These recommendations include implementing (1) a no-take regulation, (2) enhanced public education, and (3) protection of critical habitat and location of new populations.

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Introduction

The presence of suitable and available habitat is one of the most basic requirements for a species' existence in an area. Within a given area, a species may utilize different types of habitat as physiological, reproductive or other needs change across time. Understanding how species utilize their habitat and being able to predict the distribution of a species' habitat are crucial requirements for their conservation (Scott et al. 1993).

The timber rattlesnake (*Crotalus horridus*) is a forest-dwelling species that utilizes multiple habitats across the landscape. Brown (1993) and Martin (1993) identified three main types of habitat for the timber rattlesnake: denning, summer, and basking (also called "transient" habitat). Denning habitat describes sites where the snakes spend the winters, usually in holes or crevices that allow them access to an area below the frost line with adequate humidity to prevent desiccation during hibernation. Summer range describes forest surrounding the den used mainly for feeding and mating. The third type of habitat, basking area, is one of the most important and also one at which the snakes are most vulnerable to predation. Basking habitat is an area that is more exposed than the surrounding area and this is where gravid female timber rattlesnakes go to raise their body temperatures as they gestate their developing embryos. Basking areas have also been shown to be important areas for genetic mixing between different denning populations (Bushar et al. 1998). In the Pine Barrens of New Jersey, gravid female timber rattlesnakes used the edges of sand roads as basking habitat (Reinert and Zappalorti 1988). Throughout a large portion of their range in mountainous regions, they use well exposed rocky areas with crevices for protection as basking habitat. Reinert (1984) described the habitat used by gravid female timber rattlesnakes as having a higher percentage of rock and a much lower overhead canopy closure as compared to other timber rattlesnake size or age groups in eastern Pennsylvania. In Virginia, female timber rattlesnakes use well-exposed rock outcrops, ledges, and talus slopes with slabs to bask (Martin 1992, 1993, pers. obs.). In some areas in the southern portions of the timber rattlesnake's range there is not much difference between summer range and basking habitat because the average ambient temperature allows the females to keep their body temperatures warm enough without having to move to more exposed areas (W.H. Martin pers. comm.). In summary, basking sites are important to timber rattlesnakes because they are places where they can elevate their body temperatures for gestating, healing from diseases, undergo ecdysis (shedding) cycles, or encountering potential mates (facilitating genetic mixing).

Many factors affect the persistence and loss of basking habitat. Fire suppression and infrequent prescribed burning seem to be major factors allowing vegetation to overgrow and shade the ledge-type basking habitats in many areas (Fitch 2006). Frequently in these areas, timber rattlesnakes use the shoulders of roads or some other man-made structure such as a gas well or recent clear-cut to bask, if one is available (Adams 2005). One of the major problems with gravid female timber rattlesnakes using open areas associated with roads is a disproportionately higher mortality rate (Rudolph et al. 1998; Sealy 2002). Human destruction is another cause of the disappearance of basking habitat. Snake hunters often will turn or move basking rocks with car jacks and pry bars, destroying the thermal regime and cover favored by the snakes (Stechert 1980;

Brown 1993). The ability to predict areas potentially containing timber rattlesnake basking habitat could allow these areas to be identified and protected against some of the human induced threats and allow for land management actions that would favor these types of open canopied exposed rocky areas.

Many species' habitats have been successfully predicted using Geographic Information Systems (GIS) along with a variety of statistical methods (Danks and Klein 2002; Harvey and Hill 2003; Meggs et al. 2004; Browning et al. 2005). One of the methods used successfully to predict species habitats is logistic regression. Hoving et al. (2004, 2005) used logistic regression based on several large-scale factors to predict areas in northeastern North America with the potential to support Canada lynx (*Lynx canadensis*). Habitat use of black bear (*Ursus americanus*) based on habitat data and radio telemetry data was modeled with logistic regression (van Manen and Pelton 1997). Logistic regression has also been used to create predictive maps of alpine grassland communities in Switzerland (Zimerman and Kienast 1999).

There are many landscape-level factors that can be used to describe basking sites of timber rattlesnakes in a way that allows them to be predicted using GIS. Aspect, slope, elevation, landform index, and percentage of forest cover are variables that together describe these areas. Each of these measures is described below.

Aspect is the direction that a piece of ground faces from 0-360 degrees, also defined as the direction that a slope faces (Barnes et al. 1998). The aspect of a basking area has a major impact on the amount of solar radiation reaching it. For example, a site that has a southwestern aspect will get more solar radiation throughout the day than a site that has a northern aspect. Martin (1992) found that 140 of 153 (92%) confirmed timber rattlesnake dens in Virginia, Maryland, West Virginia, and southern Pennsylvania faced in a southerly direction.

Slope is a measure of steepness, usually measured in either degrees or percent (McCombs 1997). The slope of an area can yield information about a location's soil and potential forest type. In most locations very steep slopes can be indicative of thin soils and rock outcrops, and steep slopes are usually more exposed. Steep slopes of 30-45 degrees were mentioned in Martin (1992) as typical of many timber rattlesnake dens.

Elevation is the height in vertical feet or meters above sea level (Barnes et al. 1998). Elevation is an important variable for timber rattlesnakes because it has some effect over their distribution through its effect on air temperature. Timber rattlesnakes can den at higher elevations than those at which they can bask. It has been observed that gravid females need a mean July temperature of at least 18.5 degrees Celsius for successful gestation (Martin 2004).

Landform index provides information about the amount of exposure at a site. Sites that are concave will have a negative landform index value while areas that are convex will have a positive landform index value (McCombs 1997). Landform index is a function of elevation and slope.

In the eastern portion of its range, the timber rattlesnake tends to be a species associated with forested land. Sealy (2002) found that telemetered timber rattlesnakes in Hanging Rock State Park in North Carolina tended to avoid using non-forested areas unless they were using a basking site. Reinert (1984) found that non-gravid females and males used more forested lands away from the basking areas. The percentage of the surrounding area that is forested, therefore, could be a useful predictor to the occurrence of basking habitat as suggested by these studies.

The main objective of this study was to develop and test a logistic regression model that may be predictive of areas potentially containing timber rattlesnake basking habitat in Virginia. To improve my ability to identify areas potentially containing timber rattlesnake basking habitat I measured parameters at the microhabitat scale and at the landscape scale. I focused primarily on landscape scale factors that could be identified from readily available data sets in order to allow an efficient identification of areas potentially containing timber rattlesnake basking habitat.

Methods

Study Area

This study encompassed 58 Virginia counties with 6,713,400 hectares in total area (Figure 1). This area stretches from Kentucky and Tennessee, north to Washington, DC, along the West Virginia border, and south along the western side of the Piedmont Plateau. This study area represents the current range of the timber rattlesnake in Virginia (this thesis Chapter 2). The study area reaches across the Cumberland Plateau, Ridge and Valley Province, Northern Blue Ridge, Southern Blue Ridge Plateau, and the Inner Piedmont physiographic provinces as classified by the Major Land Resource Areas classification scheme used by the National Resource Conservation Service (NRCS). This area contains a great variety of habitats. Elevations range from 100 meters above sea level to over 1,525 meters above sea level and across about three degrees of latitude (≈ 330 km in north-south extent).

Microhabitat Data

The following characteristics of basking habitat were measured at 18 sites where a timber rattlesnake or freshly shed timber rattlesnake skin was located and at a point 50 m away along a randomly generated azimuth. The azimuths used were generated using the random number generator in Excel. The following variables were measured based on the methods of Reinert (1984):

- percent cover of rock
- percent cover of leaf litter
- percent cover of herbaceous vegetation
- percent cover of fallen logs (>5 cm)
- percent canopy cover
- percent cover woody vegetation (stem diameter <2.5cm)
- canopy tree density

Percent cover rock, leaf litter, vegetation, fallen logs, and woody vegetation were estimated using the following Daubenmire cover classes (Bailey and Poulton 1968):

- class 1, 0 - 1%
- class 2, 2 - 5%
- class 3, 6 - 25%
- class 4, 26 – 50%
- class 5, 51 – 75%
- class 6, 76 – 95%
- class 7, 96 – 100%

Percent cover variables were measured in 0.25 m^2 quadrats placed in each of the cardinal directions around the basking/gestating rock (Fig. 2). Quadrats were laid out using a 0.25 m^2 square frame. If a basking/gestating rock was on the edge of a ledge so that one of the quadrats was in the air, another quadrat location was selected at an azimuth between two of the cardinal directions, in this order: NW, NE, SE, and SW. Twenty-meter by five-meter quadrats and 20-m point intercept linear transects were marked off using fluorescent pin flags and a 50-m fiberglass tape (Fig. 2). Twenty-meter-long point-intercept transects were run in each of the four cardinal directions away from the basking rock to measure the cover values of rock, leaf litter, vegetation, fallen log, and woody vegetation. At every one meter interval along the transect, the variable present was recorded as a "hit" and percentage cover value was estimated based on the number of "hits" generated by a specific habitat variable. The 20-m x 5-m quadrats were laid out using the 20 m point intercept transects as the center and measuring out 2.5 m on both sides of the fiberglass tape and placing pin flags for the corners. Tree (>7.5cm diameter at breast height (DBH)) stem density was measured by direct count in the 20-m x 5-m quadrats. For each tree counted, the species was recorded and a DBH tape was used to place the tree in one of four size classes: 7.5-20 cm, 20-40 cm, 40-60 cm, and greater than 60 cm. When on the edge of a cliff or ledge, the correction method for the 20-m point intercept transects and the 20-m x 5-m quads was the same as for the 0.25 m^2 quads. Basal area was taken with a 10 factor prism from the center of the basking/gestating rock. Canopy cover percentage was measured using a hand held spherical densiometer. I used paired two-tailed t-tests to compare habitat data between snake-centered and random plots (Zar 1998).

GIS Modeling

The methodology used in creating the timber rattlesnake basking habitat model in flowchart format is shown in Figure 3. The layers of SINE transformed aspect, slope, landform index, and percent forest cover were created from U.S. Geological Survey (USGS) digital elevation models (DEM) at a 30-meter resolution. The elevation layer was the original USGS 30 m DEM data used to create the four previously mentioned layers. Then the dependent variable layers for the known basking sites and the random points were overlaid on the five independent variable layers and the values for each of the independent variable layers were extracted to each of the individual points in the known basking site and random point layers. This extraction procedure created a data set to be analyzed using logistic regression. After the data set (with the values for each of the independent variables corresponding to each known basking site and each random point) was created, 50 of the known basking sites and 100 of the random points were randomly selected and withheld from training the model to be used later for model cross-validation. The remaining known basking sites and random points were used in building the model using logistic regression analysis in SAS (Statistical Analysis Software). After the best model was chosen, the logistic equation for this model was entered into GIS and applied to the independent variable layers to create a probability layer that showed the probability of there being basking habitat within each pixel in the map of the study area. Once the probability map was created, the known basking site and random points that were withheld were plotted on the map and probabilities for each point were collected and used to cross-validate the model. Finally, the model was field tested by searching for snakes at points predicted to have a high and low probabilities of containing basking habitat.

Landscape Scale GIS Data

Dependent Variable

Basking site location data were collected by David Garst in the past 14 years and by W.H. Martin over the past 40 years. A site was considered to be a basking site if a gravid female timber rattlesnake was found there during the summer months, or if shedding snakes and or shed skins were found. The data used in this study were collected by visiting basking sites and marking the location on a USGS 7.5 minute topographic map. Most of the data were collected before the use of handheld GPS units became available. Seventeen sites were visited again since the initial point was marked on a map and GPS coordinates taken. These coordinates were plotted on the map along with the original points and the two were compared to get some idea of the accuracy of the original data. The original points were found to be as accurate as the GPS points: the error was approximately plus or minus 20 meters.

Random points were created by taking the maximum and minimum "easting" and "northing" points for the study area and generating 1000 random pairs of coordinates for this area. One thousand points were initially created because the area was not square and random points were selected from a square area, based on the maximum and minimum "easting" and "northing" values. Thus, I was able to exclude random points not within the study area while ensuring that approximately 400 points (373 total) were within the study area for comparison to the known basking sites.

Independent Variables

Elevation

Elevation data were derived from USGS 30 m DEMs (digital elevation models) for Virginia using ArcMap. Elevation data (meters above sea level) were collected as a continuous variable.

Slope

Slope data used in this study were derived from USGS 30 m DEMs by converting the elevation data to slope data using ArcMap. Slope data (in degrees) were collected as a continuous variable.

Aspect

An aspect layer was created by using USGS 30 m DEMs and converting them to an aspect layer in ArcMap. Then the basking site and random-point layers were overlaid and the values for aspect were extracted for each point. Once the aspect layer was created and the values for aspect were extracted from the layer, the data were SINE-transformed because aspect is a circular measurement. The formula used to transform the aspect data is as follows:

$$[(SIN\frac{Aspect}{2})]^2 \qquad \text{(eq. 1)}$$

This transformation set due south (180 degrees) as 1.0, then due west (270 degrees) and due east (90 degrees) were 0.49, respectively, and due north (0 or 360 degrees) was 0. This formula was applied to the original slope layer created in ArcMap to get an aspect layer that was SINE-transformed for analysis.

Landform Index

The layer used for analysis in this study was derived by taking the average slope of the pixels around a central pixel. This was done by finding the average of the corner pixels and then determining the average of the side pixels; because of the difference in distance between the corner and sides, these averages were found separately (McCombs 1997). Based on the distance of the corner and side pixels to the center pixel, a simple rise-over-run calculation was performed and a landform index was calculated.

Percent Forest Cover

For the purposes of this study, forest cover is the percentage of area forested within a 98-pixel radius of a known basking site. The 98-pixel radius was derived from the literature based on known distances moved by rattlesnakes through mark-recapture and radiotelemetry studies which have shown that the majority of timber rattlesnakes tend to stay within 2.4 kilometers of their den although some of the largest males may move up to 4 kilometers away (Brown 1982; Macartney, Gregory and Larsen 1988; Reinert and Zappalorti 1988; Sealy 2002). A 98-pixel radius is equivalent to a 2.9-km radius at the scale used here. The forest cover data used in this study were obtained online from the Virginia Department of Forestry (2002 update). I reclassified all of the forest classes into a single class with a value of 1.0, and all nonforest classes to a value of zero. I calculated the total number of pixels within a 98-pixel radius of a pixel that had any forest cover. If the central pixel was less than a 98-pixel radius from the state boundary line (forest cover data were available for the state of Virginia only), I truncated the area at the state border. For each central point, I used the proportion of all pixels in the 98-pixel radius area (complete or truncated) that contained forest cover as the desired measure of percentage forest cover.

Logistic Regression

The data were analyzed in SAS using logistic regression with the confirmed presence at a site being the dependent variable, and elevation, slope, aspect (SINE-transformed), landform index, and percent forest cover being the independent variables. Model selection was based on Akaike's Information Criterion (AIC) (Burnham and Anderson 2002) with the model having the lowest AIC value being the best model among those compared. Goodness of fit was measured using the Hosmer and Lemeshow (1998) test. In order to cross-validate the logistic equation, a threshold point, above which I considered sites to be "good" habitat and below which I considered sites to be non-or "bad" habitat, had to be established. This point was estimated by finding the probability that maximized the number of cross-validation points captured by the model while minimizing the overall area of the map predicted as "good" habitat. This was done using graphs showing the cumulative percentages of the cross-validation points compared to the pixels in the map (Figure 10). Logistic regression is best used with a binary response variable such as yes/no or occupied/unoccupied, rather than occupied/unknown (Hosmer and Lemeshow 1998). However, because of the difficulty in actually verifying a large sample of non-basking habitat sites, I used random points. Although there is a very small chance that one of the random points could be a basking site, this method has been used in previous studies using logistic regression (Hoving et al. 2005) with little to no effect on the results (Johnson et al. 2006).

Model Cross-validation

This model was tested in two ways: (1) it was cross-validated using a confusion matrix following the methods of Fielding and Bell (1997), and (2) it was field tested. Using the confusion matrix, several values (correct classification rate, false positive rate, false negative rate, and kappa) were calculated to assess model performance.

To field test the model, the Goshen Wildlife Management Area (GWMA) in Virginia owned by the Department of Game and Inland Fisheries was chosen because it was close to the center of the timber rattlesnake's distribution in Virginia and for its ease of access. After creating a statewide GIS model, the GWMA was clipped out and made into its own layer. In order to get the "good" and "bad" points, the layer was reclassified into three categories with the following probabilities of a pixel potentially containing basking habitat: class 1: 0-0.49; class 2: 0.50-0.74; and class 3: 0.75-1.0. Then the region group function was used to give each group of pixels in a certain category a unique identification number. The areas chosen to be searched were all in class 1 or class 3, the lowest and highest probability areas. Once this was done, the layer was queried for regions of class 3 that had greater than or equal to five pixels. This was done so that an area of at least 4500 m^2 was searched and not just a single pixel of 900 m^2. Values for these class-3 locations were obtained and then 15 of them were chosen at random to be field verified. Because the class-1 category was so large and connected, it formed a single region and random points had to be used to pick the "poor" locations to field-verify. The "poor" points, class-1 locations, were generated by creating 200 random points over the GWMA layer and then using a random number generator to pick 15 "poor" sites to field validate. When the class-1 sites were visited, an area of 4500 m^2 was searched for the presence of basking habitat. Once the class-1 and class-3 points were created, GPS coordinates were generated for each point using GIS enabling the point to be calculated for the center of the area to be searched. I visited 15 class-1 sites and 15 class-3 sites to search for basking habitat. The presence of a gravid female or shedding timber rattlesnake, or freshly shed skin, were the primary criteria used to confirm a basking area.

Results

Basking Microhabitat Measurements

Based on paired t-tests comparing the 18 known basking sites to paired random points (50 meters away on a randomly generated azimuth), gravid female timber rattlesnakes selected more open canopied locations ($t = 7.635$; $p = <0.0001$). The mean percentage canopy cover at the known basking sites was 48 (SE =5.162) compared to 93 (SE =1.573) at random points. Figures 4-6 show different types of basking sites with varying amounts of canopy closure. Figures 4-6 show how varied the amount of rock at a basking site can be; some sites consisted of several hectares of broken rock while others had just a few small slabs on the ground. There was also a significant difference in basal area of trees between the known snake points and the random points ($t = 7.184$; $p = <0.001$). The mean basal area for known basking sites was 4 (SE = 0.715) m^2/ha and 10 (SE = 0.417) m^2/ha for random points.

Of the percentage cover variables measured in the 0.25 m^2 quadrats, there was more rock cover at the basking sites than at random points ($t = 4.504$; $p = 0.0003$; df = 17; Fig. 7) and less cover of leaf litter at the basking sites than at random points ($t = 5.320$; $p = 0.0001$; df = 17; Fig. 7). Along the 20-meter transects there was more cover of rock ($t = 4.809$; $p = 0.0002$; df = 17; Fig. 8), and less of fallen logs ($t = 2.325$; $p = 0.033$;

df = 17; Fig. 8), leaf litter (t = 2.399; p = 0.0282; df = 17; Fig. 7) at the basking sites compared to the random points. There was an increase in the cover of woody vegetation along the 20 meter transects compared to the quadrats, but no significant difference between the basking sites and random points in the 20-meter transects (Fig. 8). This increase in the cover of woody vegetation could be an artifact of sampling over a larger area. In both the quadrats and along the transects, herbaceous vegetation was higher (but not significantly so) at the basking sites than at the random points (Figs. 7 and 8). This could be due to a more open overhead canopy at the basking sites which allowed more sunlight to reach the ground.

At the basking sites, there were a higher number of both pines and oaks in each 0.04-hectare plot (Table 1). At the random points, oaks dominated followed by the pines (Table 1). There was a significant difference between the number of oaks in the plots on the basking sites compared to the random points (Table 1). Within the oaks, there were also significant differences between the 20-40 centimeter and 40-60 centimeter categories (Table 1), showing that the random points tended to contain larger oak trees. The three most abundant species of trees at all sampled basking sites were *Pinus rigida* (pitch pine), *Quercus montana* (chestnut oak), and *Pinus virginiana* (Virginia pine). The three most abundant species at the random points were *Quercus montana*, *Pinus rigida*, and *Pinus virginiana*. Appendices 2 and 3 provides the mean number of each tree species for the 0.04 ha snake-centered and random plots.

GIS Modeling

Of 22 a-priori models tested using logistic regression, the best-fitting model incorporated the independent variables of aspect, slope, landform index, and percent forest cover (AIC=195.336; Table 2). All five of the independent variables used in model development had positive coefficients, meaning that basking habitat was more likely to occur in locations with higher values of each of the independent variables. The elevation variable did not appear in any of the five best models, and had coefficients that ranged from 0.0038 – 0.0004. Because of such small coefficient values, elevation had no appreciable effect on any of the models even when this variable was highly significant ($p<0.0001$). Based on their coefficients, aspect, landform index, and percent forest cover all had large effects on the top model with landform index having the highest effect (Table 3). Slope had a small effect on the top model because it had the lowest coefficient value (Table 3). The second-best model (ΔAIC = 14.142) showed a large difference from the top model (Table 2). Coefficients for the top-ranking model are given in table 3. Based on the Hosmer and Lemeshow Test, the data fit the top model very well (χ^2 =2.349, p=0.9684, Table 5). In fitting the data to a model, the higher the p value the more closely the data fit the logistic curve, while a lower p value would indicate a difference between the model and the data (Hosmer and Lemeshow 1998). The Somers' D value for the top model showed a very high positive association between the data and the model (Somers' D = 0.934: Table 2). Based on this model, timber rattlesnake basking habitat has a higher probability of occurring (or is more likely to occur) in a map pixel if it has a more southern aspect, steeper slope, higher landform index value, and a higher percentage of forest cover within a 2.9 km radius of the sampled plot.

The final logistic equation for the best supported model, based on the lowest AIC value, is as follows:

$$P_{\text{basking habitat}} = \frac{e^{-12.8892+4.0733*Aspect\_SIN\_Trans+0.1423*Slope\_Deg+7.2874*Landform\_Index+6.9505*Percent\_Forest\_Cov}}{1+e^{-12.8892+4.0733*Aspect\_SIN\_Trans+0.1423*Slope\_Deg+7.2874*Landform\_Index+6.9505*Percent\_Forest\_Cov}}$$

(eq. 2)

This equation was used to map the probability of timber rattlesnake basking habitat in 30-m x 30-m pixels across the 58-county study area in Virginia (Figure 9). Figure 9 shows a close-up view of the probability map showing how this model classifies the region into high and low probability pixels.

In order to cross-validate the top model, a probability had to be selected above which sites were classified as likely to contain basking habitat or below which they were unlikely to contain it. Only in this way could it be determined if test sites were correctly classified. Figure 10 shows the cumulative distribution of the 50 known basking sites withheld from model development compared to the cumulative distribution of pixels in the probability map. By setting a threshold probability equal to 0.6175, it was possible to maximize the number of basking sites that were considered correctly classified (86%) while at the same time predicting an area equal to only 4.82% of the probability map. If the probability threshold to correctly classify more of the 50 known basking site points withheld for cross-validation were decreased, any gains in capturing more basking-site points would have been lost because of the great increase in the area of the probability map deemed likely to contain timber rattlesnake basking habitat. The curve showing the cumulative distribution of the basking sites is distributed opposite from the probability model map, which provides evidence of timber rattlesnake basking habitat making up a small percentage of the probability model map. Figure 9 also shows the cumulative distribution of 100 random points withheld for model cross-validation as compared to a cumulative distribution of pixels in the probability map. When the probability threshold was set at 0.6175, only 6 of the 100 random points were predicted to be basking sites (Figure 10). Note that this is approximately what one would expect to be predicted when 4.82 percent of the probability map is predicted to be basking habitat. Based on the cumulative distribution of random points compared to the cumulative distribution of pixels in the probability map, it appears that the random points accurately represented the probability map. The overall correct classification rate for the top model was 0.91, with a false positive rate of only 0.06, and a false negative rate of only 0.14. Thus, the best-supported model had a kappa value of 0.804. According to Landis and Koch (1977), a kappa value (proportion of specific agreement) greater than 0.75 is an excellent result. The values for correct classification rate, false positive, false negative, and kappa were all calculated using a confusion matrix (Fielding and Bell 1997). Areas with a high probability of being suitable basking habitat occurred disproportionately in the Cumberland Plateau physiographic province. The total area (in hectares) for each physiographic province in Virginia along with the total area predicted to be greater than 0.6175, as well as the percentage of the total area in the province, predicted greater than 0.6175, show high concentrations in the Cumberlands but greatest area in the Ridge and Valley and Blue Ridge (Figure 11).

When the model was field-tested, 3 of 15 sites (20%) considered as “good” points had timber rattlesnakes present (Figure 12). A high proportion of the 15 “good” sites that were field-tested had rock suitable to be used as basking (80%) and open canopy to support basking (54%) (Figure 12). In contrast, none of the 15 sites (0%) classified as "poor" sites had any timber rattlesnakes or rock suitable for basking, and only a small percentage had open canopy (Figure 12). Chi-square tests showed a higher proportion of "good" sites had rattlesnakes present (χ^2 =3.333, df =1, p = 0.0679), had suitable basking rocks (χ^2 = 20.000, df =1, p = <0.0001), and had open canopy (χ^2 =10.909, df =1, p = 0.001), compared to "poor" sites.

Discussion

Gravid female timber rattlesnakes and other timber rattlesnake sex, age, and size groups that need to elevate their body temperature for physiological reasons (e.g. shedding or digesting) have been reported to use areas with higher percentages of rock cover, lower overhead canopy closure, and lower overall tree basal area (Reinert 1984a, Martin 1993). The lower overhead canopy density allows more solar radiation to reach the ground at these basking areas, thus raising the ambient temperatures and allowing for efficient basking. However, the amount of overhead canopy can be misleading in some situations. For instance, I have observed certain ledge-top basking sites to have a high overhead canopy density, but the canopy did not extend out over the edge of the ledge which still allowed strong sunlight to reach the ledge's top at an angle. A method that can measure the amount of light coming in from the sides (such as hemispheric photography; Bishop 2005, Fraterrigo et al. 2006) could be very useful in determining the true amount and location of open space around a basking site. The higher amounts of rock on the ground provide timber rattlesnakes with shelter to avoid direct sunlight and possibly to prevent overheating during the middle of the day. Protection from predators is also a factor. The amounts of leaf litter found at basking sites were lower than those of the random points. This was probably due to the lower number of trees and herbaceous species present. The significant difference for fallen logs along the 20-meter transects could be accounted for because the 20-meter transects cover a greater area and that, coupled with a higher basal area (i.e. more trees) in the random points could be causing the higher number of fallen logs present in the 20-meter transects. The basking sites seemed to be dominated by pines, whereas the random points were dominated by oaks. The two most abundant tree species found at both locations were pitch pine (*Pinus rigida*) on the basking sites and chestnut oak (*Quercus montana*) at random points. Pitch pine (*Pinus rigida*) was more common at the basking sites and chestnut oak (*Quercus montana*) at the random points.

At the landscape scale, the best-supported model used the independent variables of aspect, slope, landform index, and percentage forest cover. Based on the coefficients for each variable, basking sites are typically areas of higher slope, a more southerly aspect, and of a more convex structure based on the landform index coefficient. In addition, basking sites are typically surrounded by a large area of intact forest. A majority of the timber rattlesnakes in a population during the active season are found within one or both such sites.

Error in the GIS data could have affected the overall performance of the model. The USGS 30-m DEMs used to create four of the five layers used in model development have a certain amount of inherent error. Because each pixel in the layers of each of the independent variables represents an area of 30 meters by 30 meters, some of the variability in the real topography may be lost. This loss of variability could have decreased somewhat the overall fit of this model.

When the final basking habitat model was field-tested, timber rattlesnakes were found at three of 15 “good” sites visited (20%). Although some of the other “good” sites had the appearance of being suitable habitat for basking, no timber rattlesnakes were found. This lack of occurrence creates some speculation that the model perhaps may have yielded better results under different conditions. Detectability of this species is almost certainly less than 100%. Female timber rattlesnakes tend to become gravid every 3-5 years (Brown 1991, 1993; Martin 1993), depending on latitude and climate. This model could have been field tested during a period of low reproduction, resulting in fewer or no gravid timber rattlesnakes present at the sites checked. Air temperature could also have affected the outcome of the field test. Timber rattlesnakes tend to favor temperatures in the range of 27.8-31.1 degrees Celsius (Brown et al. 1982) and because of daytime temperatures over the 30^{o} C range with abundant sun, the weather conditions during field validation were judged not to have been the most conducive for finding timber rattlesnakes basking. Some of the rattlesnakes using the basking sites may have become too warm and were not found because they had moved off into the adjacent woods where temperatures were cooler but still warm enough to facilitate basking.

Management Implications

The ability to predict where wildlife species or their habitats occur can be paramount to the conservation and management of a species. Habitat models give biologists and land managers a tool that can be used to avoid unnecessary destruction or degradation of timber rattlesnake basking habitat. The model analyzed here can be used to aid biologists in searching for timber rattlesnakes in a given area by allowing them to prioritize areas using the probability map that was created. It can also be used to tell them where not to look, saving time and valuable resources. Land managers and foresters can use this model to limit human and rattlesnake interactions by not placing roads or trails in areas that have a high probability of containing basking habitat.

This model can also be used to see where management is needed to help improve basking habitat and possibly to create new basking areas. Also, it could be used in maintaining or creating open canopies, improving areas that already have timber rattlesnakes, or creating a basking site to be potentially populated from a nearby population. Overall, this model has great potential to help timber rattlesnake conservation across Virginia. Although it has not been tested elsewhere, it may be useful in areas with similar topography and temperature ranges, including much of West Virginia, Pennsylvania, western Maryland, and Western North Carolina.

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Table 1. Mean number of trees for each tree category (all species in genera *Quercus*, *Pinus*, *Acer*, and *Carya*, as listed) and size class from the 0.04 ha plots for basking site (snake) and random point (random) locations at Virginia sites with timber rattlesnakes. For each tree category the mean and standard error (in parenthesis) is given. The t-value and p-value (in parenthesis) come from paired t-tests comparing the basking sites and random points for each tree category and size class. N = 18 sites for all categories.

	Size Class														
	7.5-20cm			**20-40cm**			**40-60cm**			**>60cm**			**Total**		
Tree Catagory	**snake**	**random**	**t-value**	**snake**	**random**	**t-value**	**snake**	**random**	**t-value**	**snake**	**random**	**t-value**	**snake**	**random**	**t-value**
Oaks	4.667 (1.060)	5.222 (0.941)	0.515 (0.613)	2.444 (0.573)	7.667 (1.185)	**4.704 (<0.001)***	0.389 (0.164)	2.000 (0.388)	**3.825 (0.001)**	0.111 (0.111)	0.167 (0.121)	0.325 (0.749)	7.611 (1.336)	15.056 (1.526)	**6.082 (<0.001)**
Pines	6.222 (1.928)	3.167 (1.004)	1.837 (0.084)	2.722 (0.862)	1.833 (0.556)	1.008 (0.327)	0.506 (0.056)	0 (0)	1.000 (0.331)	0 (0)	0 (0)	0 (0)	9.000 (2.622)	5.000 (1.442)	1.782 (0.093)
Maples	1.667 (0.518)	2.778 (0.899)	1.240 (0.232)	0.222 (0.173)	0.389 (0.216)	1.000 (0.331)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.889 (0.523)	3.167 (1.020)	1.300 (0.211)
Hickories	1.667 (0.977)	1.111 (0.671)	1.112 (0.282)	0.278 (0.173)	0.278 (0.226)	0.000 (1.000)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.944 (1.122)	1.389 (0.793)	0.970 (0.346)
Others	3.722 (0.859)	3.611 (0.776)	0.149 (0.883)	0.444 (0.271)	1.000 (0.732)	0.712 (0.486)	0.111 (0.076)	0.056 (0.056)	0.566 (0.579)	0 (0)	0 (0)	0 (0)	4.278 (0.918)	4.667 (1.323)	0.469 (0.645)

*Bold values significant at $\alpha = 0.05$.

Table 2. Models tested using logistic regression for the development of a single most parsimonious model (rank 1) to predict timber rattlesnake basking habitat and associated values of several combinations of variables tested (see text).

								Hosmer and Lemeshow Test	
Rank	**Model**	**% concordant**	**AIC**	**ΔAIC**	**w_i**	**-2 log L**	**Somers'D**	**Chi-square**	**P-Value**
1	Aspecr_sin_trans+Slope_deg+Landform_index+Percent_forest_cov	96.7	195.336	0.000	0.9991	185.336	0.934	2.349	0.9684
2	Aspect_sin_trans+Slope_deg+Landform_index	96.2	209.460	14.124	0.0009	201.460	0.925	6.399	0.6026
3	Slope_deg+Landform_index+Percent_forest_cov	95.0	234.303	38.967	0.0000	226.303	0.900	9.930	0.2700
4	Aspect_sin_trans+Landform_index+Percent_forest_cov	94.7	243.013	47.677	0.0000	235.013	0.894	6.107	0.6352
5	Slope_deg+Landform_index	94.4	250.547	55.211	0.0000	244.547	0.889	17.364	0.0265
6	Aspect_sin_trans+Slope_deg+Percent_forest_cov	93.3	269.915	74.579	0.0000	261.915	0.866	3.567	0.8939
7	Aspect_sin_trans+Slope_deg+Elev_meter+Percent_forest_cov	93.3	271.051	75.715	0.0000	261.051	0.867	4.556	0.8038
8	Aspect_sin_trans+Slope_deg+Elev_meter	92.0	289.498	94.162	0.0000	281.498	0.841	13.495	0.0959
9	Aspect_sin_trans+Slope_deg	91.8	292.358	97.022	0.0000	286.358	0.837	9.065	0.3369
10	Landform_index+Percent_forest_cov	91.7	297.658	102.322	0.0000	291.658	0.835	1.832	0.9857
11	Slope_deg+Percent_forest_cov	91.0	308.471	113.135	0.0000	302.471	0.821	7.847	0.4485
12	Slope_deg+Elev_meter+Percent_forest_cov	91.0	309.943	114.607	0.0000	301.943	0.921	2.785	0.9471
13	Aspect_sin_trans+Percent_forest_cov	89.8	328.525	133.189	0.0000	322.525	0.797	27.653	0.0005
14	Slope_deg+Elev_meter	89.7	331.009	135.673	0.0000	325.009	0.794	9.388	0.3106
15	Slope_deg	89.5	333.430	138.094	0.0000	329.430	0.790	11.243	0.1883
16	Aspect_sin_trans+Landform_index	88.7	338.301	142.965	0.0000	332.301	0.775	4.747	0.7843
17	Elev_meter+Percent_forest_cov	86.1	374.656	179.320	0.0000	368.657	0.724	29.689	0.0002
18	Percent_forest_cov	87.0	385.805	190.469	0.0000	381.805	0.742	47.246	0.0001
19	Aspect_sin_trans+Elev_meter	84.9	389.359	194.023	0.0000	383.359	0.700	7.372	0.4970
20	Landform_index	82.2	408.655	213.319	0.0000	404.655	0.647	18.107	0.0204
21	Elev_meter	75.9	461.780	266.444	0.0000	457.780	0.521	28.463	0.0004
22	Aspect_sin_trans	74.4	462.824	267.488	0.0000	458.824	0.494	9.059	0.3373

Table 3. Coefficient estimates and associated values for the most parsimonious top-ranking logistic model.

	DF	**Coefficient Estimate**	**Standard Error**	**Wald Chi-Square**	**P-value***
Intercept	1	-12.8892	1.8342	49.3797	<0.0001
Aspect SIN Transformed	1	4.0733	0.7426	30.0884	<0.0001
Slope (degrees)	1	0.1423	0.0234	36.8351	<0.0001
Landform Index	1	7.2874	1.0719	46.2173	<0.0001
Percent Forest Cover	1	6.9505	1.8683	13.8405	0.0002

*Alpha = 0.05

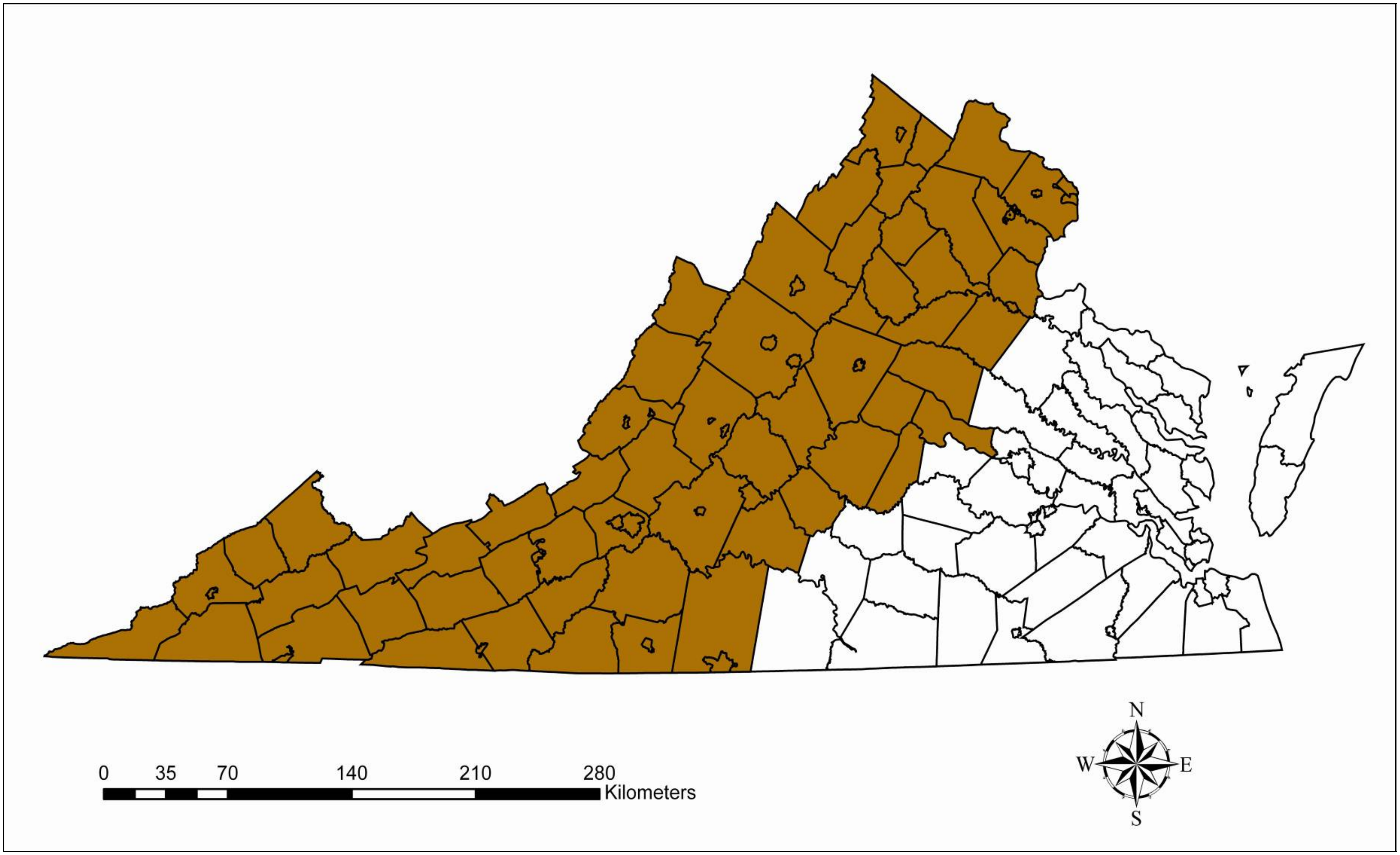

Figure 1. Map showing the range of the study area. Shaded counties represent the area in which we studied timber rattlesnake habitat in Virginia.

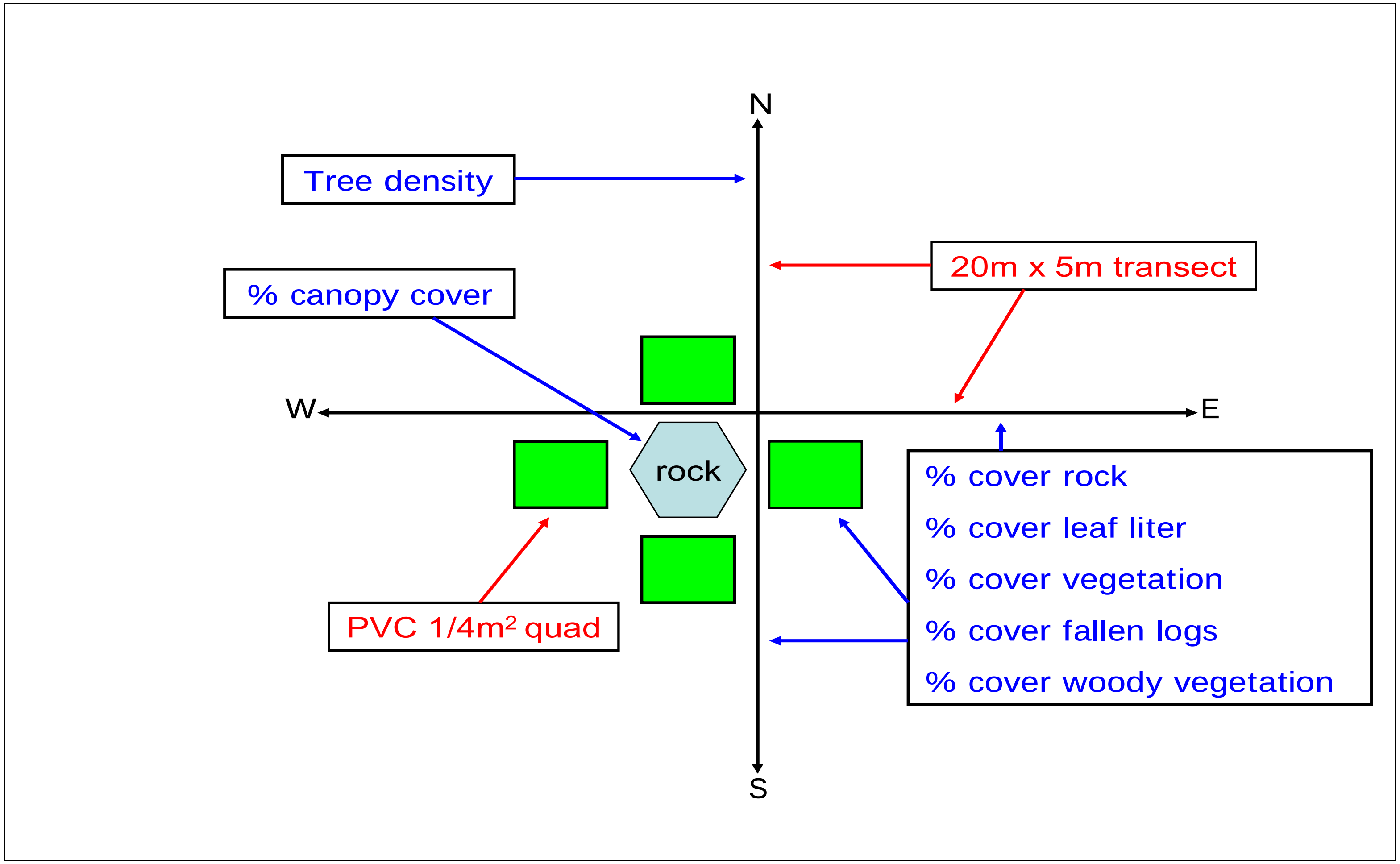

Figure 2. Schematic outline of sampling procedures and variables measured to describe basking habitat of timber rattlesnakes.

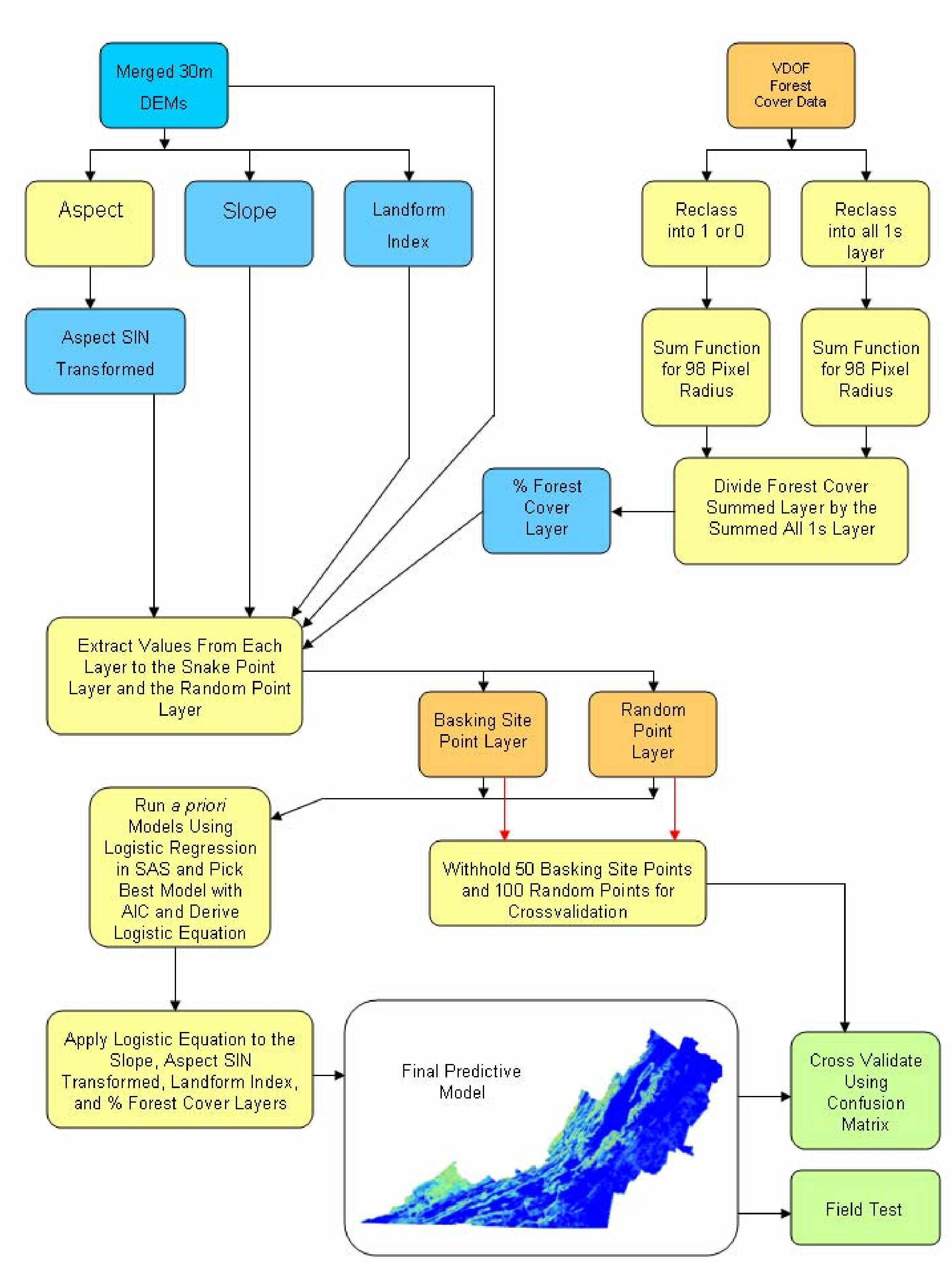

Figure 3. Flowchart showing the methodology used in creating a best-supported timber rattlesnake basking habitat model using logistic regression. The final predictive model pertains to the area mapped in Virginia. In this flowchart blue = data layer; yellow = method step; orange = intermediate data layer; green = model test.

Figure 4. An open talus slope (Smyth Co., Virginia) with an average overhead canopy closure of 67 percent. This locality is a known basking habitat. (Photo: June 2005, David Garst)

Figure 5. An open ledge-top basking site with an average overhead canopy closure of 1 percent. This locality (Scott Co., Virginia) is a known basking area for timber rattlesnakes. (Photo: July 2005, David Garst)

Figure 6. A basking site consisting of several rock slabs lying on the forest floor with an overhead canopy closure of 58 percent. This site (Craig Co., Virginia) is a known timber rattlesnake basking site. (Photo: September 1998, David Garst)

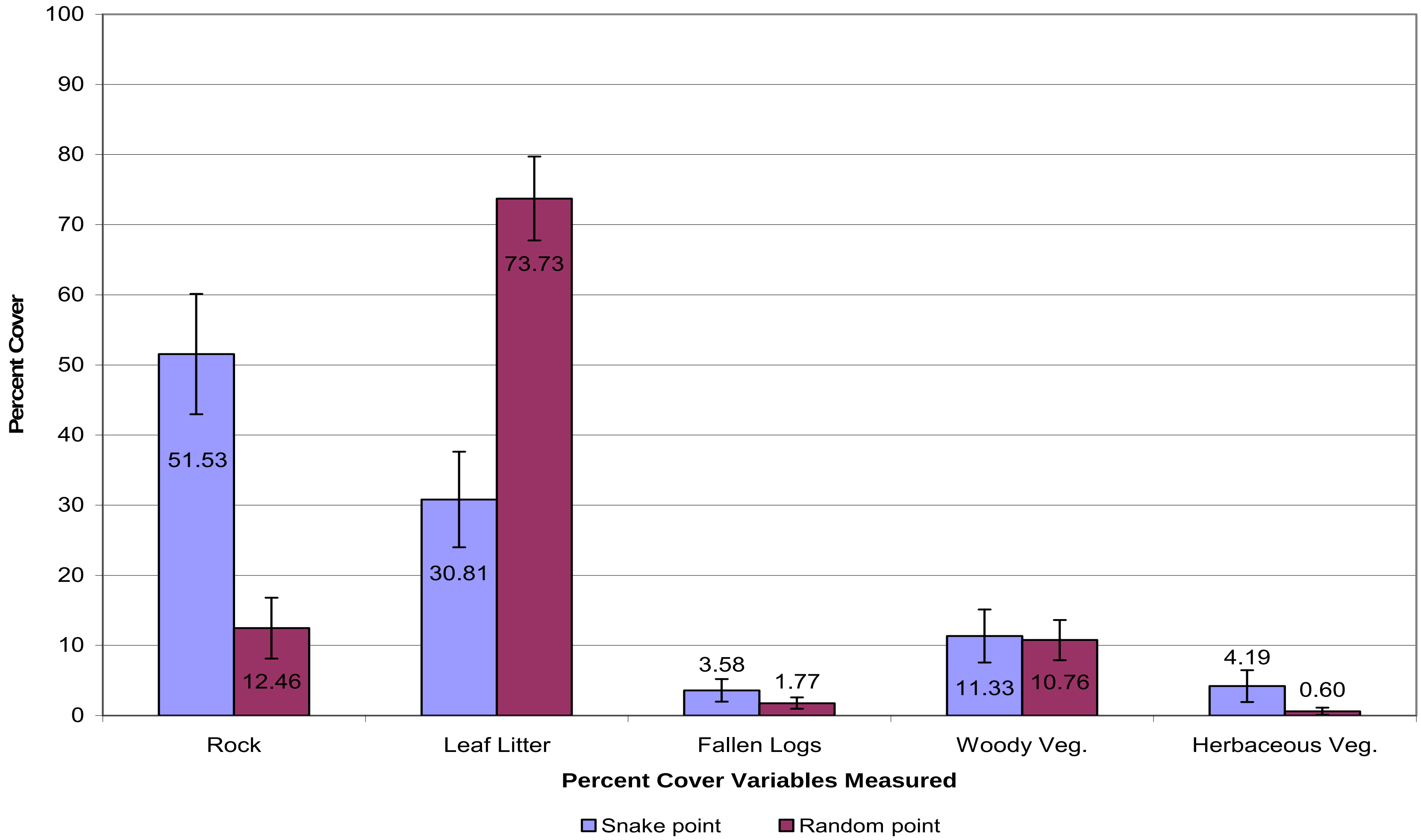

Figure 7. Mean values of the percentage cover variables immediately surrounding the basking sites (measured in the 0.25 m^2 quadrats) at each snake point and at a random point. Error bars represent ±1 standard error. N = 18 sites for all categories.

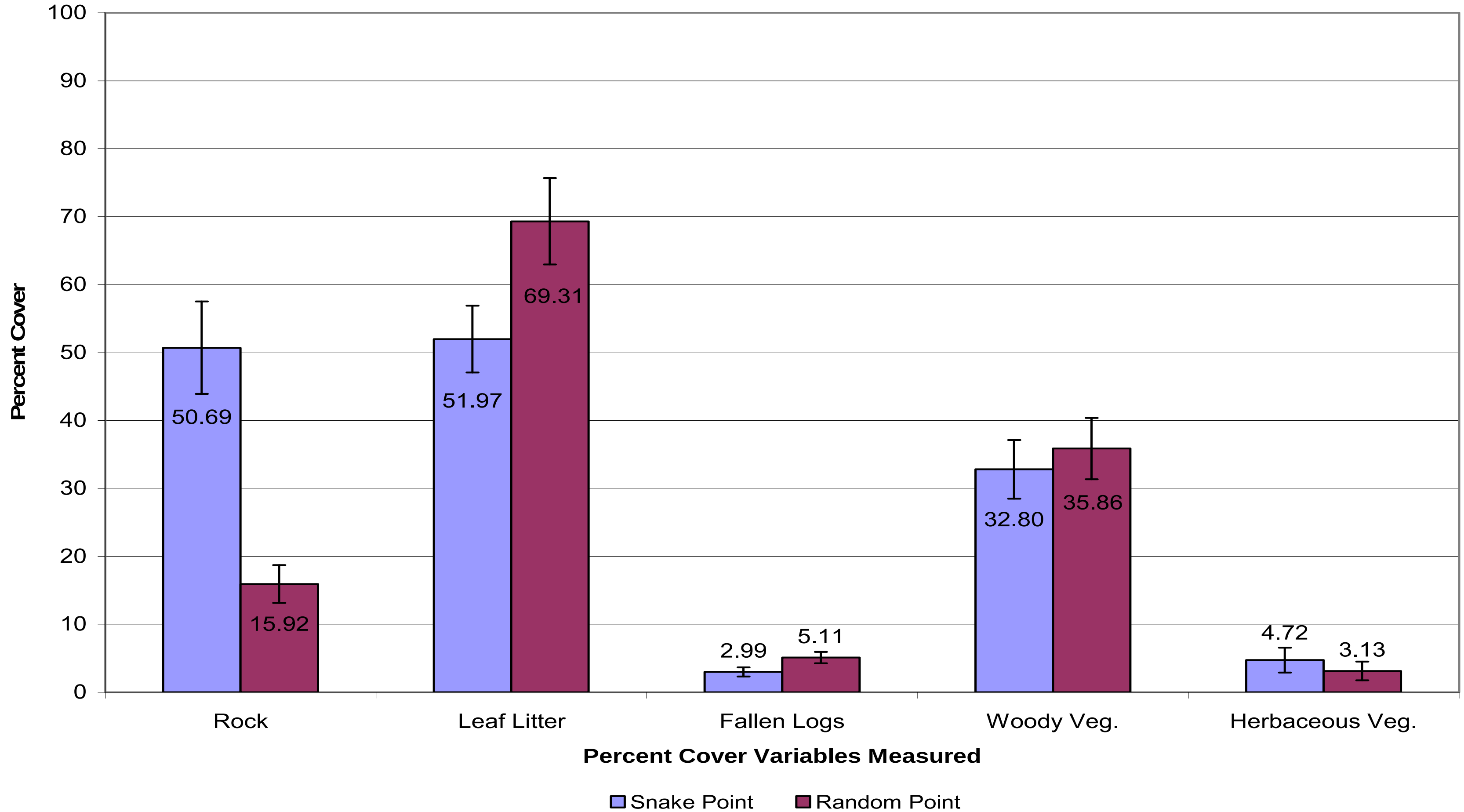

Figure 8. Mean values for the percentage cover variables in the area surrounding the basking sites (measured along the 20 meter transects). Error bars represent ±1 standard error. N = 18 sites for all categories.

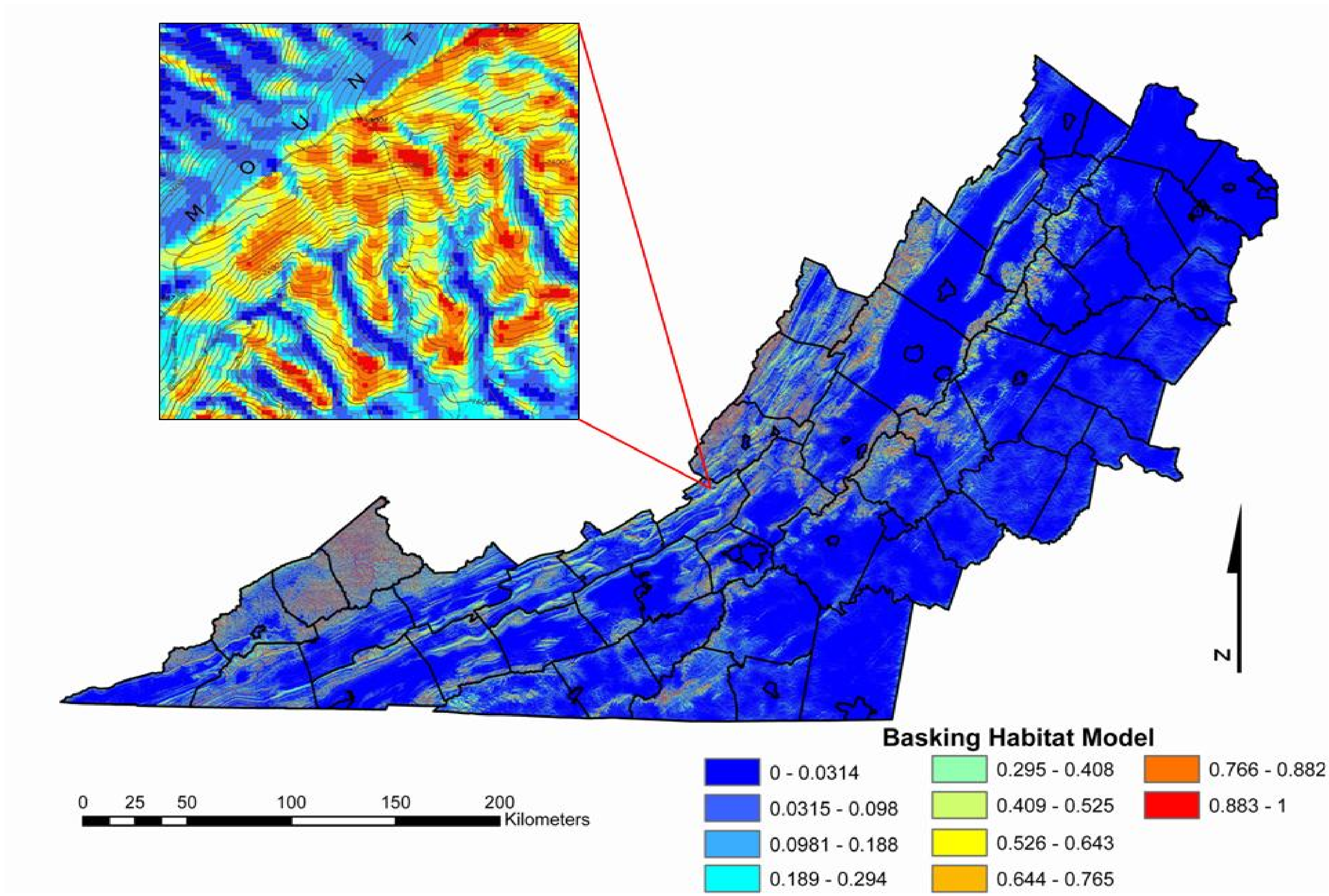

Figure 9. Probability map created using logistic regression to predict areas potentially containing timber rattlesnake basking habitat within their known range in Virginia. Inset map shows a close-up view of the model map.

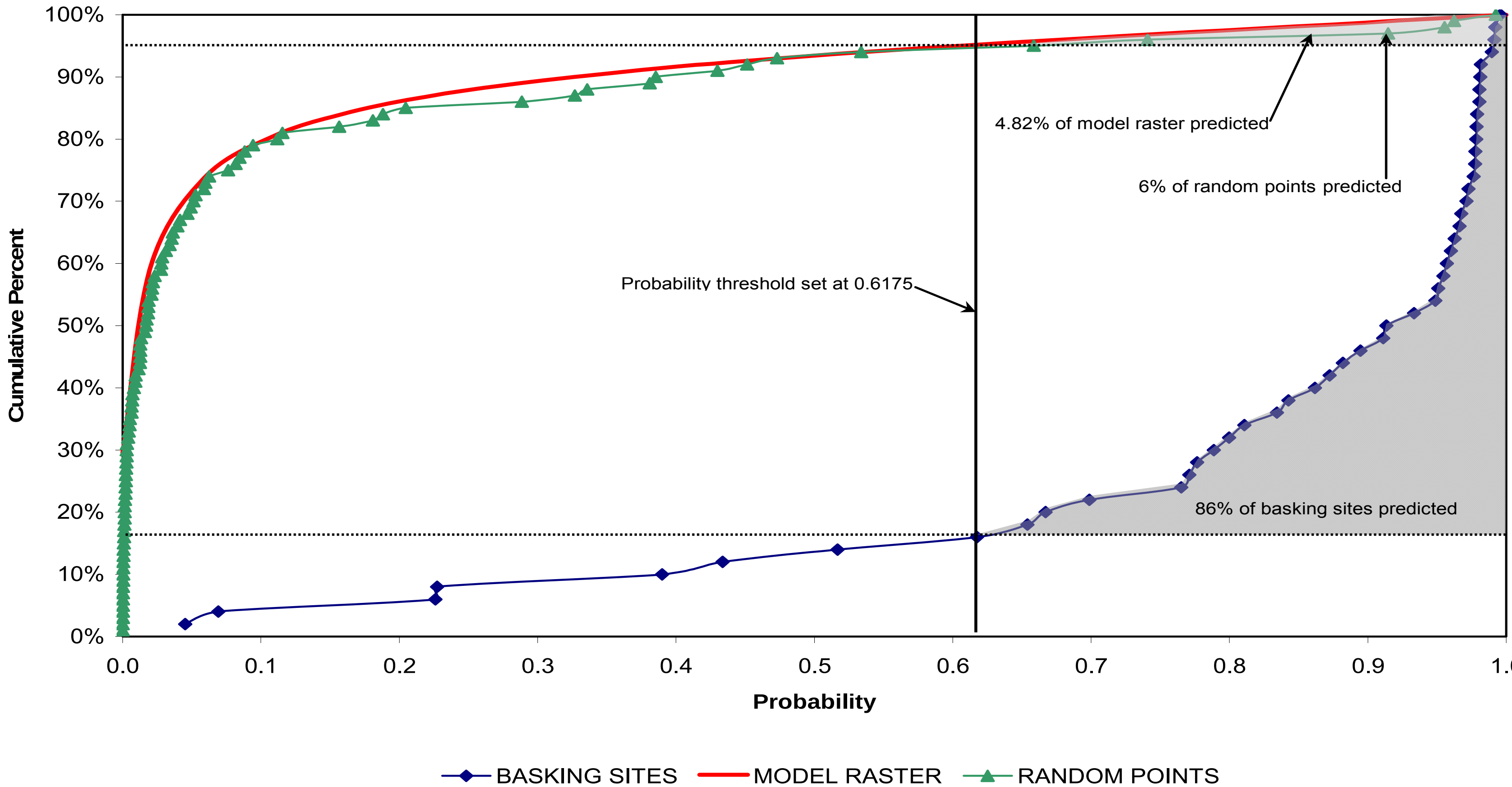

Figure 10. Distribution of basking site points and random points (withheld from model development for cross-validation) compared to the distribution of pixels in the model raster.

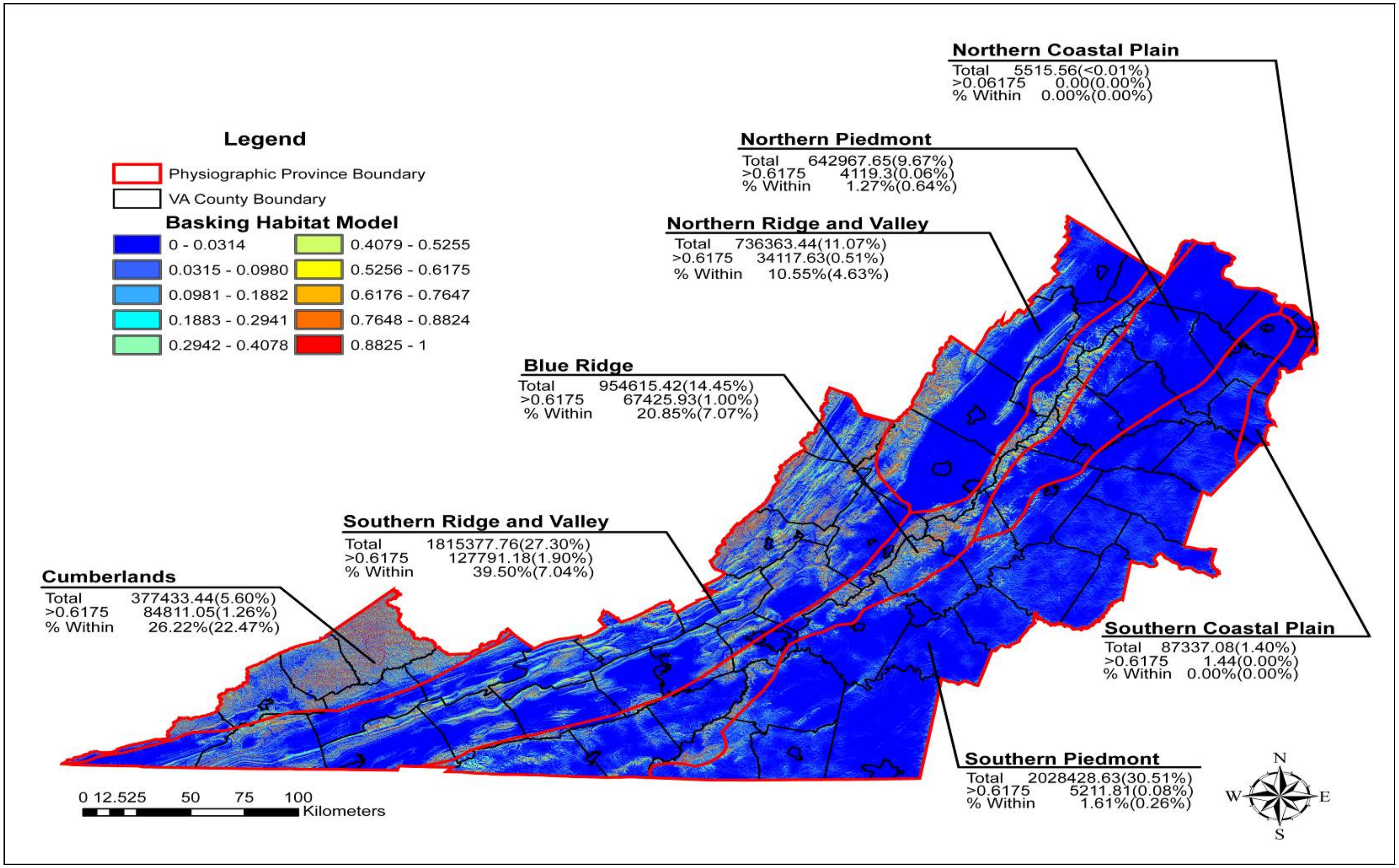

Figure 11. A map showing the physiographic provinces of Virginia within the study area overlaid on the timber rattlesnake basking habitat model. The total area (Total) in hectares for each physiographic province is given with the percentage of the entire map made up of the province given in parentheses. The area in each physiographic province with a probability ≥0.6175 (>0.6175) of having timber rattlesnake basking habitat is given in hectares with the percentage of the area ≥0.6175 for the entire map found within the province in parentheses. The percentage of the total map area with a probability ≥0.6175 for having timber rattlesnake basking habitat within (Within) each physiographic province is given for each physiographic province with the percentage of the total area within each physiographic province with a probability ≥0.6175 of having timber rattlesnake basking habitat given in parentheses.

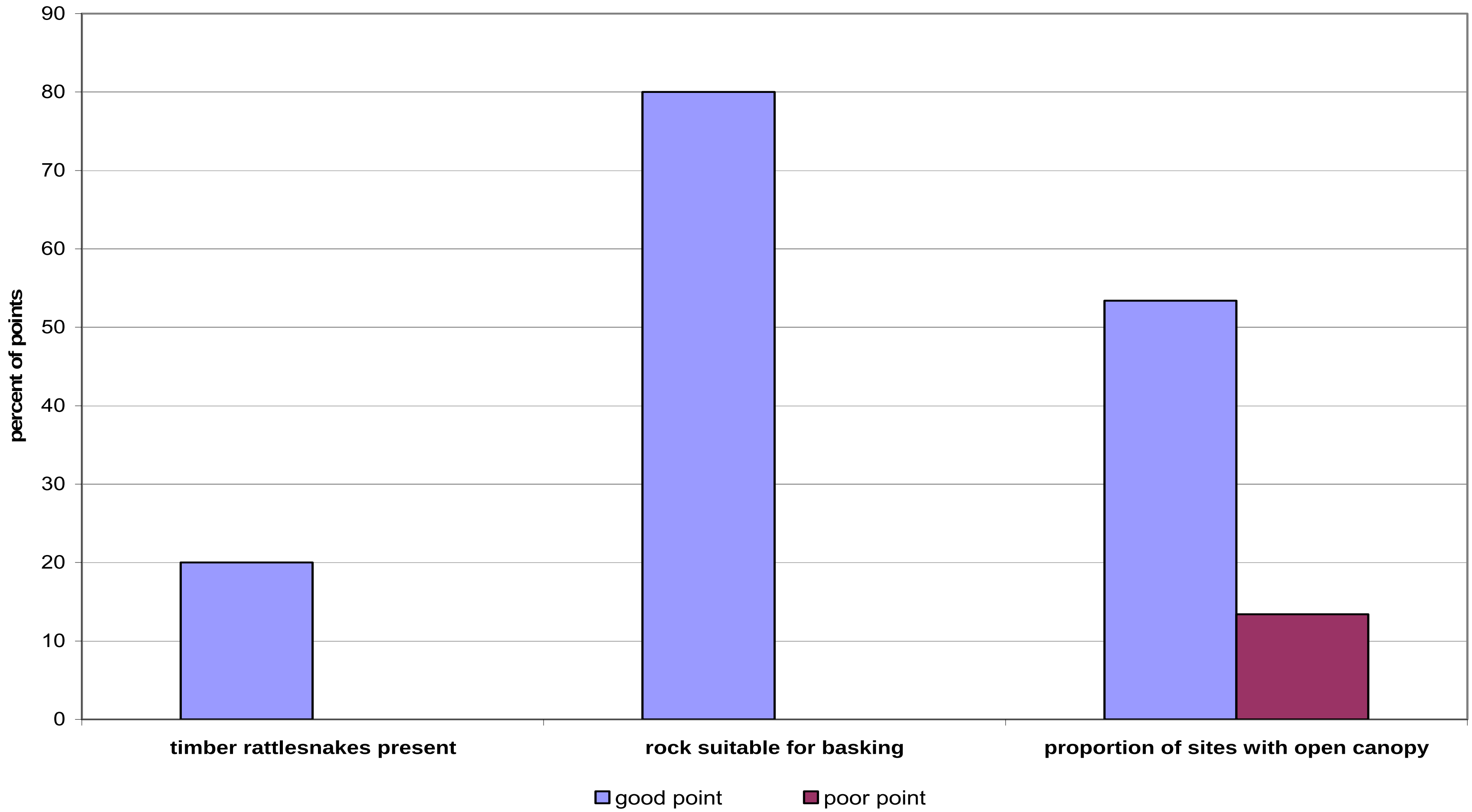

Figure 12. Results of basking habitat model field test at Goshen Wildlife Management Area, Rockbridge County, Virginia, showing that the locations predicted to be high quality basking habitat were likely to have suitable habitat (rock cover and open canopy), and in several cases did support rattlesnakes.

Chapter 2. The Historic and Current Range of the Timber Rattlesnake in Virginia

Introduction

The timber rattlesnake is a wide-ranging species that is currently found in 30 states in the eastern half of the United States (Conant and Collins 1998; Tennant 2003). In Virginia, it is currently limited to the western mountainous counties, except for the canebrake morph which is found in far southeastrn Virginia (Mitchell 1974; Linsey and Clifford 1981; Mitchell 1994; Mitchell and Reay 1999). Mitchell (1974) gives a generalized map with the mountain counties shaded. Linzey and Clifford (1981) place dots in counties where there is a record of timber rattlesnakes. Mitchell (1994) and Mitchell and Reay (1999) use mainly museum records that were verified (by Dr. Mitchell) along with some literature and collection permit records. The range maps for the timber rattlesnake in Virginia are either very generalized or consist of dots that may be incomplete because of a lack of specific records for some areas. A map that combines the general and the specific is needed for the timber rattlesnake in Virginia.

The historic range of the timber rattlesnake is a very difficult quantity to determine. In Virginia, the timber rattlesnake's range appears to have extended statewide historically (Mitchell 1994). No study of the historic range of the species has used place names as an indication of range. Place names can be an effective indicator to locate the spatial distribution of a species' historic range (Cox et al. 2002). By comparing the historic and current distribution of a species, it is possible to gain insights into factors that may be responsible for declines or changes.

The goal of this study was to determine the current and historic distribution of the timber rattlesnake in Virginia using literature records, museum records, place names, site surveys, snake hunter observations, a survey (sent out to agency personnel asking for observations), and collection permit records.

Methods

Historic range of the timber rattlesnake in Virginia was determined by examining Virginia locality records from databases, and published and unpublished (gray) literature, and using maps to locate rattlesnake place names (e.g. “Rattlesnake Hill” or “Rattlesnake Creek”). These data were compared to the data from the current range to detect differences between the current and historic ranges.

The current range of the timber rattlesnake in Virginia was determined by conducting site surveys, surveying and interviewing people whose work puts them in timber rattlesnake habitat (e.g., U.S. Forest Service personnel, Virginia Department of Game and Inland Fisheries employees) throughout the state, interviewing snake hunters, and examining records from museums, databases, and publications.

Sites were selected to survey in the field if they met the following criteria: (1) some report of timber rattlesnakes in the area within the last twenty-five years, (2) no recent prior surveys for timber rattlesnakes have been conducted in the area, (3) basking/gestating habitat in the form of rock outcrops, slides and/or slabs appeared on aerial photos of the area in question, and (4) the location would fill in gaps in the current knowledge about timber rattlesnake distribution in Virginia. All distribution surveys were conducted in the summer of 2005. Each survey consisted of searching the available apparent basking/gestating habitat plus the immediate surrounding area for timber rattlesnakes or freshly shed skins to verify the snake’s presence.

Employees of the Virginia Department of Game and Inland Fisheries and the United States Forest Service in Virginia were surveyed and interviewed to ascertain locality data. A survey was distributed to them to fill out and return if they were not directly interviewed (See Appendix 4 for survey form). Information collected from the surveys included contact information of the person being surveyed, and, for each observation of a timber rattlesnake, state, county, exact locality or GPS coordinates, habitat category (road, forest, field, residential, agricultural, or industrial/commercial), and property owner name and contact information.

Snake hunters were interviewed to collect timber rattlesnake site locality data. The same data were collected as with the agency employees and their contact information was recorded. Snake hunters were located mainly through word of mouth.

A database of museum records and scientific collection permit records maintained by the Virginia Department of Game and Inland Fisheries was searched for timber rattlesnake records. Virginia localities were searched for in the literature in the form of journal articles and reports to state and federal agencies. I searched Wildlife and Ecology Worldwide, Web of Science, and Google Scholar entering the words "timber rattlesnake", "*Crotalus horridus*", and "Virginia" to search for pertinent literature.

Results

Literature Review

While conducting this literature review many of the records were mentioned in multiple works, so when reported here they are mentioned only from the first published work. Locations of all of the published records that could be placed on a map are in Figure 1. Lederer (1672) mentioned finding a rattlesnake at the falls of the York River in

King William County on 9 March 1669. Byrd (1728) gave 3 locations for timber rattlesnakes in Virginia in Halifax, Mecklenburg, and Greensville counties. Dunn (1915a) collected a single timber rattlesnake 64 km downstream from Lynchburg on the James River (Nelson County). At White Horse (Clarke Co.), 3.2 km upstream from Berry's Ferry on the Shenandoah River, Dunn (1915b) collected a timber rattlesnake swimming in the river. Gloyd (1940) listed a total of 12 records for Virginia of which, 4 are previously mentioned from Dunn (1915a and b and 1918), 7 are museum records (included in Figure 2), and the remaining record is for Alexandria, Virginia. Hoffman (1945) said several specimens had been killed in and near Clifton Forge. At Mountain Lake Biological Station in Giles County, 19 timber rattlesnakes were collected for a study of timber rattlesnake diets (Smyth 1949). Wood (1954) listed a total of 96 records from 36 counties for the timber rattlesnake in Virginia. Of these 96 records, 14 could not be plotted on a map because of a lack of location information and an additional 15 are museum records plotted in Figure 2. The remaining 67 location records are shown in Figure 1. Wood (1954) listed a record from Floyd County at mile 169 on the Blue Ridge Parkway but, this record is incorrect because mile 169 on the Blue Ridge Parkway is on the border between Roanoke and Franklin Counties. Martin (1964) listed Piney Mountain in Nelson County and Smith Mountain in Pittsylvania County. Burger (1975) collected a timber rattlesnake 2.4 km northeast of Cumberland Gap at a place called Willis Hollow and Willis Hollow Cave. Mitchell and Pague (1984) disputed the record, considering it in error as they were unable to locate Willis Hollow or Willis Hollow Cave. Wood (1981), in a history of Floyd County, said the adventurous young men would go up on Buffalo Mountain (Floyd Co.) in the spring of the year and kill the sluggish timber rattlesnakes as they emerged from their dens. A single specimen was observed along VA route 257 just west of Bridgewater, in Rockingham County, Virginia (Jopson 1984). Mitchell and Pague (1984) found a shed skin from a timber rattlesnake at an old burned house 3.2 km east of Jonesville, but found no live specimens. Nicoletto (1985) found timber rattlesnakes on the west end of Sinking Creek Mountain in Montgomery County and the west end of Gap Mountain just above the New River, also in Montgomery County. In Alleghany County, timber rattlesnakes were found on Middle Mountain, Warm Springs Mountain, and in Rich Patch, Clifton Forge, and Longdale (Hoffman 1986). The record for Longdale is a museum record shown here in Figure 2. In 1991, 2 specimens of the timber rattlesnake were observed dead on a road in Prince William Forest Park, Prince William County, Virginia (Martin et al. 1992). Both specimens are now museum records (Figure 2). Ernst et al. (1997) mention a museum specimen from Tremont in Fairfax County, Virginia (Figure 2).

Several other works mentioned timber rattlesnakes in Virginia but only mentioned them as occurring in a large geographic area whose locations could not be plotted on a map (Uhler et al. 1939; Burch 1940a and b; Carroll 1950; Addington 1967; Bruner 1975; Freer and Hanenkrat 1980). Dunn (1918) listed specimens of the timber rattlesnake observed from Augusta, Bedford, Buckingham, Clarke, Loudoun, Nelson, and Rappahannock counties in Virginia. Martin (1979) described finding timber rattlesnakes along the Blue Ridge Parkway and Skyline Drive. A timber rattlesnake is mentioned being collected in Bedford County with no specific location given by Craig (1967). Harrison (1959) said Virginia has a sizeable population of timber rattlesnakes in the mountainous areas. The timber rattlesnake is reported to occur on Stone Mountain in southwest Virginia (Anderson 1979). The headwaters area of the Potomac River in Highland County, Virginia, is reported as a haunt for timber rattlesnakes by Watson (1953). In a short article on the three poisonous snakes of Virginia, the timber rattlesnake is said to be of general occurrence in the elevated parts of Virginia (Anonymous 1953). One record was found for timber rattlesnakes occurring on Mount Rogers, but not enough location information was given to place it on a map (Orrick 1961). Wright (1987), while looking at the activity of venomous snakes in the area around the Peaks of Otter in Bedford County, Virginia, observed 59 timber rattlesnakes from 1981 to 1983. Klauber (1997) mentions timber rattlesnakes from the areas around the cities of Blacksburg, Bridgewater, and Duffield.

Some of the more current volumes published on the snakes or reptiles of Virginia provide range maps. Linzey and Clifford (1981) show a dot in each county having some record of timber rattlesnakes. Mitchell (1994) and Mitchell and Reay (1999) are the most recently published volumes to give detailed maps for the range of the timber rattlesnake in Virginia using specific records. Mitchell (1994) used only museum records that the author verified as correctly identified as well as several records from the literature. Mitchell and Reay (1999) used museum records and timber rattlesnake observations that were reported to the Virginia Department of Game and Inland Fisheries through scientific collecting permit reports. Pinder and Mitchell (2001) gave a generalized range map that shows the timber rattlesnake as being distributed in the western mountainous counties of the state.

Museum Records

Figure 2 shows the museum records for the timber rattlesnake in Virginia. Among the 101 museum records mapped in Figure 2, 96 were provided by the Virginia Department of Game and Inland Fisheries through their database. Museum records provided by the Virginia Department of Game and Inland Fisheries were also used in Mitchell (1994) and Mitchell and Reay (1999). The remaining five museum records were located in the literature (Wood 1954, Ernst et al. 1997).

Place Names

The search of the USGS's Geographic Names Information System turned up 15 place names in Virginia with a name of "rattlesnake". All of these places are shown in Figure 3. "Rattlesnake Trail" in Fauquier County is located on "Rattlesnake Mountain". One place with a location in Washington County has the name of "Rattle Creek". There were five rattlesnake place names that fell outside of the current range of the timber rattlesnake in Virginia. They are Rattlesnake Creek in Brunswick County, Rattlesnake Creek in Campbell County, Rattlesnake Branch in Charlotte County, Rattlesnake Run in Fluvanna County, and Rattlesnake Creek in the City of Richmond. A Rattler Branch in Prince Edward County is also extra limital for the timber rattlesnake in Virginia.

The search for place names with the word "snake" in the name turned up 17 place names. Two of these could not be located on a map, ("Snake Swamp" in Northumberland county and "Snake Den Ridge" in Smyth County). All of the place names are shown on the map in Figure 3. There were five places outside of the current range for the timber rattlesnake that had names containing the word "snake". They are Snakeden Branch in Fairfax County, Snake Creek in Halifax County, Snake Island in Richmond County, Snake Branch in Sussex County, and Snake Island in Westmoreland County. Appendices 5 and 6 provide the data collected from the USGS search for place names of “snake” and “rattlesnake” in Virginia.

Site Surveys

During the summer of 2005 I conducted a total of 17 site surveys in 12 counties to attempt to locate a timber rattlesnake or evidence of one. The locations were selected in order to fill in gaps or expand the known range. A list of these sites and what was found at each is given in Table 1. Timber rattlesnakes were found at three of the sites visited and I obtained at least a verbal record from the landowner or agency personnel that timber rattlesnakes existed (had been sighted within the last 10 years) in the area of all of the remaining 14 sites except Bear Pen Ridge in Grayson County. Bear Pen Ridge is part of the Mount Rogers complex and I was unable to locate anyone who had actually seen a timber rattlesnake from this area, even though stories of their existence on Bear Pen Ridge were plentiful. I spoke with a gentleman who worked in Grayson Highlands State Park for 40 years and he said he has heard all of the stories of the rattlesnakes on Bear Pen Ridge from the old-timers but in 40 years he never observed a venomous snake of any kind in the area (Kenny Weaver, pers.comm.). This same gentleman also mentioned never seeing a venomous snake on the roads in the area, dead or alive, in a period of 40 years.

Interviews of Snake Hunters

Five snake hunters were contacted and three of them were interviewed to gain location information data. Gale McConnell provided 33 timber rattlesnake sites in Lee, Scott, and Wise Counties in southwest Virginia. Five of 18 sites provided by Tim Selmon were in Highland County, Virginia, with the remaining sites located in West Virginia. Richard Evans, who catches and provides timber rattlesnakes to the snake handling church in Jolo, West Virginia, provided 7 sites in Buchanan County, Virginia. James Mitchell provided one location in Washington County, Virginia. Dan Wells was contacted but he was unwilling to share location information. Most of the sites known by Wells were also known by McConnell. These snake hunter locations provide evidence of 46 extant populations of timber rattlesnakes in Virginia. All of the location information gained from these individuals is from within the known range of the timber rattlesnake in Virginia. This information was not put into a map because they are actual timber rattlesnake basking site and den locations that need to be protected.

Agency Personnel Survey

Timber rattlesnake sighting location forms were sent out to all of the Virginia Department of Game and Inland Fisheries wildlife biologist managers and fisheries biologist managers to be dispersed to employees supervised by them. The same form was also sent to all of the wildlife biologists within the US Forest Service in Virginia to be dispersed to people in their offices. A total of 88 site observations in 20 counties were collected through this survey. VDGIF employees provided 85 of the observations from 15 employees while 3 of the observations came from a single individual USFS employee.

All of the observations are within the current range of the timber rattlesnake and are shown in Figure 4.

The agency survey form sent out had general questions that asked about the number of years since the sighting had occurred, what type of habitat the observation was within, who owned the property where the observation took place, and the general size of the rattlesnake seen. Because not all respondents answered all questions, sample size varied for each response. Figure 5 shows that out of 31 sightings, equal numbers occurred within one year and in 1 - 5 years. Of 86 sightings, 41 occurred on roads (Figure 6). Despite most of the responses being Virginia Department of Game and Inland Fisheries personnel, 31 of 79 sightings occurred on U.S. Forest Service land (Figure 7). This plot also shows that most of the roads the snakes were observed on were forest access roads. Of 30 sightings, the majority of rattlesnakes observed by agency personnel were adult specimens greater than 76.2 cm (Figure 8). This could be because adults are simply larger and easier to see whereas juveniles evade detection.

VDGIF Collection Permit Records

Figure 4 displays the 26 location records reported on scientific collection permits provided by the Virginia Department of Game and Inland Fisheries. Some of the symbols are close enough to one another as to cause overlap on the map. One snake collected in Hanover County, on 18 September 2002 represents a sighting outside the current ranges for either the timber or canebrake rattlesnake. This record could be evidence that the timber rattlesnake could possibly still exist in the Piedmont and inner Coastal Plain of Virginia but at such low levels that it evades detection most of the time. All of the other records, both old and new, provided were within the current range of the timber rattlesnake.

Historic Range

Historically the timber rattlesnake occurred throughout all of Virginia (Mitchell 1994). Because of a lack of museum specimens and sightings from the Piedmont and inner Coastal Plain, the location of places with "rattlesnake" in their name in the Piedmont and inner Coastal Plain provide some evidence of their occurrence in these areas (Figure 3). The timber rattlesnake was probably not as widespread in the Piedmont and inner Coastal Plain as they are in the mountains. This could be because of the need for a suitable winter den. In the Piedmont and inner Coastal Plain, the exposed rock necessary for denning is located along stream corridors and this probably restricted the snakes to certain sites where they were locally abundant, but also subjecting such populations to higher amounts of persecution (W.H. Martin, pers. comm.). The estimated historic range for the timber rattlesnake in Virginia is shown in Figure 9.Widespread deforestation in these areas in the nineteenth century, making the land suitable for agriculture, probably exterminated many of these populations. There are four records in the literature for the Piedmont and inner Coastal Plain from Byrd (1728) and Lederer (1672), and these are shown in Figure 1. Just below the three records from Byrd (1728) in North Carolina there still exists a population of timber rattlesnakes in Granville and Durham Counties (Palmer and Braswell 1995). Evidence for historic occurrence on the Eastern Shore of Virginia includes, place name of "Rattlesnake Island" just north of the Virginia – Maryland line, and a letter written to Roger Conant mentioning two rattlesnakes killed on the Delmarva Pennisula, one near Bell Haven and the other near Jamesville (Mitchell 1994).

Current Range

Figure 9 shows the current range for the timber rattlesnake in Virginia. This range is based on known basking and denning areas (not published here) identified by W. H. Martin and me, and the three previously mentioned snake hunters who were interviewed. Also included are literature records, museum records, place names, site visits, personal communications, collection permit records, and a survey of state and federal agency personnel. All observations used are from within the most recent 50 years, i.e., from about 1960 to the present. Currently the timber rattlesnake is confined to the mountainous areas of Virginia in the Cumberland Mountains in the far southwest, the Ridge and Valley running from Frederick County in the north to Scott County in the south (and including the Great Valley), the Massanutten Mountains, and the Blue Ridge from Loudoun County in the north to Grayson in the south. Within this range, the timber rattlesnake is found on most of the major ridges and a few of the smaller ones. Most of the smaller ridges do not have the exposed rock suitable for basking that is needed, probably from a lack of fire. There is still a population of timber rattlesnakes on the Frederick and Shenandoah County line along Cedar Creek. Most of the other populations in the Great Valley (including the Shenandoah Valley) have probably been extirpated because of a lack of suitable basking and denning habitat and from the impacts of human development. They were probably never widespread in these valleys (W.H. Martin pers. comm.).

In the upper Piedmont, the snakes occur on small outlier mountains. These include Bull and No Business Mountains in Patrick County; Cahas, Grassy Hill, Fork, Chestnut, and Turkey Cock in Franklin County; Turkey Cock in Henry County; Smith Mountain in Pittsylvania and Bedford counties; King George and Johnson Mountains on the Bedford and Campbell County line; Appleberry Mountains and Carter Mountain in Albemarle County; Buzzard Mountain in Culpeper County; and the Bull Run Mountains on the Faquier and Prince William County line. The species is still occasionally found in the area of Prince William Forest Park and Quantico Marine Base in southern Prince William and northern Stafford Counties. The area where Culpeper and Stafford counties meet along the Rapidan River still gets occasional sightings. In Appomattox, Amherst, Buckingham, and Nelson counties, the timber rattlesnake is still found in forested areas along the James River through southern Amherst and Nelson counties, and in northern Appomattox and Buckingham counties. Their range also extends southeast along the Appomattox and Buckingham County line. There is also a record for the town of Wintergreen in Appomattox County.

Discussion

When using literature records to establish a range for a species, caution is warranted. In some of the older literature, the records are vague and difficult to locate on a map, and place names have often changed over time. The regular use of GPS technology now makes most of the modern records much more reliable. The sighting from Lederer (1672) is a valid sighting, but the date in which it was observed is questionable (In 1669 the British colonies still followed the Julian calendar [Van Helden 1995], so 9 March would correspond to 19 March in our current, Gregorian calendar.

This date is still a week before the earliest known emergence of rattlesnakes in this area, however.). The rattlesnake was reported to have been seen at the Falls of the Pamunky, in King William County, on 9 March 1669 with a whole squirrel inside it. This date seems too early for timber rattlesnakes to be active and feeding in this area of the state. In a radiotelemetry study of the coastal plain population of the species (canebrakes) near Norfolk, Virginia, approximately 50 miles to the southeast of Lederer's observation, Savitsky and Peterson (2004) documented the earliest emergence as 25 March, and the mean date of emergence as 4 April. Animals may get transported to places where they do not currently exist. Two timber rattlesnakes found just outside of Richmond, Virginia, were later found to be intentionally released in that location (J.C. Mitchell pers. comm.). A rattlesnake was killed in the town of Irvington, Virginia, well outside of the current range for timber rattlesnakes in Virginia, and was believed to have come to the town on a truck from the mountains (Anonymous 1977). In Virginia, most other species, venomous and non-venomous, look different enough that there should be no confusion as to the identification of the timber rattlesnake in Virginia. Because some of the other species of snakes will vibrate their tail in dry leaves and other debris, there could be some confusion about the identification of the species making the rattling sound if the snake can not be clearly seen, especially by someone not trained in the identification of snakes.

Museum records also can have their problems. Most museums will not guarantee the record because of errors in transcription. Mitchell (1994) only used museum records that he had verified himself in plotting his map of the timber rattlesnake's range in Virginia.

The place names probably represent a place where a species was at one time historically locally abundant (Cox et al. 2002). Obviously, this is no guarantee that a rattlesnake ever occurred at a place named “Rattlesnake Creek”, for example, but some of the place names used in this study are within the current range of the timber rattlesnake in Virginia. The place names where there are no other records of timber rattlesnakes should be used with biogeography and knowledge of natural history to judge whether it is plausible for them to occur in these places.

One of the most certain ways to know if timber rattlesnakes occur in a location is to look for them. To verify presence, one only needs to find a live specimen or a freshly shed skin, but verifying actual absence is almost impossible. Some of the sites I visited quite likely were occupied by timber rattlesnakes, but because of hot dry weather, or just not finding the right spot, I was unable to find rattlesnakes. In the case of Bear Pen Ridge in Grayson County, there are many verbal records of timber rattlesnakes occurring there, but I could not locate a single person who had actually seen one. This locality needs more site visits to locate a live timber rattlesnake on this part of the Mount Rogers complex. There is a single record of a timber rattlesnake on Mount Rogers, but it does not say which part of the mountain, and the record was from the 1930s (Orrick 1961). Based on historic records and the GIS model, other areas without confirmed locations but with a reasonable probability of supporting timber rattlesnake populations are Buchanan County; Rattlesnake Creek, Campbell County; Rattlesnake Branch, Charlotte County; and Snake Run Ridge, Alleghany County.

Information gathered from snake hunters can be very useful, often including good site data and sometimes minimum population size estimates and information on how the population has declined from hunting pressure. Victor Bates (personal communication to W.H. Martin in 1981) said that the places he hunted in Scott, Lee, and Wise counties were at population levels about 15% of what they were originally (in 1942, when he started hunting rattlesnakes). There is no way to verify this, but clearly these people saw a decline from their actions over time because they found fewer and fewer rattlesnakes. Not all individuals can read a map and accurately plot locations, so some of the data have a certain amount of human error associated with them.

The agency personnel survey had some problems as well, with the people filling out the forms incompletely and a lower-than-expected response rate. This was the cause for the differing numbers of observations used in figures 5-8. This type of survey can be a very effective way to gather information on a species distribution, but a better method may be to conduct follow-up visits to each office to encourage people to place their observations on maps so that mailing forms back to the surveyor is not required.

Collection permit records have the same problems that the other observation records do. There is a certain amount of error in the locations, coming either from human error in plotting the location or from plotting errors in the GPS receiver.

It is impossible to be certain about historic presence or absence in most locations through the state. Because of “rattlesnake” and “snake” place names being distributed throughout the state, and the occasional timber rattlesnake turning up in a location outside of its current range we can make reasonable estimates as to where they previously occurred. It would be possible to investigate some of the early works and ascertain geographic areas where some of these travelers went. Many local newspapers from the Piedmont and Coastal Plain of Virginia in the nineteenth and twentieth centuries could provide new observations, but this is a very time-consuming endeavor. Someone searching the local newspapers should start with the most recent editions and search backwards because in order to find the most recent sighting in an area. Although time did not allow this approach here, interviewing people (e.g. game wardens, postal employees, school bus drivers) in areas of interest in the Piedmont and inner Coastal Plain, among others, could turn up new locality information.

The current range as determined in this study, as the historic range, is only an estimate. Because of mining, development, fire suppression, and other economic activities destructive to timber rattlesnake habitat, populations are being extirpated. But as human pressures are lessened at some areas, the timber rattlesnake populations may rebound in these places. The main concept is that a geographic range is ever changing on small scales and, as a result, it is difficult to know the location of all populations. Much work is still needed to continue to locate timber rattlesnake populations and to work with state and federal agencies to come up with a workable timber rattlesnake conservation plan to help protect and conserve this species over the long term.

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Table 1. Timber rattlesnake survey sites visited in the summer of 2005.

Date	Place	County	TR Present
15 June	Buffalo Mountain	Floyd	1 C*‡
16 June	Bear Pen Ridge	Grayson	1 garter snake
20 June	Snake Den Mtn.	Smyth	8 TR‡
23 June	Glade Mountain	Smyth	0‡
24 June	Brumley Rim/The Butt	Washington	0‡
27 June	Detroit Cove	Washington	0‡
5 July	Cahas Mountain	Franklin	3 TR†, 2 C‡
13 July	Bottom Creek Gorge	Montgomery	0‡
18 July	Buster Rock	Patrick	0‡
21 July	Stock Creek	Scott	0‡
25 July	Bull Mountain	Patrick	0‡
26 July	Ft. Lewis Mountain	Roanoke	0‡
27 July	Smith Mountain	Bedford	1 TR, 1 C‡
28 July	Sand Mountain	Wythe	0‡
2 August	Chimney Mountain	Pulaski	0‡
4 August	Red Rock Mountain	Smyth	0‡
5 August	Walker Mountain	Wythe	0‡

*C = copperhead, †Timber rattlesnake, ‡landowner or neighbor report recent TR sighting

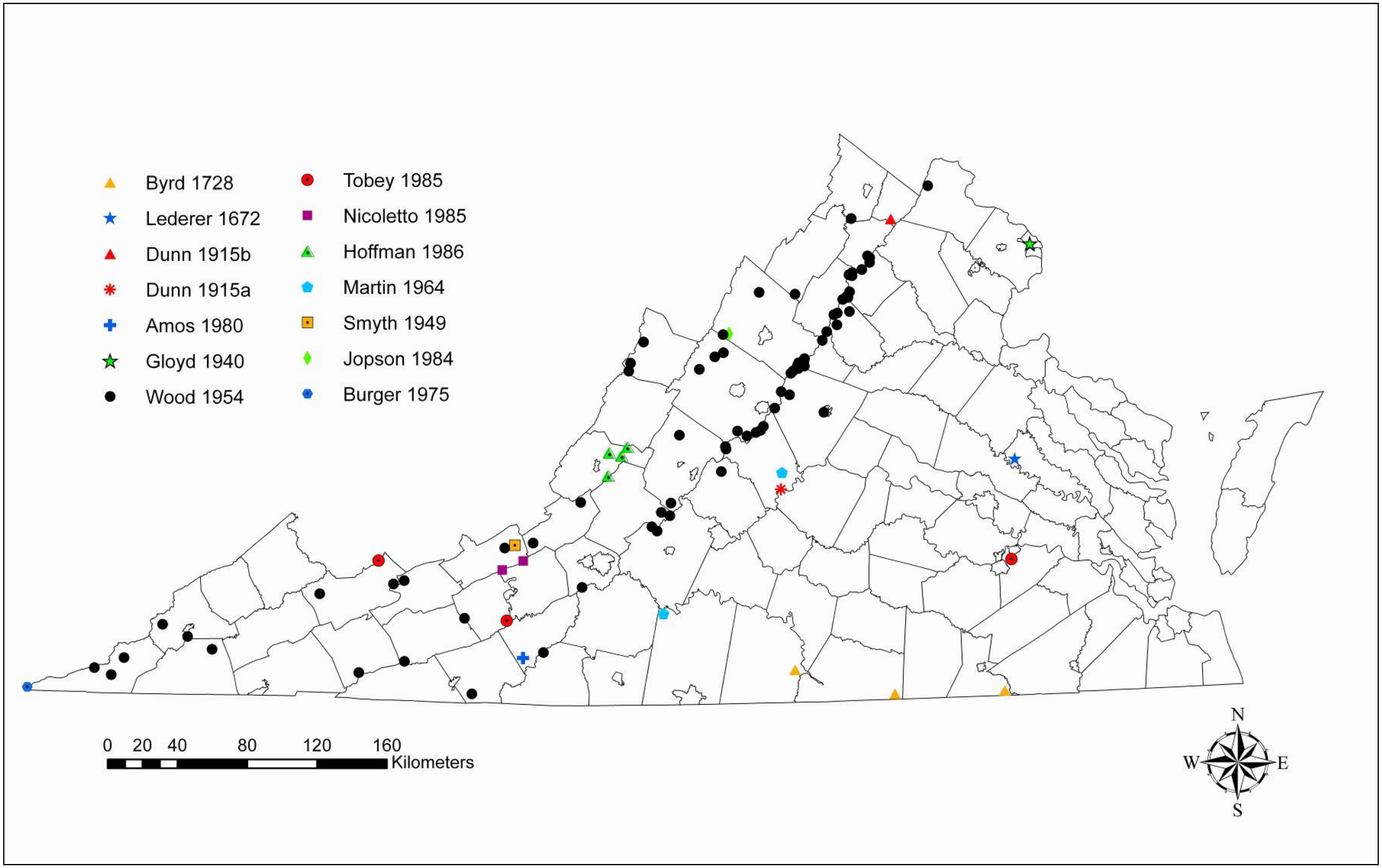

Figure 1. Records for the timber rattlesnake in Virginia found in the current and historic literature.

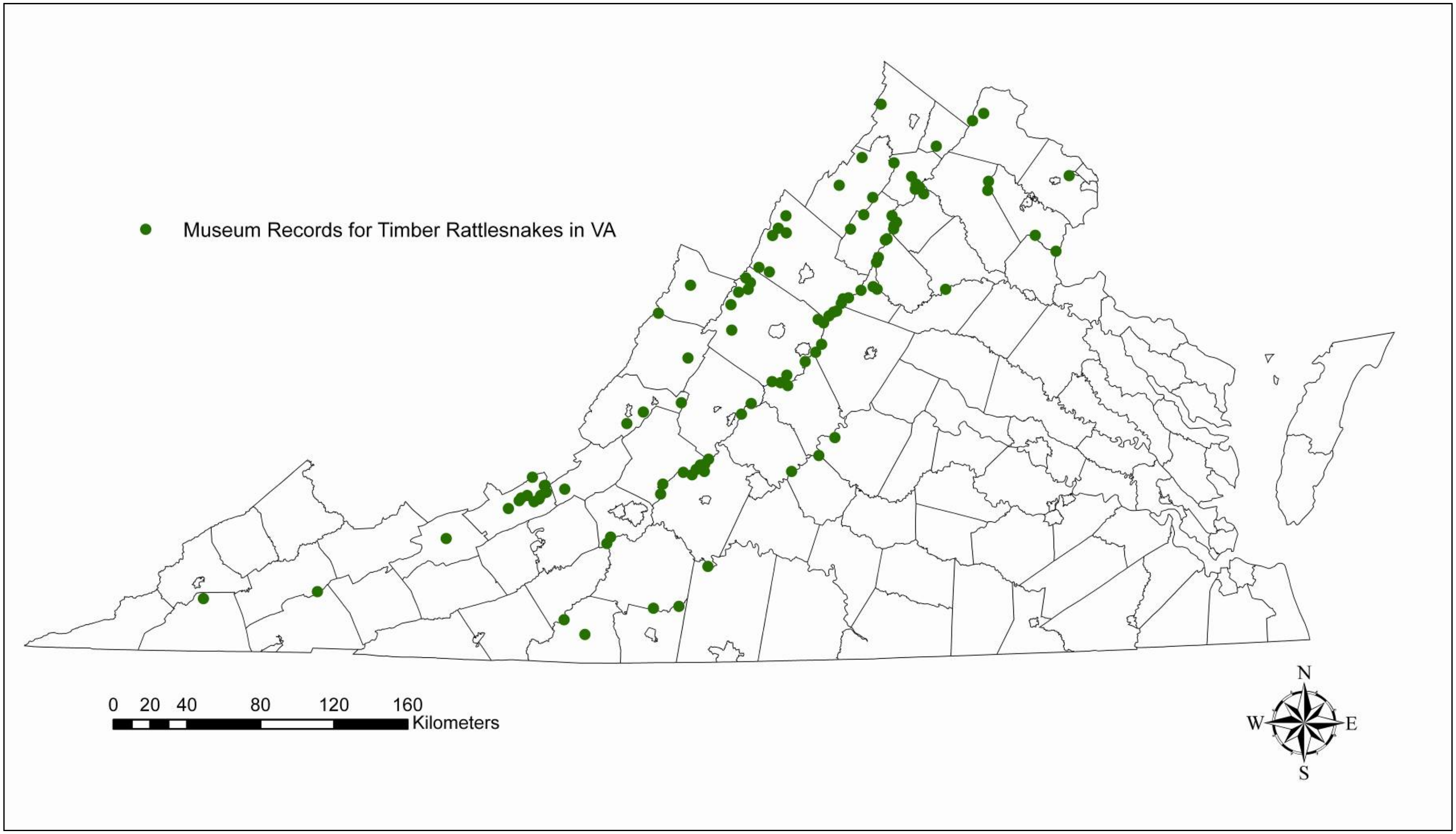

Figure 2. The distribution of museum records for the timber rattlesnake in Virginia. See text for sources.

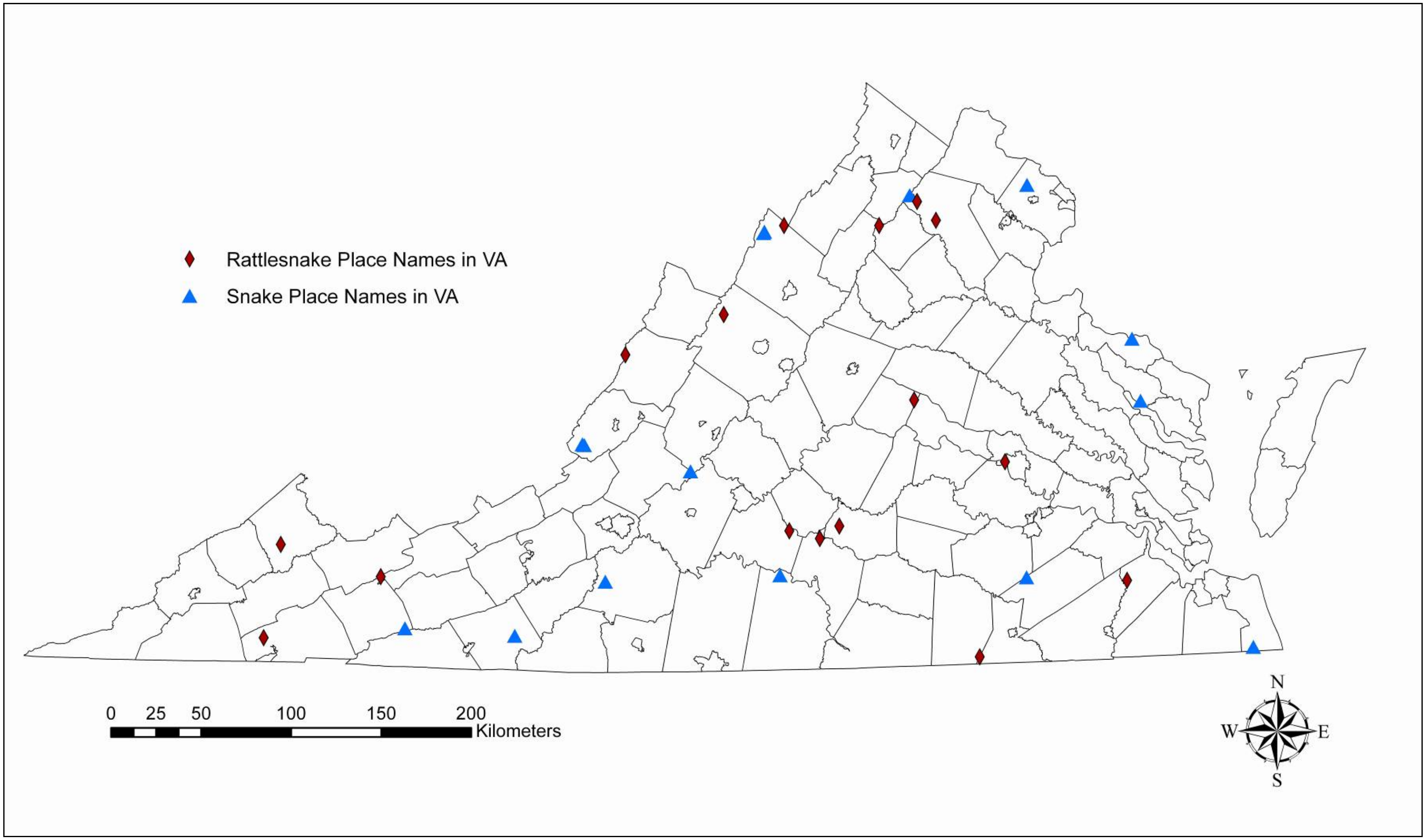

Figure 3. Map showing places in Virginia where the place names include the word “rattlesnake” or “snake”.

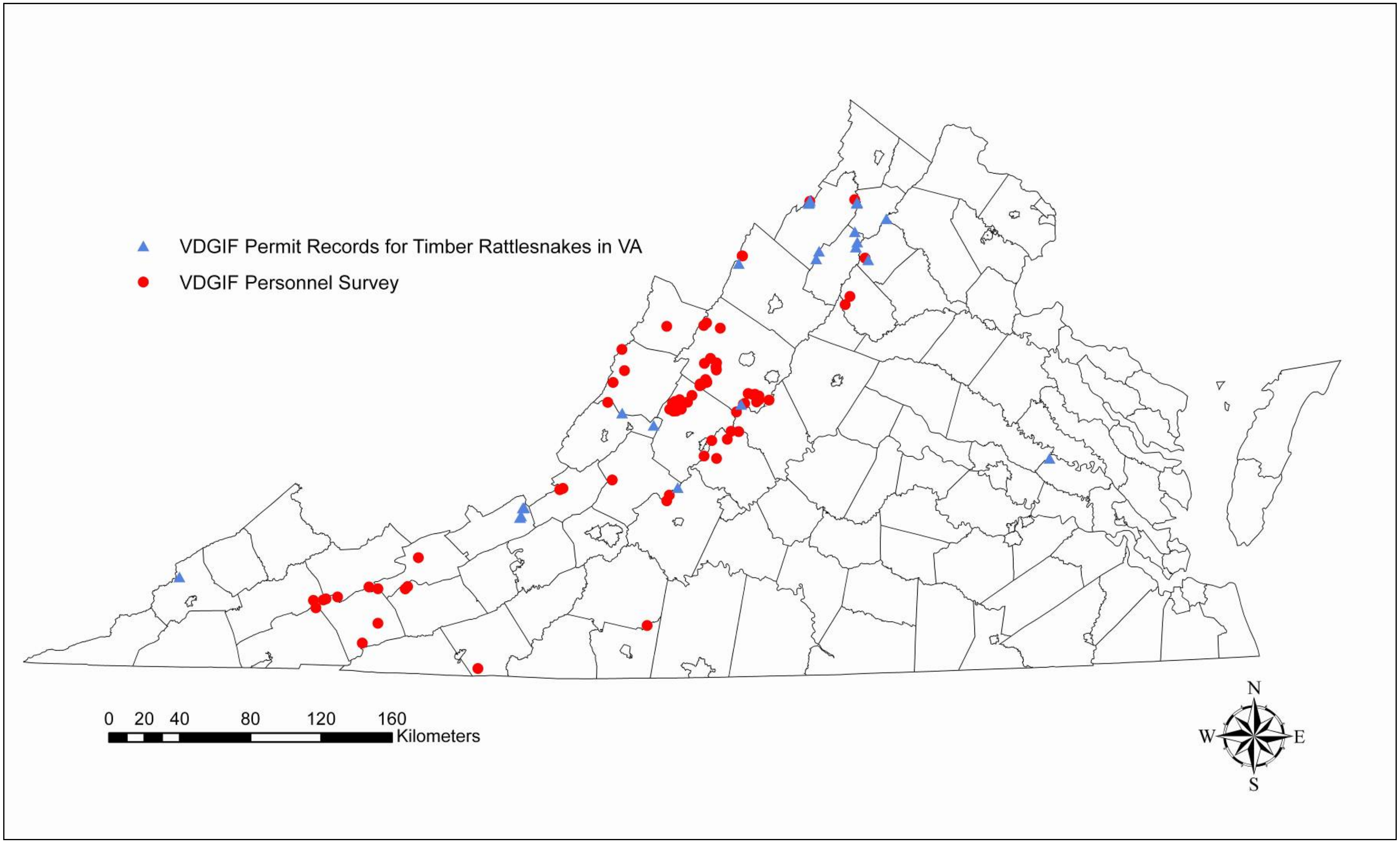

Figure 4. Map showing the location of timber rattlesnake records from VDGIF scientific collection permits and the survey distributed to VDGIF and USFS personnel.

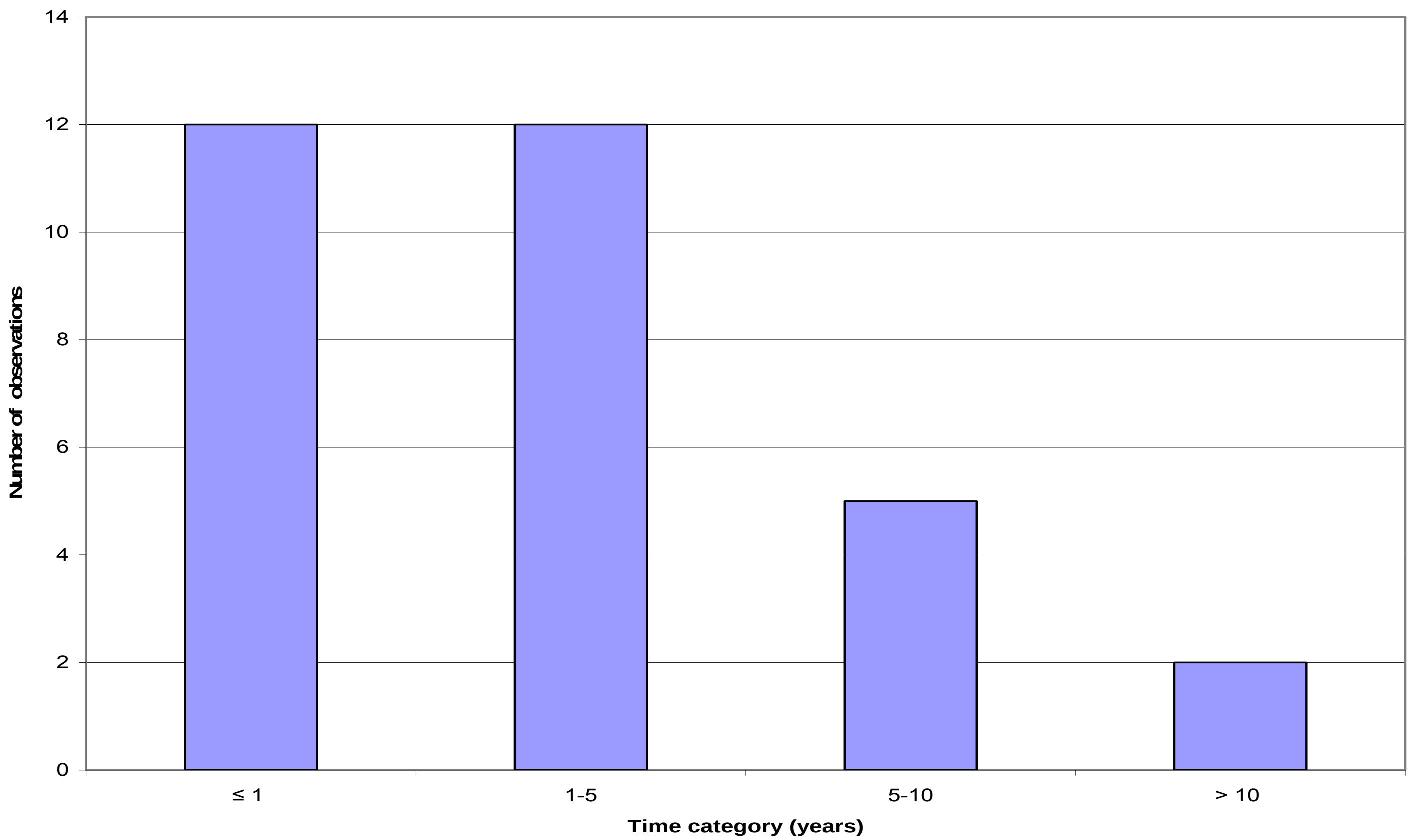

Figure 5. The number of timber rattlesnake observations for each time category of years since an observation of a rattlesnake was made by agency personnel as summarized by a survey distributed in 2006 as part of this study. Most sightings reported by agency personnel on the survey had occurred within the last five years.

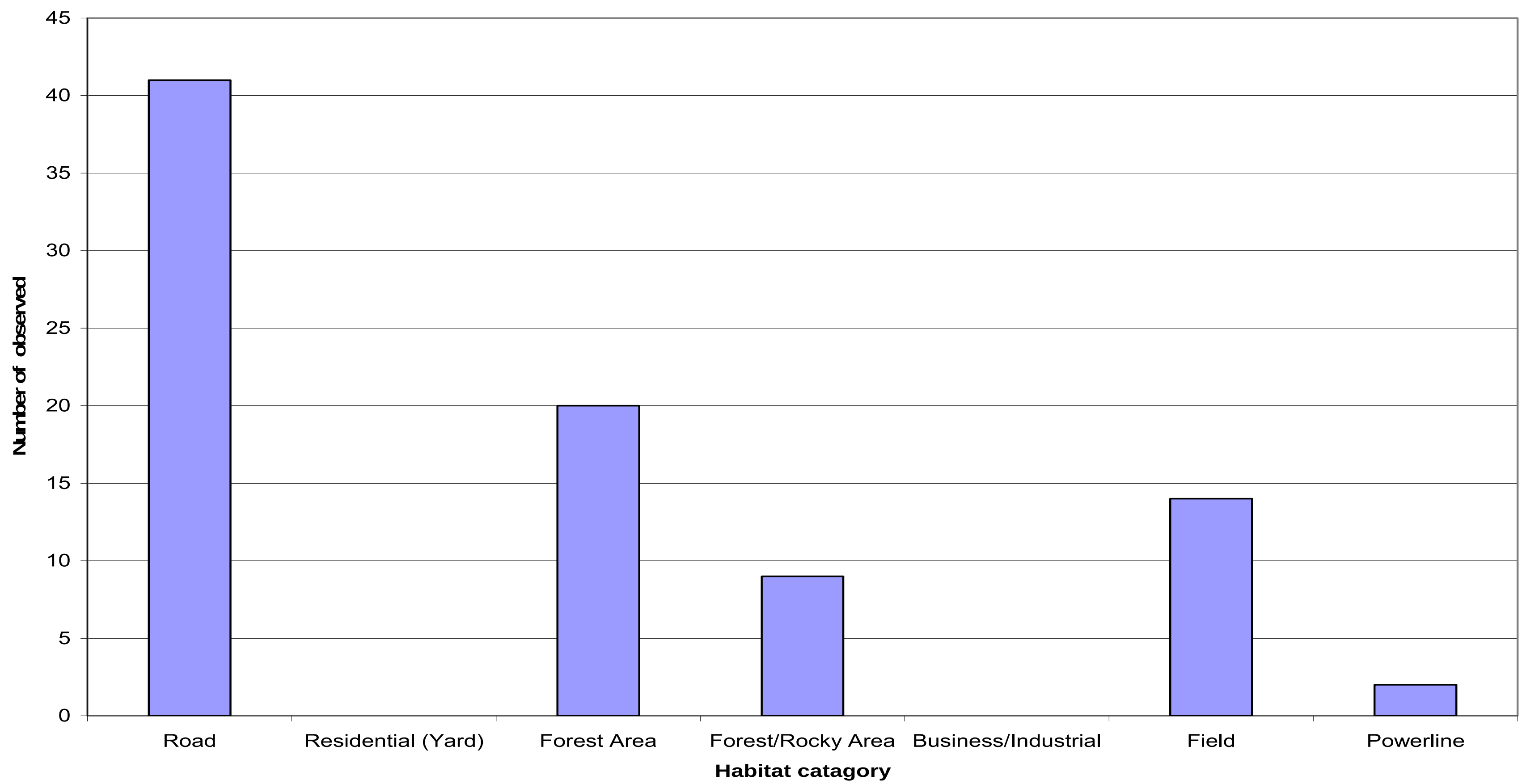

Figure 6. The number of timber rattlesnake observations for each habitat type category from the agency personnel survey (cf. Fig. 5).

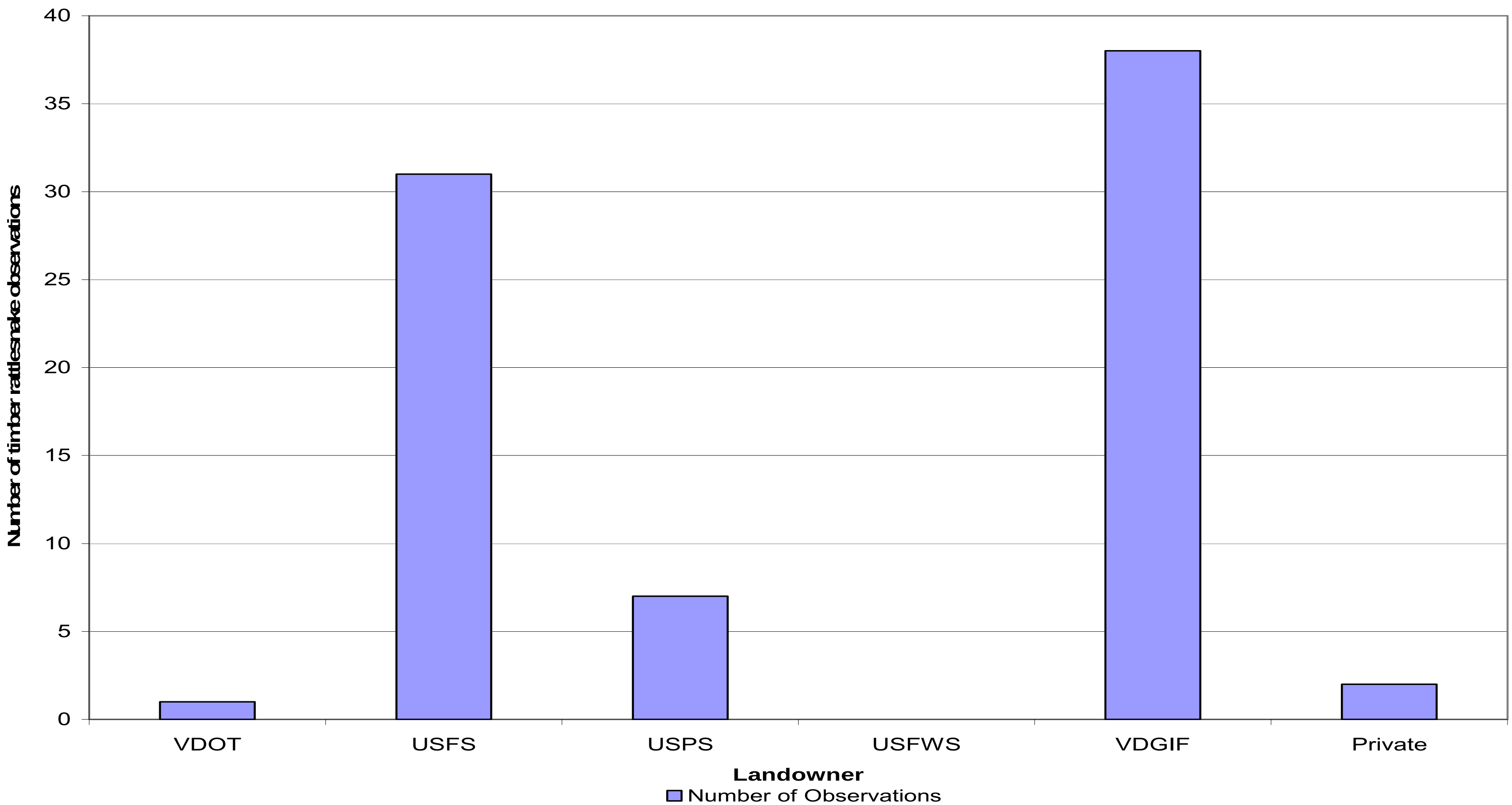

Figure 7. The number of timber rattlesnake observations for each landowner category from the agency personnel survey (cf. Fig 5). The categories are defined as followed: VDOT = Virginia Department of Transportation; USFS = United States Forest Service; USPS = United States Park Service; USFWS = United States Fish and Wildlife Service; VDGIF = Virginia Department of Game and Inland Fisheries; Private = Private Land.

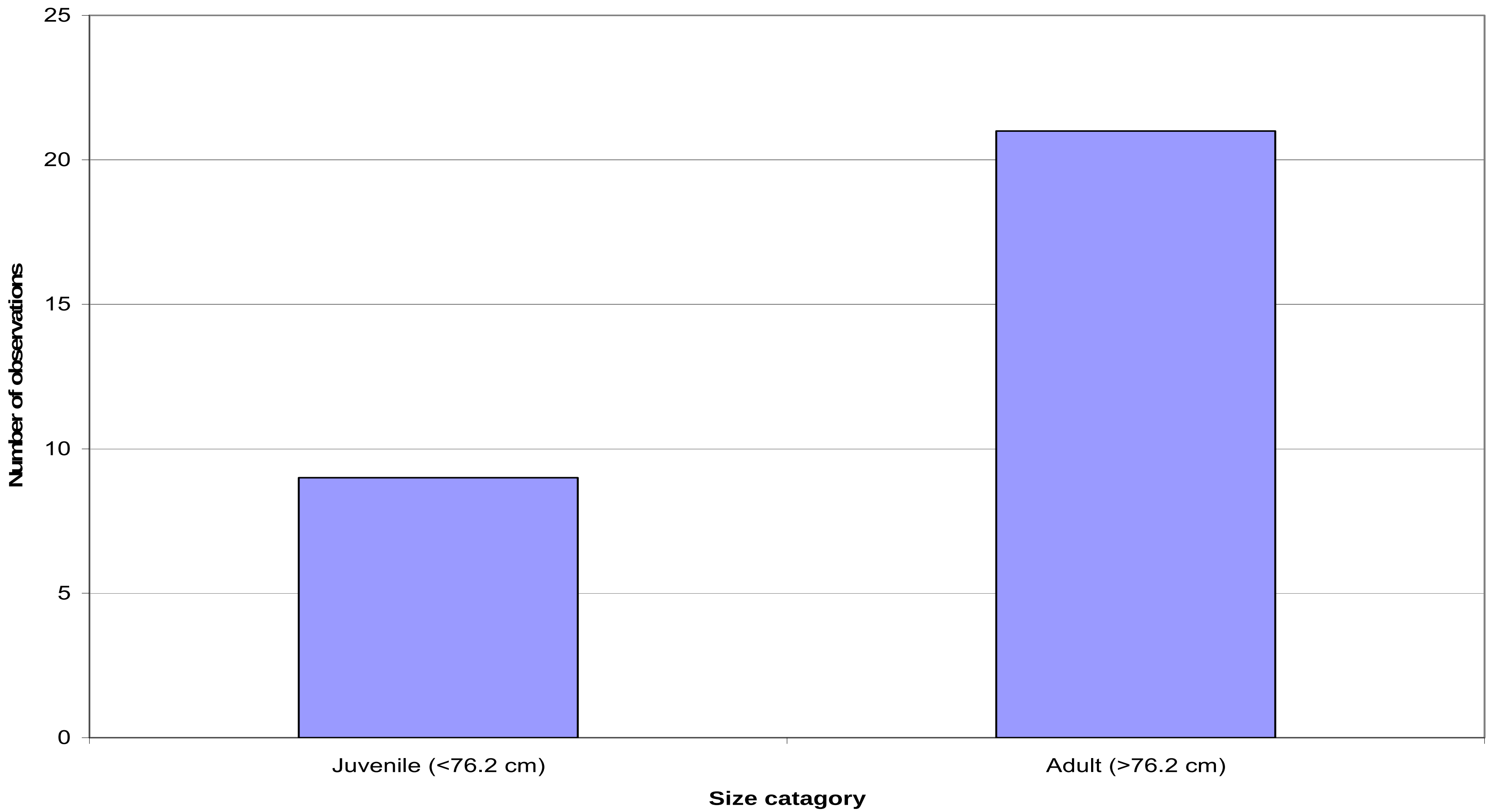

Figure 8. Number of observations in each size category (see text) from the agency personnel survey (cf. Fig. 5 for explanation).

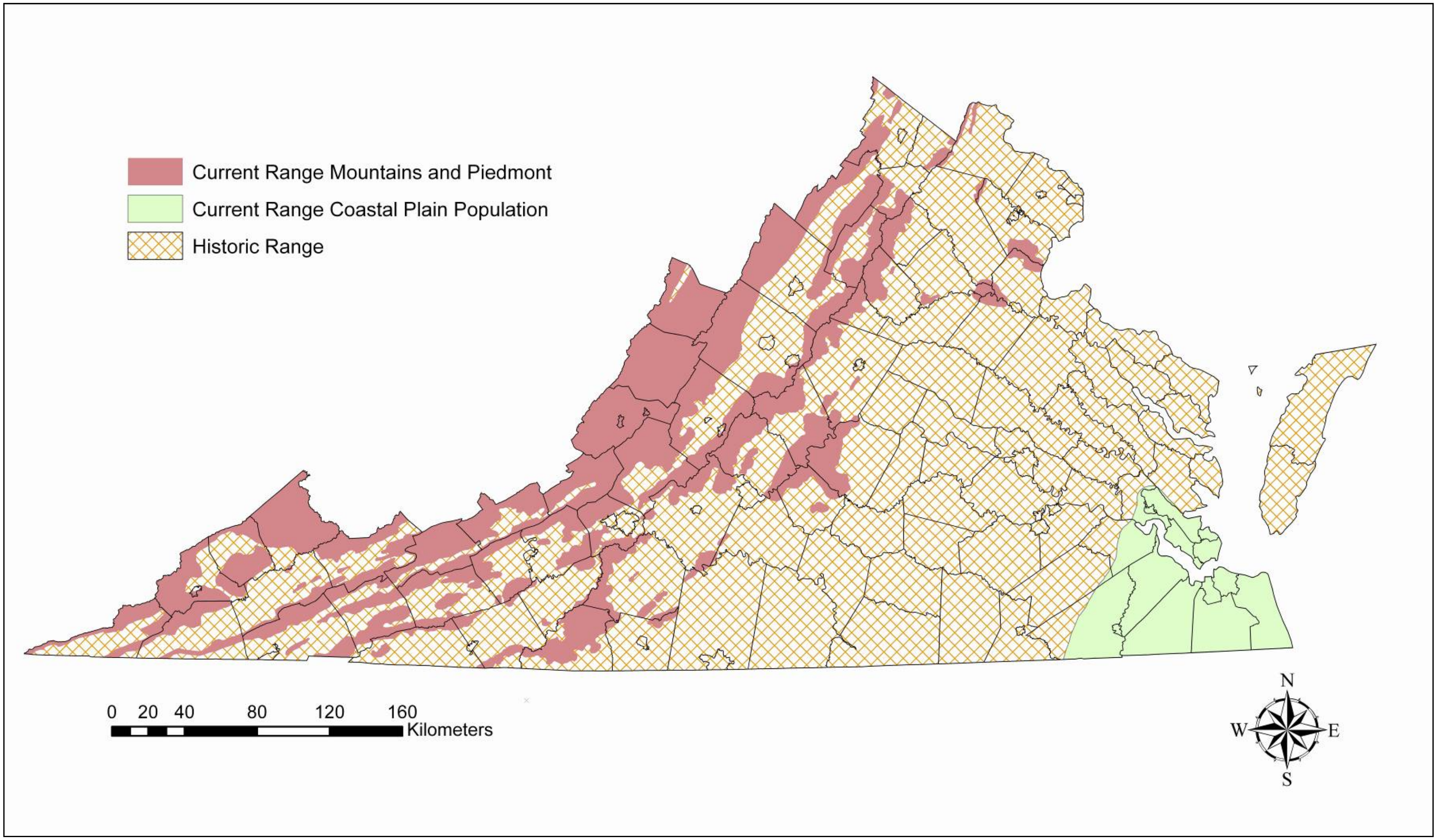

Figure 9. The current and historic ranges of the timber rattlesnake in Virginia. All currently occupied sections were part of the historic range. See text for source information.

Chapter 3. Management Recommendations for the Timber Rattlesnake in Virginia

Introduction

Species that have long life spans, slow generation times, and large home range sizes are more likely to experience local extinctions, assuming that they have a wide range (Webb et al. 2002). By understanding how life history traits affect a species' survival, more biologically informed regulation and management decisions can be made to protect the species.

From a management standpoint it is important to understand what regulations and management actions that other states have adopted to manage a species. Brown (1993) provides some recommendations for the management of timber rattlesnakes across their range. This document provides biologists and land managers with a useful compendium informing decisions about management regulations and policy. Consistency across states in management and regulation would also make enforcement easier, although now the regulations vary widely.

The purpose of this aspect of my study was to use the natural history and biology of the timber rattlesnake, and the regulations and management procedures used by other states, to make several management recommendations to the Virginia Department of Game and Inland Fisheries.

Methods

I used three sources of information to develop guidelines for applied biologists, as follows: (1) differences between the historic and current distribution of the timber rattlesnake in Virginia; (2) threats to rattlesnake populations in Virginia; and (3) an evaluation of techniques and laws in other states compared to those currently in use in

Virginia. Land-use policies of state and federal agencies in Virginia were also evaluated to see if any conservation measures exist to protect timber rattlesnakes, either implicitly or secondarily. I examined state regulations and contacted agency personnel to obtain the information.

Results

Biology and Natural History

Reproduction

The timber rattlesnake is a late-maturing species with a slow reproductive cycle (Brown 1991, Martin 1993). The females become reproductively mature when they are between five and eleven years of age, and males when they are between four and seven years of age (Keenlyne 1978, Fitch 1985, Brown 1991, Martin 1993, Aldridge and Brown 1995). Once they reach sexual maturity, female timber rattlesnakes reproduce every two to five years, with sexually mature males potentially reproducing every year (Brown 1991, Martin 1993, Aldridge and Brown 1995). Because mature females reproduce only every two to five years, only a portion (usually 20 -50%) of the mature female cohort becomes reproductively receptive in any active season. This makes reproductively receptive females a limited resource, thus skewing the operational sex ratio towards males (Brown 1995). Mating of the timber rattlesnake has been observed from late July to mid – September (Klauber 1991, Martin 1992, Brown 1995, Sealy 1996). Aldridge and Brown (1995) found the reproductive cycle of male timber rattlesnakes to correspond closely with that of females. They found fully developed spermatozoa present in the male reproductive tracts in the months of July, August and early September. Mortality on adult male timber rattlesnakes was highest during the mating season, when the males are searching for reproductively receptive females (Aldridge and Brown 1995). The reproductive cycle of females lasts approximately twelve to fourteen months; starting mid to late summer and ending late summer to early fall of the following year. Vitellogenesis, usually taking place from mid - July to early September, is believed to begin once the female has accumulated enough fat stores to support the pregnancy (Martin 1993). Vitellogenic females typically go through a shedding cycle just before mating. This shedding cycle could possibly cause the release of pheromones that stimulate mating behavior in the males (Macartney and Gregory 1988). Upon shedding, the female mates and stores the sperm in her reproductive tract until the following spring when she emerges from hibernation. Ovulation and fertilization presumably take place several weeks after emergence from hibernation as females move to exposed areas, usually a basking area (a rocky place with sparse vegetation) that allows the females to select protective rocks for thermoregulation to permit embryonic development. A female will give birth to between 2 and 16 neonates, typically from late August to early October. Newborns shed their skin for the first time six to twelve days after birth. The mother tends to remain with the newborn litter until they shed, after which she will move off into the nearby forest to feed before going into hibernation. Evidence shows newborn timber rattlesnakes find their way back to the ancestral dens by scent-trailing their mother (Brown and MacLean 1983, Reinert and Zappalorti 1988). Reproduction is energetically expensive for females which lose an average of thirty-eight percent of their body weight at parturition (Brown 1991).

Growth and Survival

Because the timber rattlesnake hibernates, it has an active season of between four and six months, when growth takes place (Martin 1992, 1993). Males are the larger sex with a snout-vent length for Virginia specimens of between 79 -122cm (average total length = 132cm), and females (the smaller sex) having a snout-vent length of between 69 -103cm (average total length = 109cm) (Mitchell 1994). Lengths of newborn timber rattlesnakes range from 21.6 - 34cm (W.H. Martin pers. comm. cited in Mitchell 1994). Maximum total lengths on the timber rattlesnake range from 155 to 188cm (Ditmars 1931, Gloyd 1940). The timber rattlesnake is a long-lived species, with records indicating a life span in captivity of greater than thirty years (Bowler 1977). In populations of the timber rattlesnake that have been marked and recaptured in field studies, survival rates range from 30 to 71% for juveniles (less than two years old) and from 73 to 98% for second-year juveniles, subadult, and adults (second growing season or older) (Martin 2004, Brown in press).

Diet and Feeding

Timber rattlesnakes primarily eat small mammals with the opportunistic consumption of an occasional bird (Uhler et al. 1939, Smyth 1949, Savage 1967, Clark 2002). Mouse species of the genus *Peromyscus* make up the largest portion of the timber rattlesnake's diet (Uhler et al. 1939, Smyth 1949, Savage 1967, Clark 2002). Some of the larger timber rattlesnakes may consume prey as large as gray squirrels or fox squirrels (*Sciurus carolinensis, S. niger*) (Uhler et al. 1939, Smyth 1949, Savitsky and Peterson 2004). Keenlyne (1972) found that gravid female timber rattlesnakes in Wisconsin ate less than timber rattlesnakes of other sexes and reproductive states. The timber rattlesnake is a sit-and-wait predator that uses rodent trails located on objects such as fallen logs, standing trees, or rocks to locate ambush sites (Reinert et al. 1984, Brown and Greenberg 1992). Clark (2002) found that timber rattlesnakes use scent trails of prey species for the selection of ambush sites. Once the timber rattlesnake locates a favorable ambush site, it will coil beside the object so that it can strike the prey when it comes into range (Reinert et al. 1984).

Habitat

The habitat of the timber rattlesnake can be subdivided into three main types: (1) den or hibernaculum, (2) basking/gestating habitat, and (3) summer range (Brown 1982, 1993; Martin 1993). The dens or hibernacula provide a place for timber rattlesnakes to spend the winter below the frost line and are found on rocky hillsides (Stechert 1980). Dens are found in ledge fissures, fallen rock talus and scree, and talus and scree partly covered by soil (Martin 1993). Timber rattlesnakes have a high fidelity to a particular den site, with den switching being very uncommon in this species (Martin 1992). Dens can range in size from harboring a single rattlesnake to providing access for more than one hundred in the largest communal dens (Martin 1992, Brown 1993). Basking/gestating habitat is characterized as an open rocky place which may have a prominent rock outcrop, slide, or individual slab in a forest clearing. Many aspects of the snake's life history take place mainly in basking/gestating habitat, making them one of the most important habitat types to timber rattlesnake (see chapter 1). Because ectotherms are dependent on a thermal environment for successfully bearing their young live, females use basking/gestating habitats as a place that offers protection as well as the ability to thermoregulate. Rattlesnakes that need to elevate their body temperatures for shedding, digesting, and healing wounds also use basking/gestating habitats. Vitellogenic females use basking/gestating habitat because of the shedding cycle they go through before mating. Bushar et al. (1998) found that exposed rock outcrops used for basking and gestating also influenced gene flow between different denning groups. Basking habitat has also been referred to as transient habitat (Brown 1993). Timber rattlesnakes also use transient habitat (basking habitat) when dispersing from the den in the spring on their way to summer range or basking/gestating habitat and returning to the den in the fall (Brown 1982). These rocks provide shelter from cold night-time temperatures in spring and fall and also provide protection from predators (W.H.Martin, pers. comm.). The term "transient" habitat was first used by Raymond Ditmars (Brown 1993). Summer range is the habitat timber rattlesnakes use when away from one of the previously listed types. It consists of closed canopy forest surrounding the other habitat types. Reinert (1984a) describes summer range as a closed canopy hardwood forest with fallen logs and sparse ground vegetation. Brown (1993) reported summer range in New York to have heavy leaf litter, an average canopy closure of 67%, and little ground vegetation. Timber rattlesnakes use their summer range for feeding and mating. Physiological condition of a snake can have an effect on habitats used (Reinert 1984b). For example, a rattlesnake needing to elevate its body temperature to digest, shed, or gestate, can be predicted to choose a more open site.

Threats

There are many threats to the timber rattlesnake in Virginia but there have been no systematic studies to evaluate the effect the threat factors may have had on timber rattlesnake populations. Development (residential or industrial) is recognized as a major threat across the state. Housing developments are continually encroaching on mountainsides in the timber rattlesnake's range, thus impacting or eliminating its habitat. Mining coal or gravel is also increasingly eliminating timber rattlesnake habitat in Virginia. Coal mines in the Cumberland Mountains have destroyed several known dens (Victor Bates pers. comm. to W.H. Martin 1981). Roads are a major source of mortality across the state, with many highways crossing through their habitat. As development continues, more roads are built in timber rattlesnake country. Although collecting or "hunting" rattlesnakes has decimated some populations in Virginia, this threat is limited. However, in Highland County, several dens in the Laurel Fork area have been hunted heavily and hunting has caused severe declines in some of the local populations (Tim Selmon, pers.comm.).

Succession in the vegetation is another threat that is receiving more and more attention (Webb, Shine, and Pringle 2005; Fitch 2006). Succession is a problem for timber rattlesnakes because it causes the shading-over of critical basking sites thus making reproduction more difficult. This shading-over of basking sites by succession is caused mainly by lack of fire or other major disturbance regime (VanLear and Waldrop 1989; Brose et al. 2004).

Agency Rules on Take of Rattlesnakes in Virginia

In Virginia, there are six major landholding agencies and one non-governmental organization that are major landholders. The rules they use to govern the take of wildlife, including timber rattlesnakes, varies. For the purposes of this study "take" is defined as the collection or killing of timber rattlesnakes. No agency in Virginia has rules specific to rattlesnakes, other than the Department of Game and Inland Fisheries. On private land

and lands owned by the Virginia Department of Game and Inland Fisheries, an individual can collect and possess up to five timber rattlesnakes. These must be kept alive for personal use. On National Park Service lands, there is a no-take policy. The Virginia Department of Forestry follows rules set forth by the Virginia Department of Game and Inland Fisheries. There is a no-take policy on all Virginia Department of Conservation and Recreation lands, including Natural Heritage lands. The U.S. Forest Service owns the largest area of public lands in Virginia, and they too follow the regulations set forth by the Virginia Department of Game and Inland Fisheries. A private group, The Nature Conservancy has a no-take policy on all lands it owns. All of the public agencies as well as The Nature Conservancy have scientific collection permit programs to allow researchers to work with rattlesnakes or other species on their lands; the policies summarized above pertain to the general public.

State Status and Regulations

The timber rattlesnake is currently found in 30 states in the continental United States, and is believed to have been extirpated from Maine and Rhode Island as well as (with less certainty) from Michigan, Delaware, and Ontario (W.H. Martin, pers. comm.). A comparison of the regulatory status in the thirty states between the early 1990s (Brown 1993) and 2007 is provided here (Figure 1). Figure 2 shows the current status in each state along with the current range of the timber rattlesnake. Appendix 1 provides the data used in figure 1.There has been, in the past 15 years, an increase in the number of states that list the timber rattlesnake as “endangered”, “threatened”, or “species of concern” and a decrease in the number of states that protect timber rattlesnakes with a blanket or general non-game legal provision. Thus, the recognition of the species as a protected game animal (Pennsylvania) or as a fully regulated animal, has increased. There is no change in the number of states where it is believed to be extirpated or in the number of states where it has no protection (Table 1). In the 30 states of occurance,19 (63%) have regulations prohibiting any take of timber rattlesnakes.

State Management

Of the 30 states that have timber rattlesnakes, only Kansas, Nebraska, Ohio, and Wisconsin actively provide for the management of the species. In Kansas, timber rattlesnake dens come under protective regulations through negotiating conservation easements, or working with landowners (Ken Brunson, Kansas Dept. of Wildlife and Parks, pers.comm.). In Nebraska, vegetation is typically removed from den sites. Mainly cedars are invasive around limestone outcrop dens. Control of cedars allows more sunlight to reach the den site (Mike Fritz, Nebraska Game and Parks, pers.comm.,). In Ohio, a large section in the state conservation plan for timber rattlesnakes provides for the removal of nuisance snakes, informing and educating the public, enhancing the habitat to make it suitable for timber rattlesnakes, and maintaining the security of known locations by having law enforcement patrol these areas during critical times of egress and ingress thereby deterring poaching (Carolyn Caldwell, Ohio DNR, Division of Wildlife, pers.comm.). In Wisconsin, assistance is provided to landowners to deal with timber rattlesnake problems and the state is beginning to do some habitat work (e.g., controlled burning) to help keep the prairie bluffs habitable for rattlesnakes (Robert Hay, Wisconson Dept. of Natural Resources, pers.comm.). Minnesota is drafting some basic management guidelines for timber rattlesnakes and hopes to start management in the next couple of years (Jaime Edwards, Minnesota Dept. of Natural Resources, pers.comm.).

Management Recommendations

Based on the biology, natural history, other state regulations, and policies used by other agencies in Virginia, I make the following management recommendations to the Virginia Department of Game and Inland Fisheries.

1. A no-take regulation on timber rattlesnakes anywhere in Virginia is recommended. An important step, based on the low reproductive rate and slow recruitment of the species, would include removing the current regulation in Virginia stating that a person can possess up to five live timber rattlesnakes. Most snake hunters tend to target rookery areas when collecting timber rattlesnakes (Reinert 1990), thus removing the reproductive aged females, and causing severe damage to this important part of the structure of a timber rattlesnake population.
2. An outreach and education program is recommended. Such a program would inform the public about timber rattlesnakes and their role in healthy forests. This would include giving talks and demonstrations to all grade levels of schools (K-12), as well as to various groups or organizations with a strong interest in nature. Agencies with law enforcement divisions which enforce regulations protecting timber rattlesnakes should be staffed or assisted in this role. Educating the public about timber rattlesnakes and the ecological roles they serve is necessary to counteract generations of negative images of snakes in general. This is important because the public has a direct stake in the survival of species. Gestating female rattlesnakes are among the most likely individuals to be encountered by humans searching for timber rattlesnakes. Unlike a songbird or small or mid-sized mammal, an adult female rattlesnake has an extremely high reproductive value, so

the loss of a few individuals can have major consequences for the rattlesnake population. By educating and generating interest in the species, the public will be less likely to kill every rattlesnake they encounter. Game wardens need also to be educated about timber rattlesnakes and that it is important to enforce the regulations applied to them.

3. The timber rattlesnake's critical habitat in Virginia is in need of protection. This would include protecting dens and basking sites from being destroyed by development, roads, harvesting timber or mineral resources, and preventing the practice of snake hunting. Other threats to the continued existence of these critical habitats should be monitored. Critical habitats should be targeted for conservation and management. Burning and cutting back vegetation from basking areas to keep them open should be undertaken. Work with landowners to establish conservation easements for the protection of critical habitats on private lands should be pursued.
4. Monitoring and locating populations of timber rattlesnakes in Virginia, in accordance with the methods investigated here, is recommended. This would include going to suspected sites and surveying for timber rattlesnakes every 2-5 years and to locate new populations. Land ownership and associated steps in recommendation number three should be activated.
5. Location information of timber rattlesnake basking and denning sites should be stored in databases that are handled and treated like endangered species data. These data should not be accessible by the general public.

Discussion

The timber rattlesnake is a long-lived, late-maturing, slow-reproducing vertebrate that has a large home range size. The home range size of the timber rattlesnake varies with sex and reproductive condition (Reinert 1988, Sealy 2002). Males tend to have larger home ranges (40 – 208 ha) than females (14 -40 ha) (Reinert 1988, Sealy 2002). Its life history makes the species more susceptible to local extinctions (Webb et al. 2002). Most of the threats that are currently having an effect on populations in Virginia are associated with human activities. It is not known how disease and introduced species may affect Virginia populations, although such threats have been reported elsewhere.

In Virginia, the largest portion of the timber rattlesnake's habitat is on publicly owned lands (National Forest, National Park, State Forest or Park, and Natural Heritage lands). Most of the state and federal agencies have policies against taking timber rattlesnakes from their lands, as does The Nature Conservancy. About 50% of state and federal agencies use the regulations set forth by the Virginia Department of Game and Inland Fisheries, which currently allow the take of timber rattlesnakes. If VDGIF changes it regulations to no-take, then all of the state and federal agencies in Virginia that hold land with public access will enjoy a no-take policy and the increased protection afforded the timber rattlesnake will improve management for this sensitive species.

Very few states actively manage for timber rattlesnakes. This is probably because timber rattlesnakes are not a popular species in the public's eye and the states may not want to encourage a perception of their state trying to create "more snakes". However, more states are becoming interested in managing for this species, as they do for other non-game species. In the near future, more states are likely to become interested in managing for their timber rattlesnakes at exposed rock outcrop habitats. Many other species of animals and plants, such as Alleghany wood rat (*Neotoma floridana magister*), rock vole (*Microtus chrotorrhinus caorlinensis*), Peters Mountain mallow (*Iliamna corei*), turkey vultures(*Cathartes aura*), and several species of bats, which use crevices in the rock outcrops for summer roosts, will benefit. These areas can be kept open by the periodic cutting of tree limbs and trees preventing sunlight from reaching the basking site, this can also be achieved by prescribed burning. In far southwest Virginia the U.S. Forest Service is using fire to restore the native chestnut oak (*Quercus montana*) and pitch pine (*Pinus rigida*) forest type in that area (Chuck Lane, U.S. Forest Service, pers.comm.). It is important to the timber rattlesnake to keep basking areas open so that gravid females have a suitable place to gestate, and shedding or digesting snakes have a place to go also to raise their body temperatures.

The proportion of states that provide some protection to timber rattlesnakes has increased over the last fifteen years, and this is an encouraging sign of progress. In the south, some states like Florida, Alabama, and Louisiana do not protect timber rattlesnakes.

As much habitat as possible needs to be protected from development and other forms of destruction. Roads, timber and mineral harvest, and direct destruction of a basking or denning site by humans should be curtailed. Housing developments are becoming more commonplace in the timber rattlesnake’s habitat, especially in the northeast portion of their range. Habitat destruction reduces the amount of summer range that is available to be used as feeding grounds, potentially reducing the frequency of reproductive efforts by females in the population or reducing the overall number of snakes the area can support. Roads can create skewed sex ratios in populations. At Hanging Rock State Park in North Carolina, because of mortality on the roads in the park, there is a 4:1, female-to-male ratio (Sealy 2004). The closer a road is to a basking or denning site, the greater its impact will be on the population. Timber harvest can have negative impacts on timber rattlesnake populations through access roads, and putting people in areas where humans and timber rattlesnakes are likely to have interactions. On the other hand, timber harvest can also have some positive impacts on timber rattlesnakes when done properly (i.e., done in winter, rocky areas not disturbed, loggers do not kill snakes, leaving slash). In areas where basking habitat in the form of rock outcrops or talus has shaded-over, timber harvest can create openings where gravid females can bask. Mineral extraction has a much more lasting effect on timber rattlesnake habitat because the rocks where the rattlesnakes den and bask are removed. The habitat is destroyed. This can occur at many scales, from the rock mason taking a few rocks to build a small wall to massive quarrying operations removing hundreds of thousands of tons of rock. However, some mining activities may be compatible with the persistence of snakes. In southeast Kentucky, reclaimed strip mines are used as basking habitat where the dens were not destroyed by the mining (Paul Vanover, snake hunter, pers. comm.). Because timber rattlesnakes have a large home range size encompassing vast amounts of habitat other than the critical basking and denning habitats, it is important that resource harvest and development projects take into consideration protecting their habitat as a whole in order to ensure the survival of timber rattlesnake populations.

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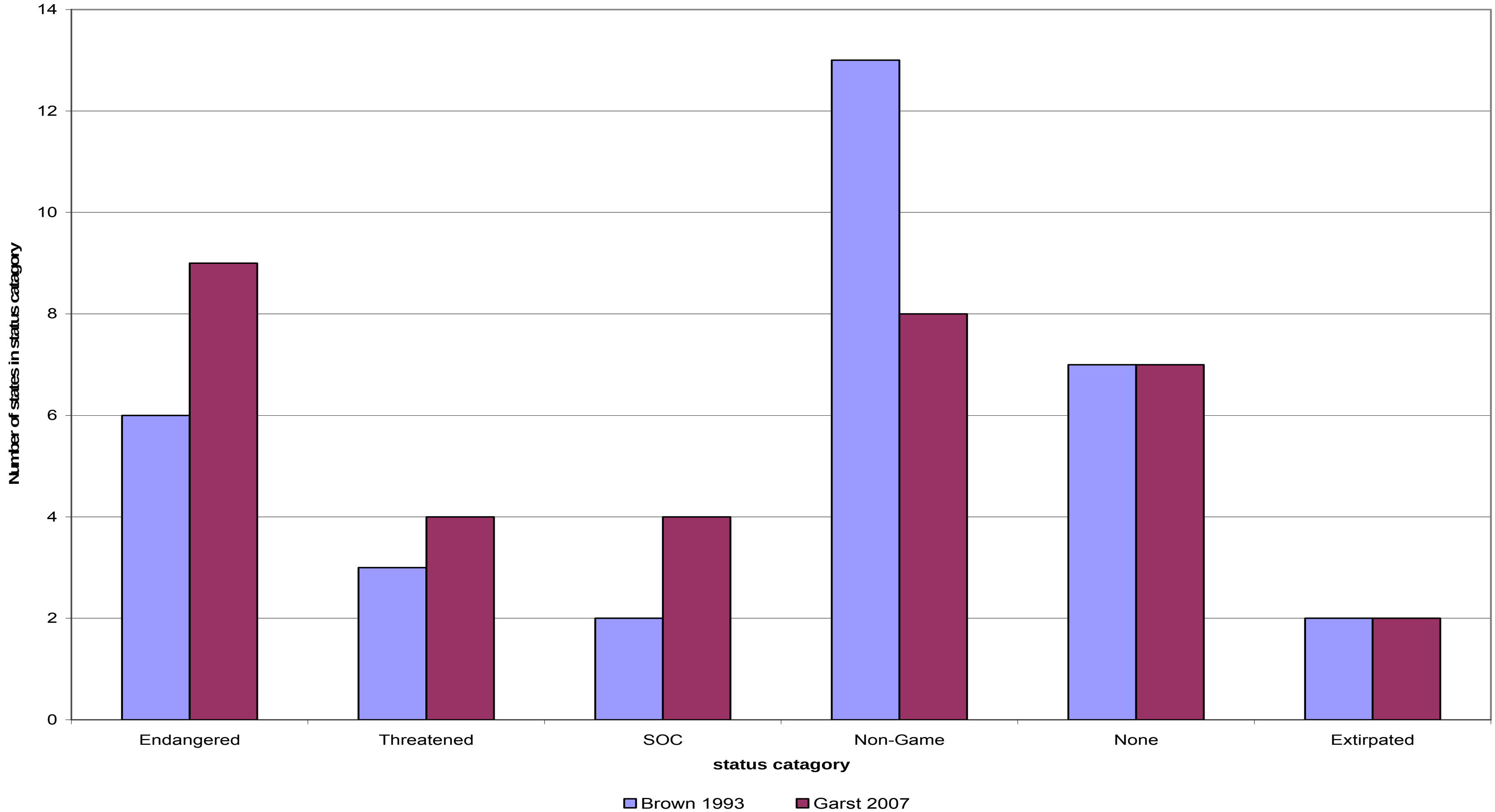

Figure 1. Comparison of the status given to the timber rattlesnake in 30 states where it currently exists. Data compiled from the two sources indicated. SOC = Species of Concern.

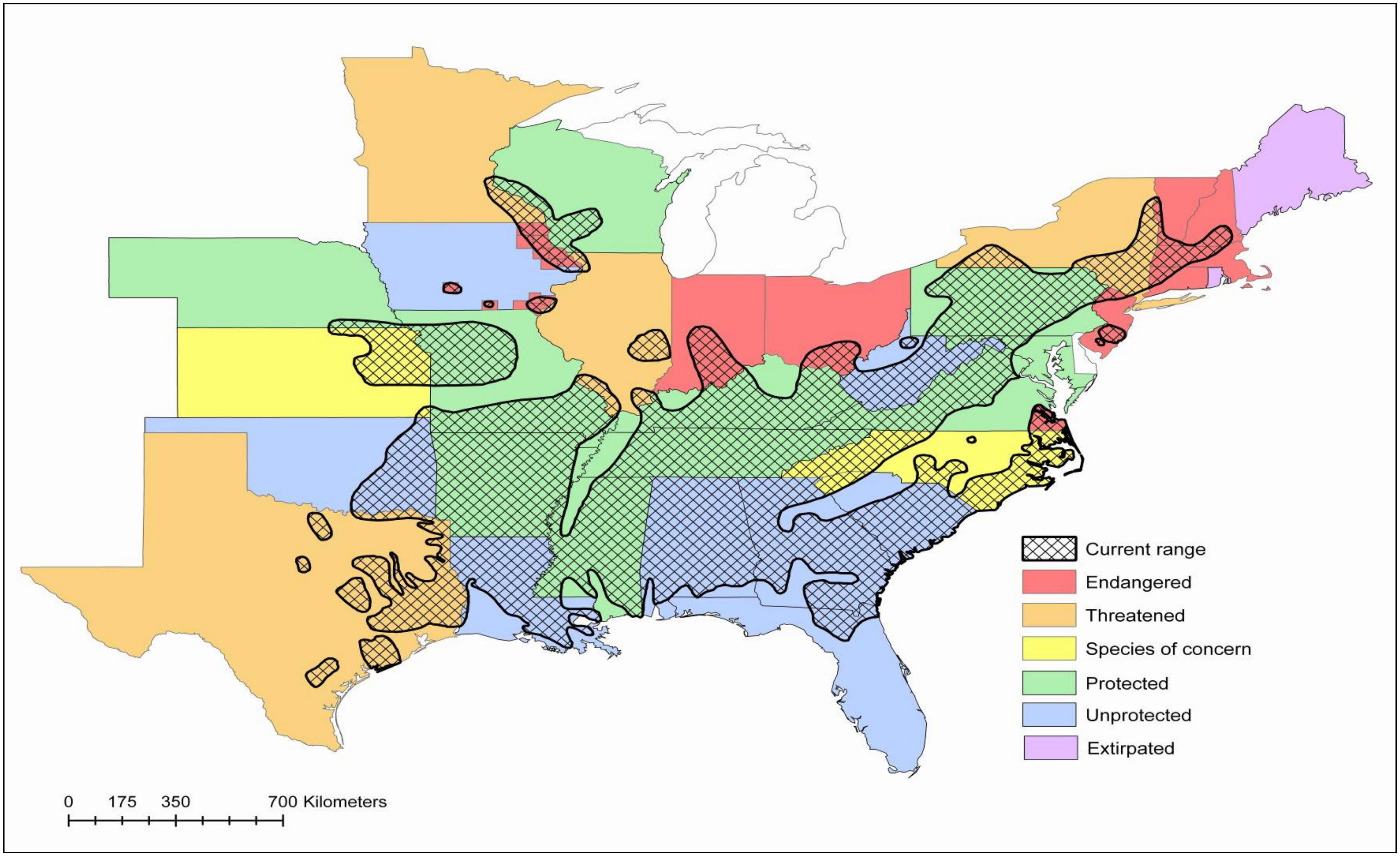

Figure 2. Map showing the 30 states composing the range of the timber rattlesnake and the status in each state. These data are accurate as of 2007.

Appendix 1. State Regulations

Table showing each state and associated regulations for the current range of the timber rattlesnake.	
State	**Regulation**
Endangered	
Connecticut	No take on endangered species is allowed.
Indiana	Timber rattlesnakes may not be taken, possessed, transport, exported, processed, sold or offered for sale, or shipped, and a common or contract carrier may not knowingly transport or receive for shipment. Scientific permits may be issued that allow the taking, possession, transportation, exportation, or shipment.
Iowa	Statewide in Iowa the timber rattlesnake shall not be protected, except in Allamakee, Appanoose, Clayton, Delaware, Des Moines, Dubuque, Fayette, Henry, Jackson, Jones, Lee Madison, Van Buren, and Winneshiek counties. In counties where it is protected it is not protected within 50 yards of a house actively occupied by human beings.
Massachusetts	No take is allowed.
New Hampshire	Under the New Hampshire Endangered Species Conservation Act, timber rattlesnakes may not be taken, possessed, transported, or sold. No rule of the New Hampshire Endangered Species Conservation Act shall interfere with the siting or construction of any bulk power supply facility or any energy facility, and shall not cause undue interference with normal agriculture or silviculture.
New Jersey	No take on endangered species is allowed.
Ohio	It shall be unlawful for any person to take, transport, sell, offer for sale or posses any of the native endangered species of wild animals, applying to endangered wild animals that are either resident within or migrate into or through Ohio. Sightings of timber rattlesnakes in Ohio can be reported to the Division of wildlife on their timber rattlesnake brochure.
Vermont	No take on endangered species is allowed.
Virginia	The Coastal Plain population of timber rattlesnakes in southeast Virginia is listed as state endangered and no take is permitted.
Threatened	
Illinois	It is unlawful for any person to possess, take, transport, sell, offer for sale, deliver, receive, carry, ship in interstate or foreign commerce, give or otherwise dispose of any timber rattlesnake or product therefore.
Minnesota	No take on threatened species is allowed.
New York	Timber rattlesnakes may not be taken, transported, sold, imported and/or possessed. Permits may be issued that allow take, transport, sale, import, and/or possession. Timber rattlesnakes receive habitat protection from a court precedence, no law or regulation exists that allows for habitat protection.
Texas	No person may take, posses, propagate, transport, import, export,

	sell, offer for sale timber rattlesnakes.
Protected	
Arkansas	An individual can posses up to 6 timber rattlesnakes in their personal residence without a permit. The timber rattlesnakes must be alive.
Kentucky	The timber rattlesnake is considered to be native wildlife and a person may posses up to five for personal use without a permit, more than five requires a permit. Timber rattlesnakes or timber rattlesnake parts may not be sold, traded, or transported out of Kentucky. Residents are permitted to kill any species of native wildlife (other than federally endangered or threatened species) in defense of person hoe or property.
Maryland	Timber rattlesnakes are protected as a non-game species, no collection or take, no disruption, and no disruption of habitat by an individual. Habitat protection does not extend to things like road projects and development.
Nebraska	Timber rattlesnakes are a species in need of conservation. There is no commercial or personal take.
Pennsylvania	Timber rattlesnakes may only be taken by individuals who have purchased and comply with the state permit ($25 for residents and $50 for non-residents) allowing the take of one timber rattlesnake annually that is at least 42 inches in length, measured lengthwise along the dorsal surface from the snout to the tail, excluding the rattle, and must posses 21 or more subcaudal scales. Timber rattlesnakes can be taken by permitted individuals from the second Saturday in June until July 31. Once a snake has been taken, caught, killed, or not released in the exact spot of capture the bag limit is considered met and hunting must cease. It is unlawful to kill timber rattlesnakes otherwise in Pennsylvania.
Tennessee	No season and no take for timber rattlesnakes. Considered a species of greatest conservation need (species proven to be declining).
Virginia	A person is allowed to collect up to 5 timber rattlesnakes from the populations in the mountainous counties (not including the Coastal Plain population).
Wisconsin	No person may take, attempt to take, transport or posses timber rattlesnakes unless expressly authorized by the Wisconsin Department of natural Resources. A timber rattlesnake may be killed in emergency situations involving immediate threat to human life or domestic animals. The kill must be reported to the DNR no later than 48 hours after the kill providing factual information related to the kill including the location, date of kill, and the name and address of the person who killed it. The DNR provides a response and assistance element for occupants or owners of land, or other persons, requesting assistance because of the presence of rattlesnakes. The DNR may investigate and authorize removal, relocation, or destruction if the rattlesnake constitutes a nuisance.

Species of Concern	
Kansas	Timber rattlesnakes may not be recreationally collected by individuals, no take is permitted. Timber rattlesnakes may be taken with a scientific collecting permit, with the number taken to be decided on a case by case basis.
Mississippi	Timber rattlesnakes are considered in need of management. Of the 20 non-game animals that can be possessed, no more than 4 can be of the same species. Any resident that takes or possesses non-game wildlife must posses a valid small game hunting and fishing license. Any non-resident must posses a valid non-resident small game hunting license. Timber rattlesnakes may be killed by individuals not possessing either license if they present a reasonable danger to human life. Timber rattlesnakes taken from the wild, or their parts, taken for personal use can not be bought, sold, offered for sale, bartered, or exported for sale.
Missouri	Residents of Missouri are allowed to posses up to five individuals of any amphibian and reptile species for educational purposes. However, no state endangered species, game animal (taken outside season), alligator snapping turtles, or venomous snake species may be taken under this rule. Under this rule, all venomous snakes are protected against removal from the wild unless with authorized permit. If an individual want to possess a venomous species they must apply for a Class II Wildlife Breeder Permit (cost = $250.00/year). The individual applying must provide written documentation that the animals they are to posses were not retained from the wild and abide by confinement standards for care and housing. The individual must also pass a 20 question test that pertains to life history information of venomous snakes, housing and care, handling techniques, holding chambers, and emergency procedures. Once an individual passes the test and follows all guidelines, they are allowed to propagate and sell offspring. The Missouri Department of Conservation does regulate the removal and sell of all venomous snakes native to Missouri, but does allow individuals to kill venomous snakes on their property if the snake is damaging property, or the individual feels endangered. It is illegal to kill any venomous snake on public lands.
North Carolina	There shall be no open season for timber rattlesnakes. It is unlawful to take or posses any timber rattlesnakes.
South Carolina	No timber rattlesnakes can be taken from the mountainous areas.
Unprotected	
Alabama	There is no legal protection for any poisonous snake, and no limit to take. The state of Alabama believes there is no shortage of timber rattlesnakes in Alabama but they have no proof or studies showing this to be true.
Florida	An individual may collect without bag limit timber rattlesnakes for personal use. Individuals must posses a permit to sell. There is no season.

Georgia	All non-game animals are protected, except for venomous reptiles. No rules or limit to take for timber rattlesnakes.
Iowa	Statewide in Iowa the timber rattlesnake shall not be protected, except in Allamakee, Appanoose, Clayton, Delaware, Des Moines, Dubuque, Fayette, Henry, Jackson, Jones, Lee Madison, Van Buren, and Winneshiek counties. In counties where it is protected it is not protected within 50 yards of a house actively occupied by human beings.
Louisiana	Timber rattlesnakes may be taken without limit by individuals possessing a state resident or non-resident fishing license for non-commercial purposes. If the purpose for taking them is commercial then a resident or non-resident collectors license is needed.
Oklahoma	An individual possessing a resident or non-resident hunting license may take timber rattlesnakes from March 1 – June 30 without limit and may legally sell lawfully taken rattlesnakes only to persons possessing a commercial or non-commercial wildlife breeders license.
South Carolina	The lowland or "canebrake" form of the timber rattlesnake has no regulations for take or possession by individuals, but a scientific collecting permit can set numbers of timber rattlesnakes taken by researchers.
West Virginia	No regulations for timber rattlesnakes. They may be collected without limit.
Extirpated	
Maine	Timber rattlesnakes have no legal protection in Maine. It could take a year or more to get timber rattlesnakes protection under the Maine Endangered Species Act. The last timber rattlesnake observed in Maine was in 1822.
Rhode Island	No timber rattlesnakes can be possessed.

Appendix 2. Mean number of trees in 0.04 ha snake-centered plots.
Mean number of trees for each size class per species for each 0.04 ha snake-point-plot. Tree species are listed in descending order based on the mean of the total of each species. Data presented are the mean with the standard error in parentheses. Dashes indicate that a species was absent from that size category.

	Tree Size Classes				
Tree Species	**7.5-20cm**	**20-40cm**	**40-60cm**	**>60cm**	**Total**
*Pinus rigida**	4.28(1.70)	1.72(0.70)	0.06(0.06)	-	6.06(2.25)
Quercus montana	3.67(0.85)	1.50(0.56)	0.33(0.14)	0.06(0.06)	5.56(1.10)
Pinus virginiana	1.89(1.07)	0.89(0.50)	-	-	2.78(1.54)
Carya glabra	1.61(0.96)	0.28(0.16)	-	-	1.89(1.11)
Acer rubrum	1.67(0.52)	0.22(0.17)	-	-	1.89(0.52)
Nyssa sylvatica	1.39(0.41)	-	-	-	1.39(0.41)
Quercus velutina	0.56(0.22)	0.50(0.25)	-	-	1.06(0.42)
Oxydendrum arboreum	0.72(0.34)	0.17(0.17)	0.06(0.06)	-	0.94(0.53)
Betula lenta	0.56(0.27)	0.22(0.22)	-	-	0.78(0.33)
Quercus rubra	0.17(0.12)	0.39(0.18)	-	0.06(0.06)	0.61(0.26)
Tsuga canadensis	0.39(0.33)	-	-	-	0.39(0.33)
Quercus ilicifolia	0.28(0.19)	0.06(0.06)	-	-	0.33(0.23)
Amelanchier arborea	0.22(0.17)	-	-	-	0.22(0.17)
Juniperus virginiana	0.11(0.11)	0.06(0.06)	0.06(0.06)	-	0.22(0.22)
Sassafras albidum	0.22(0.17)	-	-	-	0.22(0.17)
Pinus strobus	0.06(0.06)	0.06(0.06)	-	-	0.11(0.08)
Tilia americana	0.06(0.06)	-	-	-	0.06(0.06)
Prunus serotina	0.06(0.06)	-	-	-	0.06(0.06)
Carya tomentosa	0.06(0.06)	-	-	-	0.06(0.06)
Pinus pungens	-	0.06(0.06)	-	-	0.06(0.06)

*Tree names from Duncan and Duncan (1988).

Appendix 3. Mean number of trees in 0.04 ha random plots.
Mean number of trees for each size class and species for each 0.04 ha random-point-plot. Tree species are listed in descending order based on the mean of the total of each species. Data presented are the mean with the standard error in parentheses. Dashes indicate a species was absent from that size class.

	Tree Size Classes				
Tree Species	**7.5-20cm**	**20-40cm**	**40-60cm**	**>60cm**	**Total**
*Quercus montana**	4.22(0.89)	5.28(1.04)	1.44(0.38)	0.06(0.06)	11.00(1.62)
Pinus rigida	1.44(0.64)	1.06(0.42)	-	-	2.50(1.03)
Pinus virginiana	1.61(0.80)	0.67(0.34)	-	-	2.28(1.03)
Quercus rubra	0.50(0.22)	1.06(0.46)	0.50(0.25)	0.06(0.06)	2.17(0.80)
Acer rubrum	2.00(0.59)	0.11(0.11)	-	-	2.11(0.62)
Nyssa sylvatica	2.06(0.65)	0.06(0.06)	-	-	2.11(0.65)
Quercus velutina	0.28(0.16)	1.22(0.50)	0.06(0.06)-	-	1.56(0.57)
Betula lenta	0.50(0.35)	0.61(0.51)	-	-	1.11(0.83)
Carya glabra	0.89(0.62)	0.17(0.12)	-	-	1.06(0.65)
Acer pennsylvanicum	0.56(0.56)	0.11(0.11)	-	-	0.67(0.67)
Acer saccharum	0.22(0.15)	0.17(0.17)	-	-	0.39(0.29)
Carya tomentosa	0.22(0.17)	0.11(0.11)	-	-	0.33(0.28)
Pinus strobus	0.28(0.23)	0.06(0.06)	-	-	0.33(0.28)
Ostrya virginiana	0.33(0.33)	-	-	-	0.33(0.33)
Liriodendron tulipifera	0.06(0.06)	0.17(0.17)	0.06(0.06)	-	0.28(0.28)
Amelanchier arborea	0.28(0.23)	-	-	-	0.28(0.23)
Tsuga canadensis	0.17(0.17)	0.06(0.06)	-	-	0.22(0.17)
Quercus ilicifolia	0.22(0.17)	-	-	-	0.22(0.17)
Pinus pungens	0.06(0.06)	0.11(0.11)	-	-	0.17(0.17)
Cornus florida	0.11(0.08)	-	-	-	0.11(0.08)
Robinia pseudoacacia	-	0.06(0.06)	-	-	0.06(0.06)
Quercus coccinea	-	0.06(0.06)	-	-	0.06(0.06)
Fraxinus americana	-	0.06(0.06)	-	-	0.06(0.06)
Quercua alba	-	0.06(0.06)	-	-	0.06(0.06)
Sassafras albidum	0.06(0.06)	-	-	-	0.06(0.06)
Ailanthus altissima	0.06(0.06)	-	-	-	0.06(0.06)

*Tree names from Duncan and Duncan (1988).

Appendix 4. Timber rattlesnake sighting report form.

Timber Rattlesnake (*Crotalus horridus*) Sighting Report Form

Instructions:

Please fill out any information you can remember for each section. I am most interested in information pertaining to the sighting location. If possible please include a photocopied section of 7.5 minute USGS topoquad with the location marked with a dot placed at the sighting location and the name of the topoquad written on the map. Then staple the photocopied map section to this sheet. If you have more than 1 sighting to report either make a photocopy of this sheet for each sighting or request more copies of this form from David Garst: (540)-381-5656 or dagarst@vt.edu

Observer Info:

Name:_________________________ Address:___________________________________

City/Town:________________________ State:___________ Zip:___________________

Phone:_____________________ email:____

Sighting Info:

Sighting date: ☐ within past 1yr. ☐ within past 5 yrs. ☐ within past 10 yrs.
☐ greater than 10 yrs. ago ☐ exact date___________________________

Location: ☐road ☐residential (yard) ☐ forest area ☐forest/rocky area ☐ field
☐ business/industrial ☐ other:_______________________________________

Landowner: ☐ VDOT ☐ US Forest Service ☐ US Park Service
☐US Fish and Wildlife Service
☐VA Dept. of Game and Inland Fisheries
☐Private ☐ Other:____

County:____

Exact Location: Give road names, exact addresses, distances and direction to the nearest town or major intersection, GPS coordinates, or any other information important to the relocation of this point on a map. Please be as explicit as possible as possible with this information. If you can attach a section of map just write "see attached map".__________

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Biological info:

Size of observed timber rattlesnake:

☐Juvenile <30 inches ☐ Adult >30 inches

Comments:____

____

____

Appendix 5. results for USGS rattlesnake place name search.
USGS data used to create Figure 3 in Chapter 2. All sites are from Virginia.

Feature Name	County	Latitude 00°00'00"	Latitude 000°00'00"	USGS 7.5' Map
Rattlesnake Run	Augusta	381856N	0791711W	West Augusta
Rattlesnake Hollow	Bath	380742N	0795502W	Minnehaha Springs
Rattlesnake Branch	Buchanan	371109N	0820459W	Vansant
Rattlesnake Creek	Campbell	371445N	0785507W	Mike
Rattlesnake Branch	Charlotte	371148N	0784405W	Madisonville
Rattlesnake Creek	Chesterfield	373334N	0773219W	Bon air
Rattle Branch	Fauquier	384558N	0775500W	Orlean
Rattlesnake Mountain	Fauquier	385152N	0780236W	Flint Hill
Rattlesnake Trail	Fauquier	385142N	0780234W	Flint Hill
Rattlesnake Run	Fluvanna	375218N	0780614W	Caledonia
Rattlesnake Creek	Gerrnsville	363428N	0774400W	Barley
Rattlesnake Swamp	Isle of Wight	365453N	0764859W	Raynor
Rattler branch	Prince Edward	371517N	0783519W	Prospect
Rattlesnake Point	Rappahannock	384501N	0781727W	Bentonville
Rattlesnake Run	Rockingham	384606N	0785405W	Bergton
Rattlesnake Hollow	Tazewell	370147N	0812741W	Hutchinson Rock
Rattle Creek	Washington	364256N	0821245W	Wallace

Appendix 6. Results for USGS snake place name search.
USGS data used to create Figure 3 in Chapter 2. All sites are from Virginia.

Feature Name	**County**	**Latitude 00°00'00"**	**Latitude 000°00'00"**	**USGS 7.5' Map**
Snake Run	Alleghany	374045N	0801355W	Alleghany
Snake Run Ridge	Alleghany	374131N	0801117W	Alleghany
Snake Den Ridge	Botetourt	373241N	0793110W	Arnold Valley
Snake Creek	Carroll	364440N	0803743W	Fancy Gap
Snakeden Branch	Fairfax	385549N	0771827W	Vienna
Snake Run	Franklin	365959N	0800332W	Ferrum
Snake Creek	Halifax	370031N	0785733W	Brookneal
Snake Island	Richmond	374937N	0764038W	Morattico
Snake Hollow	Rockingham	384431N	0790148W	Cow Knob
Snake Hollow Mountain	Rockingham	384323N	0790130W	Cow Knob
Snake Den Mountain	Smyth	364556N	0811913W	Cedar Springs
Snake Den Ridge	Smyth	364337N	0812716W	Trout Dale
Snake Branch	Sussex	365744N	0772620W	Stony Creek
Snake Creek	Virginia Beach (city)	363411N	0760241W	Creeds
Snake Hollow	Warren	385446N	0780532W	Linden
Snake Island	Westmoreland	380817N	0764249W	Saint Clements Island