Wildlife Session

Spatially Explicit Modeling of Allegheny Woodrat Habitat in the Daniel Boone National Forest, Kentucky

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Abstract: Allegheny woodrat *(neotoma magister)* populations in the northern and western limits of the range have been greatly reduced in recent years, increasing the need to locate and monitor both threatened and seemingly stable populations. We tested the feasibility of predicting areas of suitable habitat for the woodrat in the Daniel Boone National Forest (DBNF) by using a Geographic Information System model. Several themes depicting woodrat habitat variables were overlaid to produce a comprehensive map displaying likelihood of woodrat occurrence. Logistic regression analysis was used to determine effect of each habitat variable on woodrat occurrence based on a sample of 394 known woodrat occurrence sites, 511 random sites, and habitat data including slope, landuse, site geology, forest cover, and locations of forest openings, clifflines, streams, and roads. The resulting habitat model correctly classified 97% of the 416 independent woodrat locations at the 0.50 probability level. This habitat model will provide an efficient, cost-effective method for searching out new woodrat locations, monitoring and analyzing previously known locations, managing DBNF to maintain existing habitat, and restoring previous habitat.

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The Allegheny woodrat was historically distributed from western Connecticut through Pennsylvania, along the Appalachian Mountains through Kentucky and Tennessee, and into northern Alabama (Poole 1940, Schwartz and Odum 1957). In the last quarter of the twentieth century this one prevalent mammal began to mysteriously disappear from much of its historic range (Beans 1992). Once healthy populations in New York, New Jersey, and eastern Pennsylvania have all but vanished in recent years (Beans 1992). Populations in the Virginias, Kentucky, and Tennessee, however, appear to be stable (Beans 1992). The exact reasons for this reduction in distribution have not been determined.

In Kentucky, the Allegheny woodrat was listed as a species of special concern in 1996 (Ky. State Nature Preserves Comm. [KSNPC] 1996). Current populations are believed to be stable, although recent woodrat distributions have mainly been studied in the Daniel Boone National Forest (DBNF) region of eastern Kentucky (Bommarito 1999). Woodrats are widely distributed throughout eastern Kentucky. Distribution of woodrats in central and western Kentucky has not been studied as extensively as in the DBNF and eastern Kentucky.

The Allegheny woodrat is usually found in forested ecosystems along clifflines or in caves (Newcombe 1930, Poole 1940). In DBNF, woodrats inhabit areas with a high slope, high tree density, fewer hardmast trees with diameter at breast height (dbh) between 15.1 and 30.0 cm, and a high number of softmast trees with a 0–15 cm dbh (Bommarito 1999). Balcom (1944) found that woodrat habitat in Pennsylvania included areas exhibiting high slope, high rock cover, and low basal area of overstory trees. In West Virginia, Myers (1997) found that in areas of rock outcrops, woodrats preferred regions with steeper slope, greater width of rock outcropping, fewer small trees (0.0–15.0 cm dbh), and less leaf litter. Woodrat cave habitat and its related surface habitat have not been studied in detail (Clark and Clark 1994).

A Geographic Information System (GIS) is an effective tool to analyze habitat requirements of wildlife. GIS technology has been used to analyze many aspects of habitat for various wildlife species. For example, grizzly bear *(Ursus arctos horribilis)* distribution, human conflicts, and habitat use have been modeled using a GIS (Mace and Waller 1996, Waller and Mace 1997). A GIS also has been used to analyze distribution patterns for Allegheny woodrats (Bommarito 1999) and brown-headed cowbirds (*Molothrus ater*; Coker and Capen 1995). Present habitat use versus historic habitat use has been studied for the Allegheny woodrat (Balcom 1994) and California condor (*Gymnogyps californianus*; Stoms et al. 1993). The likelihood of presence within a habitat was modeled using a GIS for black bears (*Ursus americanus*; Clark et al. 1993) and black-tailed jackrabbits (*Lepus californicus*; Knick and Dyer 1997). The Allegheny woodrat, with its recent decline, is well suited for more habitat analysis using GIS.

We had 5 objectives:

1. To digitize a statewide database of known woodrat locations.
2. To acquire habitat attributes for each woodrat location from GIS layers.
3. To build a predictive model of woodrat occurrence using logistic regression analysis of woodrat location and habitat data.
4. To produce a map depicting probability of woodrat occurrence by applying the logistic regressions equation to GIS grid layers.
5. To test accuracy of the habitat suitability map using a unique set of woodrat locations.

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Methods

This study was conducted within the proclamation boundary of the DBNF. In the first phase of the project, we created a database of the geographic coordinates for most recorded woodrat locations in the DBNF (hereafter, referred to as woodrat locations). We obtained records from KDFWR, KSNPC, U.S. Forest Service (USFS), and other previous woodrat research. The database was compiled using ArcView 3.2 (Environ. Systems Res. Inst. [ESRI] 1999) and Microsoft Access 2000 (Microsoft Corp. 1999).

We acquired habitat attributes for each woodrat location using data layers for variables such as slope, location of cliffines, type of landuse, vegetation and forest cover, age of the stand, distance to nearest road, distance to nearest stream, order of the nearest stream, and distances to non-forest, agriculture, and human disturbance patches. We also used a data layer for a variable of possible karst geology (i.e., irregular limestone formations with sinks, underground streams, and caverns).

Slope, stream, road, landuse, and vegetation coverages were provided by the Kentucky Natural Resources and Environment Protection Cabinet's Office of Information Services. Distance from each woodrat location to the nearest stream, the stream's order, and distance to nearest road were determined through spatial analysis using the appropriate data layers. Slope coverage contained 7 classes: 0%–2%, 2%–6%, 6%–12%, 12%–20%, 20%–35%, 35%–50%, 50%–100%. The landuse coverage used classes based on Anderson Level II landuse and land cover classification categories (Anderson et al. 1976) including residential, industrial, cropland and pasture, deciduous forest land, mixed forest land, evergreen forest land, streams and canals, forested wetland, and strip mines and gravel pits.

Karst geology was the attribute used to represent the likelihood of cave-forming geology and was derived from the Kentucky Geological Survey's (KGS) 1:500,000 digital geologic map. We assigned each woodrat location a karst attribute of non-karst, some karst, or intense karst, based on susceptibility of the underlying geologic unit to karstification (Ivanovich 2000).

The cliffline, forest type, and stand age data layers were provided by the USFS and DBNF. We used location of cliffline to determine distance from each woodrat location to the nearest cliffline. A cliff was defined as a naturally occurring, continuous stretch of 3.048 m of vertically exposed rock.

We used the roads layer of represent human disturbance, but several layers depicting human disturbance also were generated from the landuse layer. Distance from each woodrat location to the nearest non-forest patch was measured by creating a layer of all non-forest polygons from the landuse layer. Non-forest patch layers were generated for 4 minimum patch sizes of 0.5, 5, 50, and 100 ha. We used the ArcView Spatial Analyst Extension to determine distance from each woodrat location to the nearest non-forest polygon of each size class. We used the same method to determine distance from the woodrat location to the nearest agricultural patch with a minimum patch size of 0.5, 5, 50, and 100 ha and to the nearest area of human disturbance as represented by any Anderson Level I Urban or Built-up Land, Level I Agricultural Land, or any Level II Strip Mine (Anderson et al. 19760).

To compare with habitat attributes of woodrat locations, we generated a set of 511 random locations by matching a random x-coordinate with a random y-coordinate. Random locations were distributed throughout the study area as were woodrat locations. Habitat attributes for random locations were extracted in the same way they were for the know woodrat locations.

The extracted habitat data for woodrat locations and the random locations were compared using univariate statistics. Habitat variables with continuous distribution were each analyzed using a Wilcoxon ranked sum test (SAS 1990) to test that the mean values for the woodrat locations were different from the mean values for the random locations. We analyzed categorical variables using a Chi-Square Goodness-of-fit test (SAS 1990) to test if the distribution of woodrat locations among categories was different from the expected distribution as represented by the random locations.

From the database of woodrat locations created in the first phase of this project, only woodrat records for which a reliable, precise location could be determined were used to build the habitat model (i.e., locations from an existing field map or with corroborating evidence). Thus, 810 locations were selected. Each of the 810 woodrat locations was assigned a random number between 0 and 1 in order to create a random subset of locations. The 394 locations with random numbers <0.5 were used to build the model. The remaining 416 data points with random numbers >0.5 were used to test the accuracy of the predictive model.

Relative statistical significance of each habitat variable was compared to the other variables using logistic regression analysis. The logistic regression analysis provided and equation to determine Θ, the probability of finding suitable woodrat habitat at any given location using the coefficient and value for each significant variable at that location. Variables deemed to have biological significance to the woodrat were entered into the analysis. Vegetation, forest type, and understory class variables, for which sufficient data coverage of the study area did not exist, were not used during logistic regression analysis.

To produce the habitat suitability layer, a grid for each significant variable in logistic regression analysis was produced using the ArcView Spatial Analyst Extension (ESRI 1999). Each grid had a 30-m pixel size. We determined a probability of finding suitable woodrat habitat (Θ) in each pixel of habitat suitability grid using the map calculator of the ArcView Spatial Analyst.

To test model accuracy, we calculated percentage of test locations (the 416 woodrat locations not used to build the model) that fell in each of 6 categories of Θ (<50%, 50%–60%, 60%–70%, 70%–80%, 80%–90%, 90%–100% probability). Chi-square goodness-of-fit analysis was performed on these categories to compare distribution of test locations to the expected distribution, given the relative area accounted for by each of the probability categories. We also calculated a mean probability of finding suitable habitat at the test locations. Finally, percentage of test locations correctly classified based on a given probability level was determined.

Table 1. Habitat variables (continuous data) for locations used by Allegheny woodrats and for random locations in the Daniel Boone National Forest, Kentucky, 1974–1998.

Variable	*N*	$\bar{x}$	SE	*P*[a]
Distance to cliff (m)				
Used	395	103.94	15.43	
Random	511	1149.93	120.58	0.0001
Distance to stream (m)				
Used	395	107.82	3.40	
Random	511	112.59	5.72	0.1682
Distance to road (m)				
Used	395	298.50	11.29	
Random	511	302.92	11.46	0.4186
Forest age (years)				
Used	329	69.70	1.69	
Random	143	65.66	2.81	0.3519

a. Wilcoxon ranked sum test, $\alpha = 0.05$.

Table 2. Distance (m) to 3 landuse patch types from the landuse layer of 4 selected sizes for locations used by Allegheny woodrats and for random locations in the Daniel Boone National Forest, Kentucky, 1974–1998.

Variable		*N*	$\bar{x}$	SE	*P*[a]
Non-forest patch (m):					
>0.5 ha	Used	394	1374.08	47.72	
	Random	511	1275.45	53.63	0.0005
>5.0 ha	Used	394	1374.55	47.69	
	Random	511	1296.14	55.02	0.0008
>50 ha	Used	394	1925.32	74.05	
	Random	511	2024.99	87.98	0.1521
>100 ha	Used	394	2701.31	96.66	
	Random	511	2476.12	97.40	0.0035
Agriculture patch (m):					
>0.5 ha	Used	394	2190.51	85.86	
	Random	511	3832.18	213.59	0.0641
>5.0 ha	Used	394	2190.51	85.86	
	Random	511	3832.18	213.59	0.0641
>50 ha	Used	394	2759.16	93.57	
	Random	511	4290.28	211.37	0.0670
>100 ha	Used	394	4134.54	128.85	
	Random	511	4947.86	218.41	0.4183
Human disturbance patch (m):					
>0.5 ha	Used	394	1589.29	55.00	
	Random	511	1149.93	120.58	0.0001
>5.0 ha	Used	394	1589.65	54.98	
	Random	511	112.59	5.72	0.0001
>50 ha	Used	394	2235.95	75.95	
	Random	511	302.92	11.46	0.0027
>100 ha	Used	394	3260.32	97.07	
	Random	511	65.66	2.81	0.0001

a. Wilcoxon ranked sum test, $\alpha = 0.05$.

Results

Univariate tests suggested that mean distance to nearest cliff was lower for woodrat locations compared to random locations, whereas forest age and distances to nearest stream and nearest road were not different (Table 1). Woodrat locations were farther from non-forest patches of 0.5, 5, and 100 ha and farther from human disturbance patches of 0.5, 5, 50, and 100 ha. However, there was not difference in distance to agricultural patches of any size (Table 2). Chi-square goodness-of-fit analysis indicated a difference in distribution among categories between woodrat and random locations for slope, landuse, vegetation, forest type, and understory class, whereas order of the nearest stream and level of karst geology did no differ in distribution (Table 3).

Based on logistic regression analysis, 9 variable were significant in predicting probability of finding suitable woodrat habitat at a given location: distance to nearest cliff, distance to nearest agricultural patch >0.5 ha, distance to nearest human disturbance patch >0.5 ha, distance to nearest human disturbance patch >50 ha, geology susceptible to some karstification, deciduous or mixed forest, deciduous forest, evergreen forest, and areas with greater than 35% slope (Table 4). The relationship among theses variable is given by the logistic regression equation:

Table 3. Habitat variables (categorical data) for locations used by Allegheny woodrats and for random locations in the Daniel Boone National Forest, Kentucky, 1974–1998.

Variable	*N*	χ^2	df	*P*[a]
Karst				
Used	394			
Random	511	4.41	2	0.1100
Stream order				
Used	395			
Random	511	6.53	7	0.4790
Percent slope				
Used	324			
Random	456	26.95	6	<0.0005
Landuse				
Used	395			
Random	504	116.44	10	<0.0005
Vegetation				
Used	301			
Random	413	73.38	6	<0.0005
Forest type				
Used	329			
Random	143	39.70	23	0.0170
Understory class				
Used	215			
Random	106	27.33	13	0.0110

a. Chi-square goodness-of-fit test, $\alpha = 0.05$.

Table 4. Summary of stepwise logistic regression model to estimate probability of finding suitable Allegheny woodrat habitat in the Daniel Boone National Forest, Kentucky. Parameter estimates are maximum-likelihood estimates based on habitat data available in 2000.

Variable	Parameter estimate	χ^2	df	P^a
Intercept	–0.0216	48.0250	1	0.0001
Distance to cliff	–0.0033	74.7553	1	0.0001
Agriculture (>0.5 ha)	–0.0004	42.1920	1	0.0001
Human disturbance (>0.5 ha)	0.0003	5.8659	1	0.0154
Human disturbance (>50 ha)	0.0002	5.2884	1	0.0215
Susceptible to some karstification	1.2955	14.4545	1	0.0001
Deciduous or mixed forest	1.3513	38.0243	1	0.0001
Deciduous forest	1.4961	35.5197	1	0.0001
Evergreen forest	1.5196	18.7275	1	0.0001
Slope >35%	1.2508	7.4265	1	0.0064

a. Wald chi-square.

$$\Theta=1/\{1+\exp-[(-0.0216)+(-0.0033\cdot\text{distance to cliff})+(-0.0004\cdot\text{distance to agriculture}(>0.5\text{ ha}))+(0.0003\cdot\text{distance to human disturbance }(>0.5\text{ ha}))+(0.0002\cdot\text{distance to human disturbance }(>50\text{ ha}))+(1.2955\cdot\text{some karstification})+(1.3513\cdot\text{deciduous or mixed forest})+(1.4961\cdot\text{deciduous forest})+(1.5196\cdot\text{evergreen forest})+(1.2508\cdot\text{high slope}(>35\%))]\}$$

In the analysis of the habitat suitability map (Fig. 1) compared to the expected distribution, there were more test locations in the 0.90–1.00 range and fewer in all other ranges, especially in the 0.00–0.50 category (Table 5). The mean Θ value for all 416 test locations was 0.9097. At the 0.5 probability level, 96.88% of test locations were correctly classified, and at the 0.9 probability level 79.57% of test locations were correctly classified (Table 6).

Discussion

Woodrats were distributed throughout the DBNF (Bommarito 1999). With the importance of cave habitat to woodrats, inclusion of a layer representing the location of caves might be important, but a complete cave coverage for the DBNF does not exist. Our attempt to simulate possible cave habitat using a layer of geology susceptible to karstification appears successful. Many woodrat locations in the database occurred within caves, and the majority of woodrat locations were close to cliffs. This may be a result of collection of some woodrat location data during cliffline surveys and bat surveys and may represent a bias in the data. However, use of the cliffline layer along with the use of the geology layer showing susceptibility to karstification appears to have provided a suitable method of predicting both cave and cliffline habitat, given available data. The results of this study concur with several recent studies

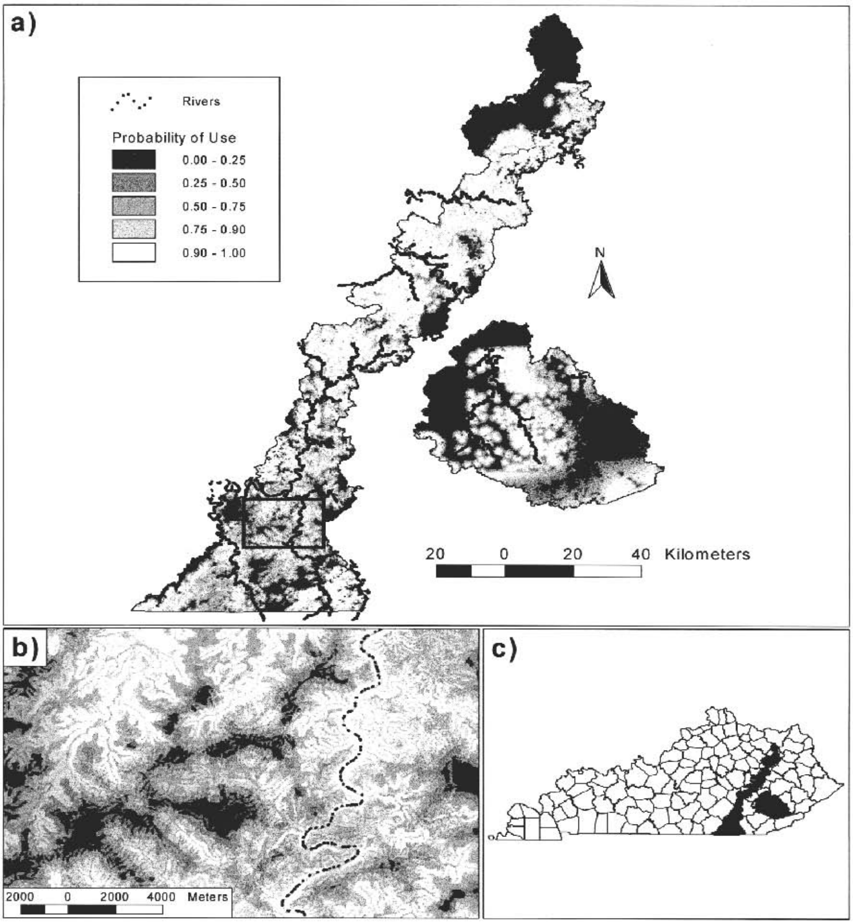

Figure 1. (a) Habitat suitability for the Allegheny woodrat in the Daniel Boone National Forest (DBNF), Kentucky. (b) Enlarged inset box area from Fig. 1a. (c) Location of DBNF in Kentucky with county boundaries.

of woodrat habitat (Balcom 1994, Myers 1997, Bommarito 1999) that suggest woodrats prefer areas with high slope and certain types of vegetation cover.

Woodrat locations were farther from all sizes of human disturbance patches than random locations. Furthermore, the difference in distance was greatest with the 100-ha patch size and least with the 0.5-ha patch size. In West Virginia, Myers (1997) indicated that disturbances within 1,000 m did not affect woodrat use of a site. According to Balcom (1994) woodrats in Pennsylvania were not highly sensitive to human activity near nest locations as indicated by proximity to clearcuts and roads.

Table 5. Chi-square goodness-of-fit analysis of the predicted probability (θ) of suitable habitat for Allegheny woodrat test location in the Daniel Boone National Forest, Kentucky ($P<0.001$, $\alpha=0.05$; df=5).

θ	*N* locations	% Total area[a]	Expected locations[b]	χ^2
0.000–0.499	13	0.3341	138.98	114.20
0.500–0.599	4	0.0441	18.34	11.22
0.600–0.699	5	0.0565	23.52	14.58
0.700–0.799	23	0.0800	33.30	3.18
0.800–0.899	40	0.1178	49.01	1.66
0.900–1.000	331	0.3674	152.85	207.64
Total	416	1.0000	416.00	352.47

a. Percent of area within DBNF with θ values in each category.

b. Number of locations expected based on percent total area if 416 locations were randomly distributed throughout DBNF.

Table 6. Classification table for test locations of the Allegheny woodrat habitat model of the Daniel Boone National Forest, Kentucky.

Probability Level	% Correctly classified	% Incorrectly classified
0.500	96.88	3.13
0.600	95.91	4.09
0.700	94.71	5.29
0.800	89.18	10.82
0.900	79.57	20.43

Like Balcom (1994) and Myers (1997), we found that distance to nearest road was not a significant determinant of woodrat habitat. Our results, however, indicate that, at least on the landscape level, woodrats are likely affected by proximity to human disturbance.

The effects of forest fragmentation on woodrats appear to be dependent on spatial scale. In West Virginia, Myers (1997) found that at the level of the forest stand, fragmentation disturbances did not have any measurable impact on woodrat site use. In Pennsylvania, Balcom (1994) did not find a difference in habitat heterogeneity between historically occupied and currently occupied woodrat sites according to an Anderson Level II landuse classification. However, Balcom (1994) postulated that reclassifying according to a broader Level I landuse type might yield different results. This appears to be the case with the assessment of forest versus non-forest in our study, in which 3 of 4 non-forest patch sizes showed differences between woodrat and random location distances. The effect of forest fragmentation in woodrats is supported by Hassinger et al. (1996) who found that woodrat colonies closer to a non-forest edger were more likely to be unoccupied than those farther away.

The location of woodrat habitat at greater distances from human disturbance seems intuitive, but their tendency to be located closer to agricultural patches upon first analysis was confusing. We suggest that this proximity is a function of the region as represented by the landuse data layer. Central areas of DBNF, where most woodrat locations were located, is represented by mainly forest with many 0.5-ha agricultural patches dispersed throughout, making proximity to such patches unavoidable. Random locations, on the other hand, were just as likely to be near the edge of DBNF, close to larger agricultural patches, but not as close to many 0.5-ha patches, which tended to be in the interior of DBNF. A second possible explanation for the presence of woodrats near agriculture involves a type of observer bias on the part of the biologists who initially recorded woodrat locations. It is likely that more accessible areas were visited by biologists more frequently, and that these areas tended to be closer to agriculture than more remote areas.

Our habitat suitability map can be used to more easily search out new woodrat locations, monitor and analyze previously known locations, manage DBNF to maintain existing habitat, and restore previous habitat. In the southern part of the range of Allegheny woodrats, the primary threat to the current stable population appears to be landscape-level forest fragmentation as a result of development practices, management of the forest for timber harvest through clear-cuts, and management for early and mid-successional habitat. Addressing immediate impacts of forest management, Castleberry (2000) found that although local clearcuts have minimal impact when sufficient intact forest is retained adjacent to colonies, woodrats were not found on rocky outcrops where overstory trees had recently been completely removed. This was despite evidence of previous woodrat presence at those outcrops. Periods of increased stress may exaggerate the effects of habitat fragmentation. For example, woodrats increased home range size and distance traveled in clearcuts following a decline in hard mast production when compared to intact forest sites (Castleberry 2000).

Habitat fragmentation may also increase the risk of genetic isolation to woodrat populations. Castleberry (2000) advocates the retention of dispersal corridors between proximate colonies to ensure gene flow and maintain genetic diversity. Our landscape-level analysis of distance of woodrat locations from human disturbance areas also emphasizes the threat of forest fragmentation to woodrat habitat. To maintain current woodrat populations, development practices and timber harvest activities that result in major landuse changes must accommodate woodrat needs. But management based on a model for a single species is often not practical. Hence, future efforts should concentrate on modeling for multiple species.

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