

A FEMALE BLACK BEAR DENNING HABITAT MODEL USING A GEOGRAPHIC INFORMATION SYSTEM

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Abstract: We used the Mahalanobis distance statistic and a raster geographic information system (GIS) to model potential black bear (*Ursus americanus*) denning habitat in the Ouachita Mountains of Arkansas. The Mahalanobis distance statistic was used to represent the standard squared distance between sample variates in the GIS database (forest cover type, elevation, slope, aspect, distance to streams, distance to roads, and forest cover richness) and variates at known bear dens. Two models were developed: a generalized model for all den locations and another specific to dens in rock cavities. Differences between habitat at den sites and habitat across the study area were represented in 2 new GIS themes as Mahalanobis distance values. Cells similar to the mean vector derived from the known dens had low Mahalanobis distance values, and dissimilar cells had high values. The reliability of the predictive model was tested by overlaying den locations collected subsequent to original model development on the resultant den habitat themes. Although the generalized model demonstrated poor reliability, the model specific to rock dens had good reliability. Bears were more likely to choose rock den locations with low Mahalanobis distance values and less likely to choose those with high values. The model can be used to plan the timing and extent of management actions (e.g., road building, prescribed fire, timber harvest) most appropriate for those sites with high or low denning potential.

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Key words: black bear, denning, geographic information systems, GIS, habitat modelling, habitat quality, *Ursus americanus*.

A variety of methods have been used to delineate wildlife habitat in recent decades including ground surveys, air photo interpretation, and satellite image analysis. While such techniques are useful, they generally only consider a 1- or 2-dimensional view of wildlife habitat selection. Multivariate statistics have been increasingly used to obtain a multi-dimensional perspective of wildlife-habitat relationships. Until recently, however, spatial representations in >2-dimensional space have been impractical and unwieldy.

With the recent development and proliferation of geographic information system (GIS) technologies, multi-dimensional habitat relationships across broad geographic areas can now be quantified. Tabular data can be linked to geographic locations with this tool, allowing sophisticated operations such as proximity analysis, buffering, and matrix calculations. We now can use GIS to examine habitat selection and to build multivariate predictive models of potential habitat use (Koeln et al. 1994).

Adequate den sites are vital to black bear conservation. Parturition and the first 8–10 weeks of cub development occur in dens, and black bears can spend over half their lives in winter dens. During denning, black bears do not eat, drink, urinate, or defecate, yet can expend 4,000 kcal daily (Nelson et al. 1983). Secure, well-insulated den sites are vital because poor sites can lead to decreased survival and productivity (Johnson and Pelton 1981).

We initiated research in 1988 to study the ecology of black bears in the Interior Highlands of Arkansas. One

aspect of the research focused on den selection and associated habitat characteristics. Hayes and Pelton (1994) found that, due to geological and vegetative differences, suitable den sites in the Ouachita Mountains may not have been as abundant as were potential sites in the nearby Ozarks. Our objectives were to develop predictive GIS models to identify potential bear denning habitat on the Dry Creek study area in the Ouachita Mountains based on a multivariate analysis of existing den sites and to test those models with additional den sites selected by bears subsequent to original model development.

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STUDY AREA

The Dry Creek study area (518 km²) is located in the Ouachita Mountain region of Arkansas and is characterized by flat-topped mountains and ridges separated by

narrow valleys and fast-flowing streams (Fig. 1). The study area lies in the frontal division of the Ouachita Mountains which were formed through vaulting of sedimentary rock with subsequent weathering and erosion. The mountain range consists of a series of east-west ridges with numerous rock outcroppings and benches. Sandstones, noviculites, cherts, and shales predominate (Johnston 1984). Soils are poor and thin with Mountainburg, Enders, Linker, and Nella the most common soil types (Vodrazka et al. 1969). Dominant tree species include white oak (*Quercus alba*), northern red oak (*Q. rubra*), and black oak (*Q. velutina*) on north-facing slopes, and shortleaf pine (*Pinus echinata*) and blackjack oak (*Q. marilandica*) on south-facing slopes. The area is 68% pine forest compared to 18% in upland hardwood forest (U.S. For. Serv., Booneville, Ark., unpubl. data).

MATERIALS AND METHODS

Trapping and Den Location

We trapped black bears with spring-activated foot snares (Johnson and Pelton 1980) and with barrel traps from May through July during 1988–90. Traps were placed to as-

sure complete coverage of the area without large gaps in the sampling pattern. Bears were tranquilized with a 2:1 mixture of ketamine hydrochloride (Ketaset®, Bristol Laboratory, Syracuse, N.Y.) and xylazine hydrochloride (Rompun®, Haver-Lockhart, Inc., Shawnee, Kans.; Addison and Kolenosky 1979). Once immobilized, adult (≥ 2 years old) female bears ($n = 17$) were fitted with MOD 500 radiocollars (Telonics Inc., Mesa, Ariz.) and tracked to winter dens.

Bears were radiotracked to winter dens from 1989 through 1995. Dens were first located from an airplane equipped with radiotelemetry gear and then investigated on foot from early February through mid-March. Females were immobilized at den sites and their reproductive status was recorded. Dens were classified as natural rock cavities, excavations dug by the bears, thickets or brushpiles in clearcuts, tree cavities, or open nests (Hayes and Pelton 1994). Universal transverse mercator (UTM) coordinates of den sites were determined from 1:24,000 topographic maps.

Den Habitat Modelling

Black bears in the Arkansas Highlands use a wide array of den types. Hayes and Pelton (1994) reported that

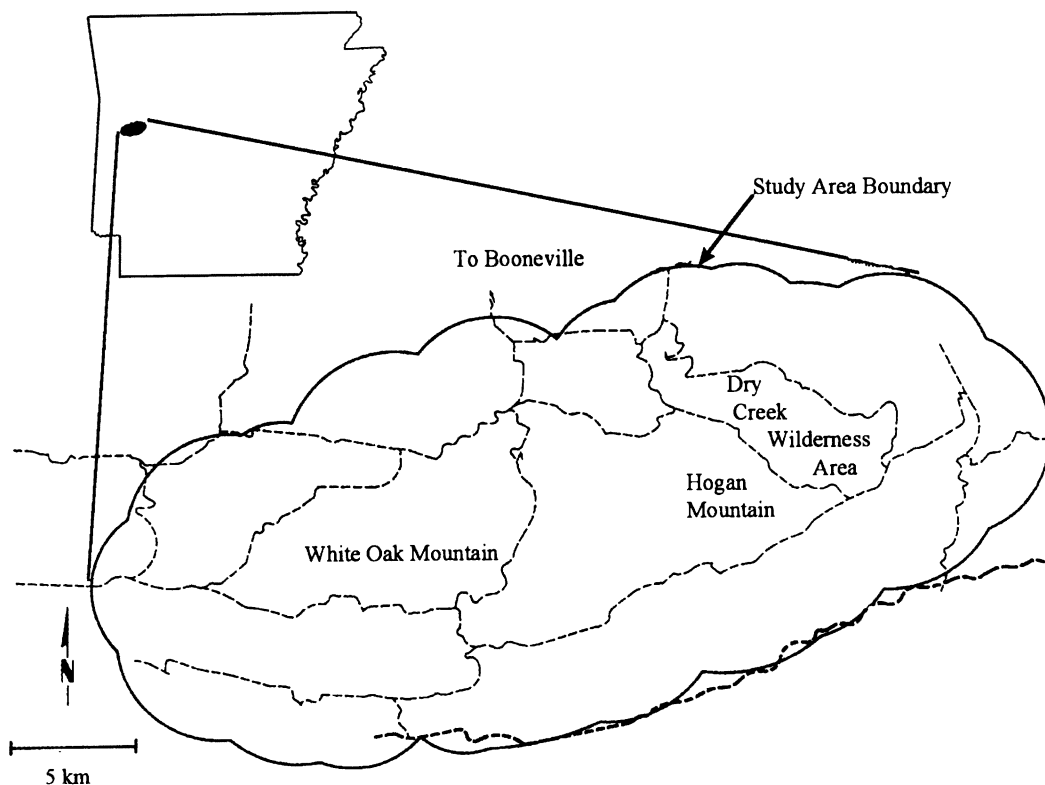


Fig. 1. The Dry Creek study area in the Ouachita Mountains of Arkansas.

32 of 48 dens were in rock cavities (67%), 6 were in excavations (13%), 6 were in clearcuts (13%), 2 were in open nests (4%), and 2 were in trees (4%). Initially, we used all the den locations collected on Dry Creek from February 1989 through March 1990 for model development. However, Hayes and Pelton (1994) found significant physical and vegetative differences among these den classes, so we expected some loss of statistical power by pooling den types. Therefore, we also developed a model restricted specifically to dens in rock cavities. Rock cavities were chosen because that den type was the most commonly used, is the most persistent, and has good thermal characteristics, but may have been in limited supply on Dry Creek (Hayes and Pelton 1994). Twenty-four dens were used to develop the general denning model and 11 dens were used for the rock den model.

The GIS models were developed using Geographic Resources Analysis and Support System (GRASS 3.0) software, developed at the U.S. Army Corps. Seven data layers were chosen to describe specific den habitat conditions: forest cover type (e.g., pine, hardwood–pine, bottomland hardwood–pine, cedar (*Juniperus virginiana*), scrub oak (*Quercus ilicifolia*), white oak–red oak–hickory (*Carya* spp.), pine–hardwood, and bottomland hardwoods), elevation, slope, aspect, distance to roads, distance to streams, and a measure of forest cover type richness (see Clark et al. [1993a, b] for a more detailed explanation of the map layers). Forest cover type was digitized from U.S. Department of Agriculture Forest Service maps developed from the Continuous Inventory of Stand Condition (CISC) management system (U.S. Dep. Agric. For. Serv. 1981). Elevation data were obtained as U.S. Geological Service (USGS) digital elevation models and slope and aspect data layers were created from those. A richness index of forest cover was calculated using the “neighbors-diversity” tool of GRASS. Road systems were digitized from U.S. Geological Survey quadrangle maps and stream maps were obtained as USGS digital line graphs. Distance categories to roads and streams were created by performing a proximity analysis within the GIS. All data layers were standardized to a 60-m cell resolution.

The denning habitat models are based on the Mahalanobis distance statistic,

$$\text{distance} = (\mathbf{x} - \hat{\mathbf{u}})' \hat{\Sigma}^{-1} (\mathbf{x} - \hat{\mathbf{u}})$$

where \mathbf{x} is a vector of habitat characteristics associated with each cell, $\hat{\mathbf{u}}$ is a mean vector of habitat characteristics estimated from the known den sites, and $\hat{\Sigma}$ is the estimated covariance matrix, also from the known den sites

(Rao 1952, Morrison 1976:241). Mahalanobis distance is a measure of dissimilarity and represents the standard squared distance between some set of sample variates, \mathbf{x} , and an ideal habitat represented by $\hat{\mathbf{u}}$. We estimated $\hat{\Sigma}$ and $\hat{\mathbf{u}}$ with Proc DISCRIM of the Statistical Analysis System (SAS Inst., Inc. 1985).

Mahalanobis distances were calculated with GRASS by performing the step-by-step matrix algebra among the various map layers as described in the above algorithm (Clark et al. 1993a, b). That produced a map containing a Mahalanobis distance value within each cell. This procedure was used for both the general model and the model specific to rock cavity dens.

Once the models were developed, we collected additional empirical data for model testing. Our empirical data set consisted of 32 general and 18 rock den locations collected subsequent to original model development, from 1991 to 1995. Those den locations represent all 17 female bears that were either barren, with cubs, or with yearlings. Although many of these den locations were of individual bears located in dens used in the original model development, we assumed dependence was minimal because den reuse was low (5%) and we observed no clear tendency for individuals to reden in similar den types. We performed a recoding of each of the 2 resulting maps to combine ranges of distance values so that expected den site frequencies would be >1 for all categories (Snedecor and Cochran 1980). A goodness-of-fit test was performed for each model to test the null hypothesis that female bears used habitats with low Mahalanobis distance values (consistent with habitat characteristics selected by study bears for denning) no more frequently than those habitats with high distance values.

Marcot et al. (1983) listed 23 criteria that may be used for wildlife habitat model validation, 1 of which is reliability. We selected reliability because it was appropriate for our data set and the objectives of our models, and because it incorporates elements of both Type I and Type II error (Morrison et al. 1992). We calculated reliability as $(a + d)/(a + b + c + d)$, where a is the number of dens in our sample present in habitats where presence is predicted by the model, b is the number of dens not present when presence is predicted, and c and d are the number of dens present and not present, respectively, when presence is not predicted (from Marcot et al. 1983).

RESULTS

Mahalanobis distance values associated with the 32 bear dens that were used to test the generalized den model were not found to be different from random lo-

Table 1. Goodness-of-fit test for generalized denning habitat model based on 32 black bear den locations collected subsequent to original model development, Dry Creek study area, Interior Highlands, Arkansas (1991–95).

Mahalanobis distance values	Percentage of coverage	Expected frequency	Actual frequency	χ^2
1–1,000	17.3	5.5	6	0.039
1,001–2,000	24.8	8.0	6	0.479
2,001–3,000	14.6	4.7	7	1.153
3,001–4,000	9.7	3.1	2	0.399
≥4,001	33.6	10.7	11	0.007
Totals		32.0	32	2.077

cations ($\chi^2 = 2.08$, 4 df, $P = 0.7781$; Table 1). Using a subjective Mahalanobis distance value of 2000 to discriminate between habitats where den presence or absence is predicted (Table 1), the reliability of this model would be 50%, no better than random chance. However, the 18 rock dens located from 1991 to 1995 were different from random ($\chi^2 = 14.79$, 4 df, $P = 0.0026$), with den sites more likely to occur in cells with low Mahalanobis distance values (Table 2). Using a subjective value of 1,000 to discriminate between den presence or absence (Table 2), the reliability of the rock den model was 89%. Those 18 rock den sites were more likely to be located at middle to high elevations ($\chi^2 = 15.50$, 4 df, $P = 0.0016$), near roads ($\chi^2 = 16.45$, 4 df, $P = 0.0008$), on steep slopes ($\chi^2 = 52.64$, 3 df, $P < 0.0001$), and in areas of high forest type richness ($\chi^2 = 42.19$, 5 df, $P < 0.0001$). No relationships were found between those dens and forest cover type, aspect, or distance to streams ($P > 0.05$).

DISCUSSION

Marcot et al. (1983) state that model evaluation should be an integral part of model building; our study results strongly support that philosophy. Even though the generalized model was statistically sound, it performed poorly when tested with data collected subsequent to model development. This was not unexpected because Hayes and Pelton (1994) found significant differences in rock, excavation, and clearcut den types based on slope and understory stem densities. By pooling all those den types, the model failed to find a consistent suite of habitat characters for generalized den sites. However, when we reduced the variability by restricting the model to a specific den type, model performance was good, despite the low sample sizes ($n = 11$) used for development of the original model.

Table 2. Goodness-of-fit test for rock cavity denning habitat model based on 18 black bear den locations collected subsequent to original model development, Dry Creek study area, Interior Highlands, Arkansas (1991–95).

Mahalanobis distance values	Percentage of coverage	Expected frequency	Actual frequency	χ^2
1–500	13.9	2.5	7	8.036
501–1,000	36.1	6.5	9	0.956
1,001–1,500	33.8	6.1	1	4.232
1,501–2,000	8.5	1.5	1	0.187
≥2,001	7.7	1.4	0	1.381
Totals		18.0	18	14.792

Rock dens located from 1991 to 1995 on Dry Creek were more likely to be found at higher elevations, near roads, on steeper slopes, and in areas of high vegetative richness. This is consistent with the 1989–91 findings by Hayes and Pelton (1994). Rocky outcroppings generally occurred in creek drainages or along blufflines, both of which are common locations for roads. Furthermore, vehicle traffic during winter months is extremely light. This may explain the tendency of bears to den near roads rather than selection for the roads themselves.

Bear denning habitat may be especially critical in the Southeast due to the lack of insulating snow cover through the winter months (Johnson and Pelton 1981). Rock cavities may be the most desirable den type in the Arkansas Highlands because they are secure, they are thermally efficient, they persist for the longest period of time, and they require little preparation. Our model identifies habitats where characteristics are consistent with areas where bears have used rock dens. It could be used by land managers to make decisions regarding land use as they affect bear denning habitat. For instance, managers might decide to avoid the use of fire in habitats where and when bear denning is likely. Or, timber harvest in areas where dens are likely to be found might be rescheduled for a time when denning is not occurring. These data and methods are robust because the assumptions of this multivariate technique are few, the data set targets a specific bear behavior (unlike general radiotelemetry data), and it is tested with data collected subsequent to model development. Furthermore, the technique could be used to identify other critical habitats for bears or other species if locations and behaviors at those sites are known.

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