Research Article

Landscape Analysis of Bobcat Habitat in the Northern Lower Peninsula of Michigan

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ABSTRACT Controversy over bobcat (*Lynx rufus*) management in the northern Lower Peninsula of Michigan (NLP), USA, stimulated a need for information on the distribution of Michigan bobcats. From March 2003 to October 2004, we conducted a radiotelemetry and scent-station survey study of bobcats in the NLP. We developed a spatial model to predict bobcat distribution throughout the NLP based on bobcat area requirements, habitat and landscape variables derived from remotely sensed land-cover data, and a multivariate distance statistic. Bobcat 50% minimum convex polygon core areas were comprised of more lowland forest (51%), nonforested wetlands (9%), and streams (3%) than the surrounding NLP. The NLP was comprised primarily of upland forest (44%) and field (32%). Habitat in the northeast and central regions of the NLP was most similar to the habitat composition of bobcat core areas. This model will be useful in aiding Michigan wildlife management agencies with assessing the status and distribution of the NLP bobcat population by identifying areas important to bobcats and supporting the development of regional strategies for carnivore conservation. (JOURNAL OF WILDLIFE MANAGEMENT 71(8):2699–2706; 2007)

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KEY WORDS bobcat, core area, habitat model, landscape, *Lynx rufus*, Michigan, Penrose distance, radiotelemetry, scent-station survey.

A need exists for the development of efficient and reliable methods to adequately survey and monitor populations of furbearer species, including bobcats (*Lynx rufus*; Earle 2001, Rolley et al. 2001). Accurate indices and models (e.g., methods of estimating abundance and population trends) of bobcat populations are rare. Bobcats are secretive, making it difficult to adequately survey and monitor their populations. Consequently, it is also difficult to obtain sufficient data on reproduction and survival to incorporate into population models. In Michigan, USA, bobcats are a harvested furbearer species, and controversy between furbearer user groups and management agencies over the management of the bobcat population has fueled a need for more information on Michigan's bobcat populations, particularly in the northern Lower Peninsula (NLP).

Recently, the increased use of Geographic Information Systems (GIS) modeling to identify and predict areas of suitable habitat has allowed wildlife managers to focus their management and conservation efforts more efficiently. In addition, the development of region-specific models is important to more effectively direct bobcat management (Lovallo et al. 2001).

From March 2003 to October 2004, we conducted a radiotelemetry and scent-station survey study of bobcats on a study area in the NLP. We then followed a method developed by Nielsen and Woolf (2002) to model the similarity of habitat at the core-area scale between areas known to contain bobcats and the NLP. Our objective was to develop a spatial model to identify areas of suitable habitat for bobcats based on 1) assessments of bobcat area requirements, 2) habitat and landscape variables derived from remotely sensed land-cover data, and 3) a multivariate distance statistic.

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STUDY AREA

Our study area was located in the central NLP of Michigan and encompassed 4,253 km^2 (Fig. 1). The study area included all of Roscommon and Missaukee counties and portions of Clare, Crawford, Gladwin, Kalkaska, Ogemaw, Osceola, and Oscoda counties. The study area was comprised of upland forest (47%), field (26%), lowland forest (11%), transportation (6%), nonforested wetland (4%), open water (4%), streams (1%), and urban (1%) cover types. The field cover type included agriculture and grassland habitats. Forested areas were dominated by oaks (*Quercus* spp.), aspens (*Populus* spp.), and pines (*Pinus* spp.) on upland sites and northern white cedar (*Thuja occidentalis*) and balsam fir (*Abies balsamea*) on lowland sites (Leatherberry 1994). The study area was located within the portion of the NLP open to bobcat harvest (Fig. 1).

METHODS

Trapping and Radiotelemetry

We used model 209.5 Tomahawk® cage traps (Tomahawk Live Trap, Tomahawk, WI) and modified number 3 Victor Soft-Catch® padded foot-hold traps (Earle et al. 2003; Oneida Victor, Inc., Euclid, OH) to trap bobcats during 2 trapping periods from March to July 2003 and May to July 2004. We immobilized trapped bobcats with an intramuscular injection of 10 mg/kg ketamine hydrochloride (HCl) plus 1.5 mg/kg xylazine HCl (Kreeger 1999). We determined age class (juv: <1.5 yr; ad: ≥ 1.5 yr), sex, reproductive condition, and weight for each bobcat. We determined age class based on size, weight, and examination of teeth (Crowe 1975). We gave each bobcat uniquely numbered ear tags and a 63-g radiotransmitter with a

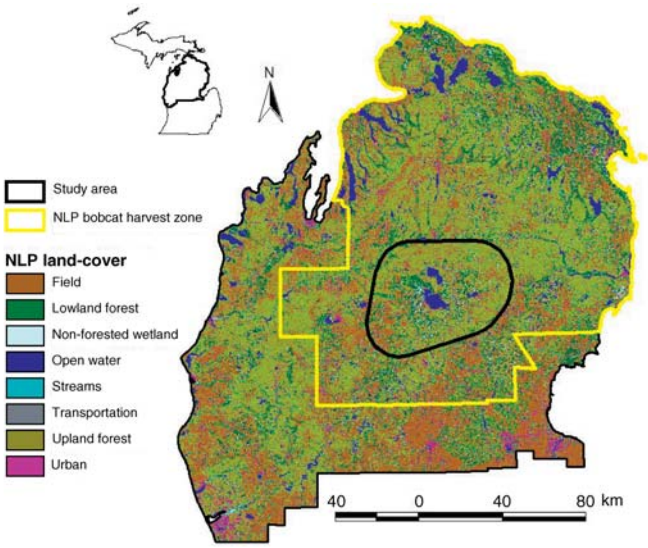

Figure 1. Map of the northern Lower Peninsula (NLP) of Michigan, USA, detailing land-cover, the NLP bobcat harvest zone, and the study area used for a radiotelemetry and scent-station survey study of bobcats (2003–2004).

mortality sensor (Holohil Systems Ltd., Carp, ON, Canada). After handling, we gave each bobcat an intramuscular injection of 0.125 mg/kg yohimbine HCl as a xylazine antagonist (M. R. Johnson, Global Wildlife Resources, Inc., personal communication) and placed each individual in a cage trap to recover. We released bobcats when they appeared fully alert. We conducted trapping and handling procedures under permit from the Michigan Department of Natural Resources (MDNR; no. SC 1172) and the Institutional Animal Care and Use Committee of Central Michigan University (no. 03-03).

We located radiocollared bobcats using standard telemetry techniques (White and Garrott 1990). We searched for missing animals using aerial telemetry. From May 2003 to October 2004, we used triangulation methods to locate bobcats 0–3 times per 24-hour period using a vehicle-mounted, 4-element Yagi directional antenna and an electronic compass (Lovallo et al. 1994). We determined telemetry bearing error (2.5°) by taking bearings to reference transmitters (n = 30) placed at known locations. We obtained all bearings for bobcat location estimates within 20 minutes to reduce error related to animal movement. We attempted to obtain locations at randomly determined times to adequately depict bobcat home-range use. We estimated locations using $\geq$2 bearings. We estimated locations and associated error polygons using the maximum likelihood estimator (Lenth 1981) in the software program LOCATE II (Nams 1990). For locations obtained with only 2 bearings, we attempted to maintain an angle of intersection near 90° to minimize error (White and Garrott 1990). We allowed the use of locations estimated using 2 bearings due to limited road access into several areas of our study site. We would have been unable to adequately represent portions of several bobcat home ranges had we omitted the use of these locations.

Core Area Estimation

We used the Home Range Extension (Rodgers and Carr 1998) for ArcView GIS to estimate 50% core areas of radiocollared adult bobcats using the minimum convex polygon (MCP) method (Mohr 1947). We modeled at the scale of a core area because core areas are estimated more reliably than home ranges (Seaman et al. 1999), and core areas of radiocollared bobcats in the NLP exhibited little intersexual or intrasexual overlap, whereas home ranges exhibited extensive overlap (Preuss 2005). Additionally, MCP core-area size did not differ significantly between male and female bobcats in the NLP (Preuss 2005). We used the MCP estimator because it provides one area of use per individual, which was suitable for our analysis (Nielsen and Woolf 2002). To assess whether core areas were adequately estimated, we developed home-range area accumulation curves. We plotted home-range area against number of locations for each adult bobcat (Kenward 2001). If the home range of an adult bobcat reached stability, we included its core-area estimate in further analyses.

Habitat Classification

We obtained 2001 IFMAP/GAP Lower Peninsula Land Cover data with 30-m resolution developed by the Forest, Mineral, and Fire Management Division of the MDNR. We reclassified the original 32 cover classes into 8 major cover classes using ArcGIS 8.3. We incorporated roads and streams missing from the original land-cover data by converting vector digital line graph road and stream data (Michigan Center for Geographic Information 2003) to raster format and merging it with the land-cover data to provide complete land-use coverage of the NLP (Fig. 1).

Model Variable Selection

We created a grid of 9,113 nonoverlapping hexagons and overlaid it on land-cover of the NLP. Each hexagon had an area equal to the average MCP core area of radiocollared adult bobcats. Within each hexagon, we calculated 139 habitat and landscape variables from 8 metric groups (Table 1) using the Spatial Statistics by Regions interface of the Patch Analyst Grid 3.0 extension to ArcView GIS 3.2. We $\log_{10}$-transformed habitat proportions and used a value of 0.0001 for null proportions (i.e., habitats that were not present within a hexagon; Aebischer et al. 1993). Habitat proportions were $\log_{10}$-transformed because they would be more likely to obtain a normal distribution than their raw values (Aebischer et al. 1993). We relied upon univariate statistics to reduce the number of variables for analysis. We performed all statistical analyses ($\alpha = 0.05$) in SPSS (SPSS, Inc., Chicago, IL). We used the following method to reduce the number of variables for modeling: 1) we retained the $\log_{10}$-transformed proportion of each habitat class; 2) we conducted nonparametric Spearman rank correlations within each habitat class for variables within each metric group and determined the number of nonsignificant correlations per variable; and 3) we eliminated one of all pairs of correlated variables within each metric group depending on the number of nonsignificant correlations with other

Table 1. Habitat (class) and landscape variables calculated for potential use in modeling bobcat habitat in the northern Lower Peninsula of Michigan, USA, 2003–2004. We calculated variables using the Spatial Statistics by Regions interface of the Patch Analyst Grid 3.0 extension to ArcView Geographic Information System 3.2.

Calculation[a]	Acronym	Metric	Unit
Area metrics			
Class	%LAND	% of landscape	%
Class-landscape[b]	LPI	Largest patch index	%
Patch metrics[c]			
Class-landscape	NP	No. of patches	no.
Class-landscape	MPS	$\bar{x}$ patch size	ha
Class-landscape	PSCV	Patch size CV	%
Edge metrics[c]			
Class-landscape	ED	Edge density	m/ha
Shape metrics[c]			
Class-landscape	LSI	Landscape shape index	
Class-landscape	MSI	$\bar{x}$ shape index	
Class-landscape	AWMSI	Area-weighted $\bar{x}$ shape index	
Class-landscape	DLFD	Double log fractal dimension	
Core area metrics[c,d]			
Class	C%LAND	Core area % of landscape	%
Class-landscape	CAD	Core area density	no./100 ha
Class-landscape	MCA1	$\bar{x}$ core area per patch	ha
Class-landscape	CACV1	Patch core area CV	%
Class-landscape	CACV2	Disjunct core area CV	%
Class-landscape	MCA2	$\bar{x}$ area per disjunct core	ha
Class-landscape	TCAI	Total core area index	%
Class-landscape	MCAI	$\bar{x}$ core area index	%
Diversity metrics[c]			
Landscape	SHDI	Shannon's diversity index	
Landscape	MSIDI	Modified Simpson's diversity index	
Landscape	PR	Patch richness	no.
Landscape	PRD	Patch richness density	no./100 ha
Landscape	SHEI	Shannon's evenness index	
Landscape	MSIEI	Modified Simpson's evenness index	
Nearest-neighbor metrics[c]			
Class-landscape	MNN	$\bar{x}$ nearest-neighbor distance	m
Contagion metrics[c]			
Class-landscape	IJI	Interspersion and juxtaposition index	%

[a] We calculated class metrics for field, lowland forest, nonforested wetland, open water, stream, transportation, upland forest, and urban habitats unless noted otherwise.
[b] Landscape refers to the total composition of habitats within each hexagon.
[c] Not calculated for stream and transportation habitat classes.
[d] Not calculated for the water habitat class.

variables in the group. We retained variables in each habitat class most representative of the variables within each metric group. When ties occurred between variables, we relied on the presumed importance of variables to bobcats and selected the variable suspected to be of greater biological importance. This resulted in 53 potential variables for modeling.

We continued to reduce the number of potential variables by retaining the $\log_{10}$-transformed proportion of each habitat class, as well as the variable most correlated to others within each habitat class. This resulted in 15 variables for habitat modeling (Table 2). Because further analysis required data normality, we transformed 2 variables to normal distributions (Wilk–Shapiro statistic = 0.86–0.97). We transformed the proportion of lowland forest by taking the logarithm of the squared value. We transformed the mean nearest-neighbor of upland forest by taking the logarithm of the square root of the value. No transformation was necessary for the other variables because they were distributed normally (Wilk–Shapiro statistic = 0.83–0.98).

Habitat Model

We developed a model of habitat similarity throughout the 48,518-km^2 NLP based on the habitat characteristics from core areas of radiocollared bobcats. We calculated a mean habitat vector as the mean values of the 15 habitat and landscape variables within bobcat core areas. We then used the Penrose distance statistic to measure habitat similarity between the mean vector from bobcat core areas and the habitat and landscape characteristics within each hexagon of the NLP grid. We calculated Penrose distance as

Table 2. Mean values of 15 habitat variables used for modeling bobcat habitat in the northern Lower Peninsula (NLP) of Michigan, USA (2003–2004) and the correlations between each variable and Penrose distance (PD). We calculated values from 50% minimum convex polygon core areas of 11 radiocollared bobcats and from within hexagons of a hexagon grid overlaid on the NLP. We calculated the mean habitat vector as the mean values of the 15 habitat and landscape variables within bobcat core areas.

	$\bar{x}$ vector		NLP hexagons		
Variable[a]	Value	SE	Value	SE	Correlation between NLP hexagons and PD[b]
% of field cover	15.8	2.5	32.4	0.2	−0.467
% of lowland forest cover	51.3	5.0	10.5	0.1	0.422
% of nonforested wetland cover	8.5	1.4	2.3	0.1	−0.425
% of open water cover	1.2	0.6	3.2	0.1	0.100
% of stream cover	2.0	0.7	0.9	0.1	−0.222
% of transportation cover	3.0	0.5	5.2	0.1	−0.373
% of upland forest cover	17.8	4.2	43.7	0.2	−0.461
% of urban cover	0.3	0.2	1.7	0.1	−0.073
Edge density of open water	3.5	1.4	5.7	0.1	0.197
Edge density of urban	3.2	1.4	15.8	0.2	0.411
Lowland forest core area % of landscape	27.7	4.5	3.6	0.1	−0.438
$\bar{x}$ area per disjunct core of landscape	0.7	0.1	2.6	0.3	0.902
$\bar{x}$ nearest-neighbor of field cover	49.5	2.4	44.9	0.1	0.214
$\bar{x}$ nearest-neighbor of upland forest cover	55.4	7.1	43.6	0.3	0.085
Nonforested wetland patch size CV	206.1	28.4	120.1	0.8	−0.382

[a] Percentage of habitat cover values are presented as raw percentage and not their $\log_{10}$-transformed equivalents.
[b] All correlations between NLP hexagon variables and PD were significant ($P \leq 0.05$).

$$P_{ij} = \sum_{k=1}^{p} \left[\frac{(\mu_{ki} - \mu_{kj})^2}{pV_k} \right]$$

where population i represented core areas of radiocollared bobcats, population j represented NLP hexagons, p was the number of habitat variables evaluated, μ was the variable value, k was each observation, and V was variance (Manly 2005). The habitat and landscape characteristics of hexagons with values close to zero were most similar to the characteristics of core areas of radiocollared bobcats, whereas hexagons with large Penrose distance values had habitat characteristics less similar to those of bobcat core areas. We performed all calculations in a spreadsheet and appended the final output to the hexagon grid in ArcView GIS to create a regional map of Penrose distance throughout the NLP. We determined the relative importance of each variable to the calculation of Penrose distance across the NLP by correlating Penrose distance to each habitat variable selected for modeling.

Model Validation

Scent-station survey.—We conducted scent-station surveys during October–November 2003 and August–September 2004 to provide a validation of the presence and distribution of bobcats throughout our study area. We designed our scent-station survey after methods described by Linhart and Knowlton (1975), with modifications by Roughton and Sweeny (1982) and Sargeant et al. (1998). Scent stations consisted of a 0.9-m diameter circle of sand with a fatty-acid scent tablet (Pocatello Supply Depot, United States Department of Agriculture, Pocatello, ID) placed in the center as an olfactory attractant. We checked 70 transects with 10 stations along each transect for 2 nights. We placed scent-station transects along paved and unpaved roads and 2-track forest trails, and in all available habitat types (excluding open water and streams), throughout the study area. We placed stations approximately 480 m apart along each transect and transects were located ≥5 km from the nearest transect (Sargeant et al. 1998). We recorded the locations of scent stations visited at least once by bobcats, overlaid those locations on our map of Penrose distance, and calculated frequency distributions of the percentage of scent-station visits that occurred in each Penrose distance class. We then performed chi-square tests to determine whether locations of scent stations visited by bobcats occurred more or less than expected within each Penrose distance class (Neu et al. 1974). In each Penrose distance class, we compared the proportion of hexagons in which bobcat detections occurred to the proportion of hexagons available within the study area. If this test was significant ($\alpha = 0.05$), we followed the methodology developed by Neu et al. (1974) to determine within which Penrose distance classes detections occurred more or less than expected.

Harvest data.—We utilized an independent set of locations ($n = 196$) obtained from harvested bobcats registered with the MDNR during the 2002–2003 bobcat hunting season to provide a validation of the presence and distribution of bobcats throughout the NLP. Despite potential bias in bobcat harvest locations, this was the only dataset available for the majority of the NLP. We overlaid these locations on our map of Penrose distance and calculated frequency distributions of the percentage of harvested bobcats occurring in each Penrose distance class. We then performed chi-square tests to determine whether locations of harvested bobcats occurred more or less than expected within each Penrose distance class (Neu et al. 1974). In each Penrose distance class, we compared the proportion of hexagons in which locations of harvested bobcats occurred to the proportion of hexagons available

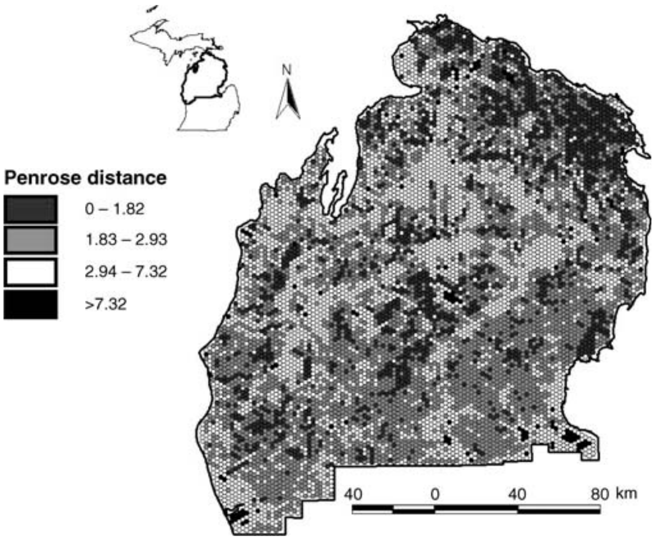

Figure 2. Penrose distance map depicting habitat similarity between core areas of radiocollared adult bobcats and the northern Lower Peninsula of Michigan, USA (2003–2004). Lower Penrose distance values indicate a greater similarity of habitat to bobcat core areas.

within the bobcat harvest zone of the NLP. If this test was significant ($\alpha = 0.05$), we followed the methodology developed by Neu et al. (1974) to determine within which Penrose distance classes detections occurred more or less than expected.

RESULTS

We captured and radiocollared 13 adult bobcats (8 M and 5 F). We obtained 915 total locations from May 2003 to October 2004. Investigation of plots of home-range area against number of locations indicated that 11 adult bobcats (6 M and 5 F) were suitable for use in estimation of core-area size. The average core-area size for adult bobcats was 5.1 ± 6.1 (SD) km^2.

Habitat Model

Hexagons containing bobcat core areas were comprised of 4.8 times more lowland forest, 3.7 times more nonforested wetland, and 2.2 times more stream cover than surrounding NLP hexagons. The NLP was comprised of 5.7 times more urban, 2.7 times more open water, 2.5 times more upland forest, 2.1 times more field, and 1.7 times more transportation cover than hexagons containing bobcat core areas. Edge density of urban cover and edge density of open water were 4.9 times and 1.6 times smaller, respectively, for hexagons containing bobcat core areas than for the surrounding NLP. Lowland forest core area percentage of landscape was 7.7 times greater for hexagons containing bobcat core areas than for surrounding NLP hexagons. Mean area per disjunct core of landscape was 3.7 times smaller for bobcat core areas than for NLP hexagons. Mean nearest-neighbor of upland forest and mean nearest-neighbor of field were 1.3 times and 1.1 times greater, respectively, for hexagons containing bobcat core areas than for NLP hexagons. The nonforested wetland patch size coefficient of variation was 1.7 times greater for bobcat core areas than for NLP hexagons. All 15 model variables had significant correlations with Penrose distance (Table 2). The variable most correlated to Penrose distance was mean area per disjunct core of landscape. Percentage of open water cover, percentage of urban cover, and mean nearest-neighbor of upland forest were least important in determining Penrose distance across the NLP. Mean Penrose distance for bobcat core areas was 1.82 ± 1.1 ($\bar{x}$ ± SD) and ranged from 0.34 to 5.92. Mean Penrose distance for NLP hexagons was 2.93 ± 3.1 ($\bar{x}$ ± SD) and ranged from 0.23 to 57.19. No locations of bobcats occurred in hexagons with a Penrose distance value >7.32. Throughout the NLP, 1,810 of 9,113 (20%) hexagons had a Penrose distance ≤ 1.82 (Fig. 2). In other words, the model predicted 9,231 km^2 of the NLP (20% of total area) to contain habitat at least as suitable as the average bobcat core area. Areas with habitat characteristics most similar (i.e., lowest Penrose distance) to bobcat core areas occurred in the northeast and central parts of the NLP. Primary habitat composition in areas with low Penrose distance was lowland forest and nonforested wetland cover. Habitat characteristics of the west and north-central areas of the NLP were least similar to bobcat core areas. The primary habitat components of these areas with higher Penrose distances were upland forest and field habitats.

Model Validation

Scent station survey.—Bobcats were the third and fourth most detected species at scent stations in 2003 (7.0% visitation) and 2004 (4.9% visitation), respectively, compared to other mammal species. Frequency distributions indicated that 67.5% of scent-station visits occurred in the top 2 Penrose distance classes (Table 3). However, locations of scent stations visited by bobcats did not occur more or less than expected within each Penrose distance class ($\chi^2_3 = 3.015$, $P = 0.389$).

Harvest data.—Frequency distributions indicated that 84.7% of harvested bobcats occurred in the top 2 Penrose distance classes (Table 3). Locations of harvested bobcats did occur more or less than expected within each Penrose distance class ($\chi^2_3 = 68.682$, $P < 0.001$). Harvested bobcats occurred more frequently than expected in hexagons with Penrose distance ≤ 1.82. In the Penrose distance class 1.83–2.93, bobcat harvest locations occurred as expected. Within the remaining Penrose distance classes, bobcat harvest locations occurred less than expected.

DISCUSSION

The model we developed for the NLP was at a scale at which a bobcat might perceive its surrounding environment because past research has demonstrated that mammals and other vertebrates perceive their environment at different spatial scales or at different levels of resolution (Zollner and Lima 1997, Gehring and Swihart 2003). Therefore, it is important to understand how bobcats interact with the landscape at a scale that may be more biologically meaningful (e.g., a home range or core area).

Lowland forest and nonforested wetland habitats were

Table 3. Bobcat occurrences within each Penrose distance class determined from locations of scent stations visited by bobcats within the study area in the northern Lower Peninsula (NLP) of Michigan, USA (2003–2004) and locations of harvested bobcats from within the bobcat harvest zone of the NLP (2002–2003).

	Study area			Bobcat harvest zone of NLP		
Penrose distance class	No. of scent stations visited	% of scent stations visited	Available hexagons[a]	No. of harvested bobcats	% of harvested bobcats	Available hexagons[a]
0–1.82	22	26.5	216	94	48.0	1,393
1.83–2.93	34	41.0	318	72	36.7	2,415
2.94–7.32	27	32.5	356	30	15.3	1,927
>7.32	0	0.0	11	0	0.0	57

[a] For comparison, we present available hexagons in each Penrose distance class for the study area and the bobcat harvest zone.

important components of bobcat core areas. Mean area per disjunct core of landscape was the most important variable in determining Penrose distance across the NLP. This variable was indicative of landscape structure and evaluated the level of landscape patchiness. A value of zero indicated a high level of patchiness, whereas higher values signified more contiguous habitat patches. Bobcat core areas had a higher degree of patchiness than the rest of the NLP. This may be indicative of the use of multiple habitats by bobcats within their core areas (Preuss 2005). The importance of landscape patchiness in determining the similarity of habitat in the NLP to habitat within bobcat core areas is likely because of natural patchiness in the landscape (e.g., aspen stands interspersed within a lowland conifer forest) rather than fragmentation of the landscape due to human alterations (e.g., road and urban development).

Interpretations of the model we developed for the NLP should be considered cautiously. Model data came from a single, albeit large, study area in the center of the NLP and applied across the NLP. Also, we developed the NLP model for a harvested bobcat population; however, distribution and abundance would likely differ depending on the presence or absence of a harvest. Population dynamics, particularly in terms of density, can be quite different between harvested (Rolley 1985) and unharvested (Nielsen and Woolf 2001) bobcat populations.

The validation of the model provided varied results. Validation of the study area using scent-station surveys indicated that bobcat detections within hexagons occurred within expected frequencies in comparison to available hexagons of each Penrose distance class. The use of bobcat harvest locations to validate the model within the bobcat harvest zone of the NLP indicated that locations of harvested bobcats occurred more than expected in the lowest Penrose distance class, as frequently as expected in the second lowest class, and less than expected in the 2 highest classes. This may be a good model validation; however, it may also indicate that bobcat hunters simply select good bobcat habitat in which to hunt. The potential bias associated with bobcat harvest locations may be due to the probability that bobcat hunters are likely to hunt in areas with high densities of bobcats and avoid hunting in areas with presumed low bobcat density (law of diminishing returns). Because locations of harvested bobcats may be biased, better model validation might be achieved from having multiple study areas or conducting regional surveys (e.g., scent-station surveys, snow-track counts) throughout the NLP. Furthermore, the use of harvest effort would provide an important contribution to this validation, as well as providing insight into estimates of relative abundance. The level of harvest effort necessary to harvest one animal is inversely related to the population size (i.e., if more animals are in a population, less effort should be needed to harvest an individual animal), and accurate estimates of harvest effort provide an indicator of population trends (e.g., relative abundance) over time (Lancia et al. 1996). Appropriate and accurate validation is important because many deficiencies in modeling efforts occur when researchers extrapolate models to inappropriate spatial scales and when data collection occurs over a short time frame (Roloff and Kernohan 1999).

Spatial models such as these are important for landscape planning, particularly in areas experiencing impacts related to urbanization and habitat fragmentation. Bobcats are sensitive to levels of habitat fragmentation (Crooks 2002). Fragmentation of habitat can reduce the abundance and distribution of wildlife populations (Saunders et al. 1991), including species of mammalian predators (Gehring 2000, Gehring and Swihart 2003). A specific concern relating to habitat fragmentation is that mammals such as gray wolves (*Canis lupus*) and bobcats may be exposed to increased human induced mortality because of increased human access (Mladenoff et al. 1995). Saunders et al. (2002) suggested that road development has contributed to habitat fragmentation in the Great Lakes region more than urban expansion, rural home development, or other types of land-use conversion. The NLP is experiencing substantial loss and fragmentation of habitat, and landscape level species planning would benefit from the development of a regional conservation plan. Mammalian carnivores are good candidates for focal species in conservation planning because their patterns of distribution are often indicative of population processes at a regional scale (Carroll et al. 2001, Gittleman et al. 2001, Noss 2001). With the recent discovery of gray wolves in the NLP, it is becoming important to consider the needs of several carnivore species and to institute management efforts at the landscape level (Gehring and Potter 2005). The development of spatial models of distribution and relative abundance for multiple carnivore species may aid in the delineation of critical areas needed to promote carnivore conservation within the NLP.

MANAGEMENT IMPLICATIONS

The habitat model we developed for the NLP identifies areas of suitable bobcat habitat and potential bobcat distribution. Furthermore, this model identifies focal areas for the surveying and monitoring of the NLP bobcat population. This model has the potential to aid wildlife managers in Michigan in quantifying the allocation of bobcat harvest based on predicted distribution of bobcats, and, in combination with data on reproduction, survival, and abundance, may aid in predicting responses to varying levels of harvest. For example, if the majority of harvest pressure is localized in key areas that are important to bobcats, management agencies can redefine harvest regulations to reduce the pressure on those key areas. This may lead to the delineation of harvest zones or the establishment of bobcat harvest quotas based on the spatial patterning of high-quality bobcat habitat. If used and incorporated with other data (e.g., harvest effort, survival) this model will be a helpful tool in directing bobcat management in Michigan's NLP.

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