

PREDICTING SPATIAL DISTRIBUTION AND RELATIVE ABUNDANCE
OF BOBCATS IN THE NORTHERN LOWER PENINSULA OF MICHIGAN

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"God made the wild animals according to their kinds...
And God saw that it was good."
Genesis 1:25

This is dedicated to Stephanie, my amazing wife,
for her endless love, support, and encouragement.

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Most deserving of my thanks is Jesus Christ, my Lord and Savior, for creating me, all those around me, and all the fauna and flora of this beautiful Earth.

ABSTRACT

PREDICTING SPATIAL DISTRIBUTION AND RELATIVE ABUNDANCE OF BOBCATS IN THE NORTHERN LOWER PENINSULA OF MICHIGAN

by Timothy S. Preuss

Bobcats (*Lynx rufus*) are a harvested furbearer species in Michigan. Controversy over the management of bobcats in the northern Lower Peninsula of Michigan (NLP) has stimulated a need for more information on the ecology, distribution, and abundance of Michigan bobcats. I conducted a radio-telemetry study on bobcats in a 4,253-km² study area in the NLP from March 2003 – October 2004. Fifteen bobcats were live trapped, radio collared, and monitored to investigate area requirements and habitat use. Bobcat home ranges and core areas were estimated using minimum convex polygon and adaptive kernel methods to determine an appropriate scale for modeling distribution and relative abundance. I conducted scent-station surveys ($n = 1400$ stations) to assess bobcat presence/absence and to aid in distribution and relative abundance modeling. I used remotely sensed land cover data and the Penrose distance statistic to model the similarity of habitat within core areas of radio-collared bobcats to the rest of the NLP. Bobcat core areas were comprised of proportionately more lowland forest (51%), non-forested wetlands (9%), and streams (3%) than the surrounding NLP.

The NLP was comprised primarily of upland forest (44%) and agriculture/openland (32%). I then modeled relative abundance and distribution based on radio-telemetry and scent-station data. Bobcat distribution was predicted to be patchy throughout the NLP with areas of greatest density in the northeast, central, and southeast regions of the NLP. I validated the abundance model with an independent set of bobcat harvest locations ($n = 196$). The majority (75%) of independent bobcat harvest locations occurred in areas of the NLP predicted to have greatest bobcat density. Given the current controversy over the management of bobcats in the NLP, this model may aid state management agencies in assessing the status of the NLP bobcat population, as well as in identifying areas important to bobcats and areas to monitor and survey for bobcats.

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INTRODUCTION

Since the early 1970's concern for mammalian predator populations, including bobcats (*Lynx rufus*), has increased (Anderson 1987, Woolf and Nielsen 2001). This concern was made apparent for the bobcat in 1975 when it was listed in Appendix II of the Convention on International Trade in Endangered Species (CITES). This listing requires that state agencies provide the U.S. Fish and Wildlife Service with data on the status and viability of bobcat populations. However, despite this listing, information important for making some wildlife management decisions is still lacking. Effective management of wildlife populations requires ecological data pertaining, in part, to abundance, distribution, and habitat use of species, and management of a harvested species requires additional scientific information. Rolley et al. (2001) identified information needs for harvested bobcat populations to include mandatory harvest registration, population indices, population models, user statistics, market-value surveys, and periodic habitat inventories. Bobcats are a harvested furbearer species in Michigan and harvest levels have increased in recent years (Cooley et al. 2003); current census and monitoring methods, however, lack dependability. Earle (2001) emphasized a need for the development of efficient and reliable methods to census furbearer species. The difficulty of adequately monitoring bobcat populations also was a concern of Rolley et al. (2001).

Recently, the increased use of geographical 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. Models developed by Lovallo et al. (2001) have resulted in the first harvest of bobcats in Pennsylvania in 30

years. Nielson and Woolf (2002) developed models that linked habitat and relative abundance to evaluate distribution and abundance of bobcats in Illinois. These models were used to assess bobcat status and contributed to the delisting of bobcats as a threatened species in Illinois (Woolf et al. 2002). Integrating demographic data (e.g., data determined via telemetry methods) and GIS spatial models can provide a tool to focus management efforts. These tools are rare for management of bobcats and other solitary carnivores. Region specific models should be developed to more effectively direct bobcat management (Lovallo et al. 2001).

In Section 1, I investigate home-range attributes and patterns of habitat use for bobcats in the northern Lower Peninsula, Michigan (NLP). My objectives were to estimate home-range and core-area size for female and male bobcats, and assess the use and selection of habitats by bobcats in the NLP. I predicted that average home-range and core-area size would be larger for male than for female bobcats. In the Great Lakes Region, intersexual differences occur in the degree to which bobcats are territorial (Lovallo and Anderson 1996). Female bobcats typically have smaller home ranges and exclude other females from their territory. This behavior likely reduces competition (e.g., energy consumption) with other females during periods when energy needs are critical (e.g., kitten rearing). Male bobcats, however, appear to be less territorial toward other males, yet have large home ranges encompassing several female home ranges in order to increase mating opportunities with females. Additionally, I predicted that bobcats would utilize habitats disproportionately to their occurrence. Habitats that are more suitable (e.g., high prey density, available den sites, fewer competitors) are likely to be preferred. In the Great Lakes Region, bobcats are known to prefer lowland conifer forests due to the

availability of prey species as well as the thermal cover provided (Berg 1979, Fuller et al. 1985, Lovallo and Anderson 1996).

In Section 2, I develop a computer-based model to predict the abundance and distribution of bobcats in the NLP. My objective was to integrate assessments of home-range dynamics and habitat use (Section 1) with digital land-cover data to predict bobcat distribution and relative abundance throughout the NLP. I predicted that bobcat abundance and distribution would be linked primarily to variables associated with lowland forest cover. Lowland forests have been shown to be an important component of bobcat home ranges in Wisconsin (Lovallo and Anderson 1996) and Minnesota (Berg 1979, Fuller et al. 1985), as well as in Michigan (Section 1). A predictive spatial model would provide wildlife managers with information on bobcat distribution and suitable bobcat habitat throughout the NLP. Additionally, wildlife managers could use such a model to identify areas in which to focus management and monitoring efforts in order to promote bobcat conservation.

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SECTION I

HOME-RANGE SIZE AND HABITAT USE BY BOBCATS IN THE NORTHERN LOWER PENINSULA OF MICHIGAN

Abstract

Controversy over the management of bobcats in the northern Lower Peninsula, Michigan (NLP) has stimulated a need for more information on the ecology of Michigan bobcats. I conducted a radio-telemetry study on bobcats in the NLP from March 2003 – October 2004. Fifteen bobcats were live trapped, radio collared, and monitored to examine home-range characteristics and habitat use. Home ranges of male bobcats were >3 times larger than those of females ($Z = -2.74$, $P = 0.006$). Analysis of habitat use indicated that bobcats selected lowland coniferous forest, lowland deciduous forest, and non-forested wetland habitats, while upland forest, urban, and open habitats were avoided. The identification of bobcat area requirements and habitat needs may aid biologists in management efforts.

Introduction

Since 1975 when bobcats (*Lynx rufus*) were added as a “threatened look-alike” species to Appendix II of the Convention on International Trade in Endangered Species (CITES), studies on bobcat ecology and behavior have increased substantially generating a wealth of information on bobcats. However, since bobcats are widely distributed throughout much of North America it is difficult to extrapolate data from region to region. Bobcat home-range size and overlap, as well as habitat use, are particularly variable throughout the bobcat’s distribution. In general, home ranges of bobcats in the northern latitudes are substantially larger than those in southern latitudes, likely due to

lower prey abundance and increased thermal demands in the northern regions (Anderson and Lovallo 2003). In Maine, male bobcat home ranges averaged 112 km² (Litvaitis et al. 1987), however home ranges of male bobcats in Alabama averaged 2.6 km² (Miller and Speake 1979). Additionally, home ranges of male bobcats are typically 2 to 3 times larger than female home ranges (Anderson and Lovallo 2003). In the southern regions, female bobcats usually maintain exclusive home ranges, while male bobcat home ranges overlap minimally (Miller and Speake 1979, Rolley 1985). In these regions, bobcats are able to keep intrasexually exclusive home ranges while maintaining relatively high densities (Miller and Speake 1979). In the northern regions, female bobcats are also likely to maintain exclusive home ranges, however home ranges of males tend to overlap extensively with other males and encompass the home ranges of 2 or 3 females (Lovallo and Anderson 1996a). In these regions bobcats typically occur at lower densities compared to bobcats in southern regions, likely due to prey resources that are not usually as abundant in harsher climates (Bailey 1981). However, the understanding of bobcat home-range dynamics may be confounded depending on the presence or absence of a harvest (e.g., hunting and/or trapping). Rolley (1985) observed no intrasexual overlap in home ranges of male and female bobcats in a harvested population in Oklahoma. However, in the absence of a harvest, male and female bobcats in southern Illinois exhibited a high degree of intrasexual overlap (Nielson and Woolf 2001). It is important to understand home-range dynamics in order to effectively manage bobcat populations, particularly harvested populations.

Bobcat habitat use also varies greatly throughout its geographic distribution, and appears to be focused in habitats that provide abundant prey and allow for hunting by

either ambush or stalking (Anderson and Lovallo 2003). In Minnesota and Wisconsin, lowland coniferous forests were preferred habitat for bobcats (Fuller et al. 1985, Lovallo and Anderson 1996a). Bobcat habitat use in Maine included hardwood and coniferous forests depending on the density of the understory layer (Litvaitis et al. 1986).

Additionally, bobcats in the southeast tend to prefer bottomland forests, whereas bobcats in the west are found most often in dry, rocky habitats (Anderson and Lovallo 2003).

Identifying habitats that provide the necessary resources for bobcats is important in order to identify areas that should be conserved, or preserved, particularly when these types of habitat are scarce (Fuller et al. 1985).

Few studies exist on bobcat home-range size and habitat use in the Great Lakes region (Erickson 1955, Berg 1979, Fuller et al. 1985, Lovallo and Anderson 1996a). Erickson (1955) used winter snow tracking methods to investigate home-range size and habitat use by bobcats in Michigan, however current quantitative data on bobcat home-range characteristics and habitat use is lacking for Michigan, particularly in the northern Lower Peninsula (NLP). The extensive geographic variability in bobcat ecology makes the extrapolation of population characteristics between regions problematic (Anderson and Lovallo 2003). Furthermore, local dynamics (e.g., hunting and trapping pressure, levels of human encroachment, levels of habitat fragmentation, and management strategies) also make the extrapolation of population characteristics between states within a region troublesome. Data on bobcat habitat use in Michigan is collected from winter track surveys in the Upper Peninsula (UP; Earle 2001). Habitat use information from these data is difficult to extrapolate to the NLP because habitat composition varies somewhat between the UP and NLP, and road density, area of land in agricultural

production, and level of urbanization are much greater in the NLP. Additionally, bobcats are a harvested furbearer species in Michigan. The UP experiences greater harvest pressure than the NLP resulting in greater numbers of bobcats being harvested in the UP as compared to the NLP (Cooley et al. 2003, Frawley et al. 2004).

I conducted a radio-telemetry study from March 2003 – October 2004 to assess area and habitat requirements of bobcats in the NLP. The objectives were to: 1) estimate home-range and core-area size for female and male bobcats; and 2) assess the use and selection of habitats by bobcats.

Methods

Study Area

The 4,253-km² study area included portions of Clare, Crawford, Gladwin, Kalkaska, Missaukee, Ogemaw, Osceola, Oscoda, and Roscommon counties, Michigan (Figure 1). I delineated the study area by extending a 17-km buffer (equivalent to the length of the longest adult bobcat home range from this study) around the outermost home ranges of radio-collared bobcats. I obtained 2001 IFMAP/GAP Lower Peninsula Land Cover data with 30-m resolution developed by the Forest, Mineral, and Fire Management Division of the Michigan Department of Natural Resources (MDNR). I reclassified the original 32 cover classes into 8 major cover classes using ArcGIS 8.3 (Environmental Systems Research Institute, Redlands, California, USA). I identified cover classes in the study area as: agriculture/openland (28%), lowland coniferous forest (6%), lowland deciduous forest (5%), non-forested wetland (4%), open water (4%), upland coniferous forest (22%), upland deciduous forest (29%), and urban/transportation

(2%). Forested areas were dominated by oak (*Quercus* spp.), aspen (*Populus* spp.), and mixed pine (*Pinus* spp.) on upland sites and northern white cedar (*Thuja occidentalis*) and balsam fir (*Abies balsamea*) on lowland sites (Leatherberry 1994).

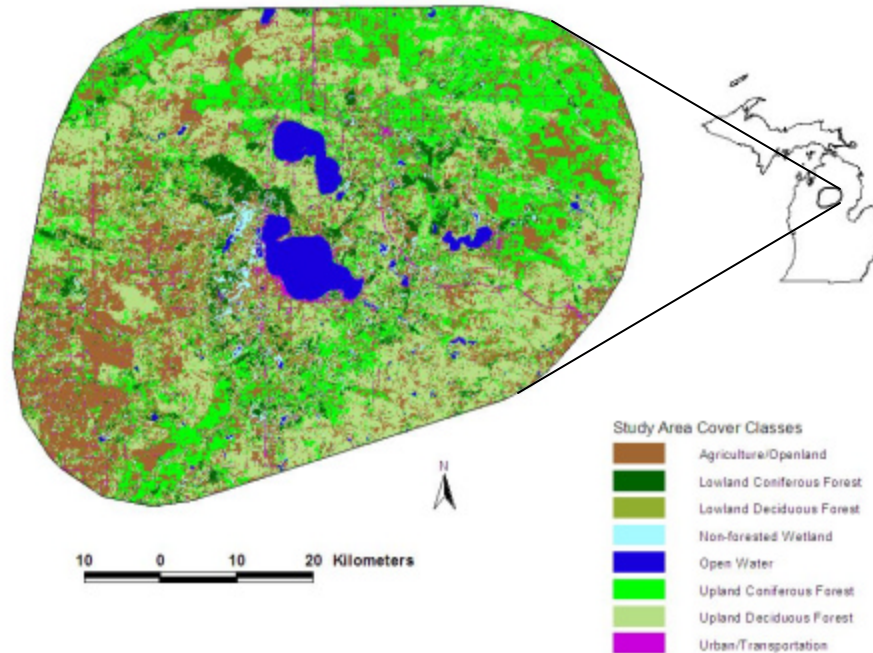


Figure 1. A radio-telemetry study of bobcat home-range size and habitat use was conducted between March 2003 and October 2004 in a 4,253-km² study area in the northern Lower Peninsula, Michigan. The study area included portions of Clare, Crawford, Gladwin, Kalkaska, Missaukee, Ogemaw, Osceola, Oscoda, and Roscommon counties. The enlarged 30-m resolution study area map displays 7 habitat cover classes used for examining bobcat habitat selection (the open water cover class was excluded from habitat selection analysis).

Trapping

Bobcats were trapped during 2 trapping periods from March– July 2003 and May – July 2004. Model 209.5 Tomahawk[®] cage traps (Tomahawk Live Trap, Tomahawk, Wisconsin, USA) and #3 Victor Soft-Catch[®] padded foot-hold traps (Oneida Victor, Inc., Euclid, Ohio, USA) were used in 2003, and foot-hold traps were used exclusively in 2004. Cage traps were made of galvanized wire mesh and measured 38 x 50 x 107 cm. Each foot-hold trap was modified (Earle et al. 2003), attached to a 183-cm chain with

drag, and double swivels were placed between the trap and chain, half way between the trap and drag, and between the chain and drag. Traps were selectively placed in areas known or suspected to support bobcats. Cage traps were covered with balsam fir boughs and baited with combinations of bobcat urine, commercial trapping lures, meat baits, and visual attractants. Foot-hold traps were placed in blind sets, cubby sets, dirt-hole sets, and urine-post sets. Cubby sets and dirt-hole sets were baited with combinations of bobcat urine, commercial trapping lures, meat baits, and visual attractants. Traps were checked daily and the status of each trap was recorded. Trap-nights of operation were calculated for each trapping period.

Trapped bobcats were restrained with a 51-cm diameter wire-mesh net connected to a 183-cm pole and a pole syringe was used to deliver an intramuscular injection of 10 mg/kg ketamine hydrochloride (HCl) plus 1.5 mg/kg xylazine HCl (Kreeger 1999). Age class (juvenile: <1.5 yr; adult: \geq 1.5 yr), sex, reproductive condition, and weight were determined for each bobcat. Age class was determined based on size, weight, and examination of teeth (Crowe 1975). Measurements of body length, tail length, ear length, hind foot length, and neck circumference were taken. Bobcats were given uniquely numbered ear tags, fitted with a 63-g radio transmitter with mortality sensor (Holohil Systems Ltd., Carp, Ontario, Canada), and examined for injuries. Juvenile bobcats were only radio collared if their neck circumference was close to that of an adult, thereby avoiding placement of a collar that was too loose, but could also accommodate growth to adult size. Tissue samples were taken from an ear punch for future genetic analysis. After handling, bobcats were given an intramuscular injection of 0.125 mg/kg yohimbine HCl as a xylazine antagonist (M.R. Johnson, DVM, Global Wildlife Resources, Inc.,

personal communication). Bobcats were placed in a cage trap and allowed to recover in a secluded, shaded area. Bobcats were released when they appeared fully alert. Procedures used to trap and handle bobcats were conducted under permit from the MDNR (SC 1172) and approved by the Institutional Animal Care and Use Committee of Central Michigan University (IACUC# 03-03).

Radio Telemetry

Radio-collared bobcats were located by triangulation using standard telemetry techniques (White and Garrott 1990). Aerial telemetry was used to locate missing animals. Bobcats were located 0-3 times/24-hr period from May 2003 – October 2004 using a vehicle-mounted, 4-element Yagi directional antenna and an electronic compass (Lovallo et al. 1994). Telemetry bearing error (2.5°) was determined by taking bearings to reference transmitters ($n = 30$) placed at known locations. All bearings for bobcat location estimates were obtained within 20 min to reduce error related to animal movement. I attempted to obtain locations at randomly determined times to provide a representative sample of bobcat habitat use. Locations for individual bobcats were taken >4 hr apart to achieve independence of successive locations. The level of autocorrelation between successive locations would likely be negligible at this interval (Swihart and Slade 1985a, 1985b). Locations were estimated using ≥ 2 bearings. Locations and associated error polygons were estimated with ≥ 3 bearings using the maximum likelihood estimator (Lenth 1981) in the software program LOCATE II (Nams 1990). For locations obtained with only 2 bearings, I attempted to maintain an angle of intersection near 90° to minimize error (White and Garrott 1990). For data analyses, I

classified bobcat locations based on sex and biological season. Biological seasons (summer = 15 May to 14 October, winter = 15 October to 14 May) were defined according to the reproductive biology of bobcats (Lovallo and Anderson 1996a). In summer, female bobcats are typically rearing young which suggests that a female's home-range size and use of habitat may be influenced by the presence of kittens. In winter when the majority of bobcat breeding occurs, females are generally protecting their home ranges from other females, while males are seeking mating opportunities. In addition, prey resources may be scarce during winter forcing bobcats to expand their home range in search of food. Only data from adult bobcats were used in analyses. Juvenile bobcats were excluded from analyses because their use of the landscape was not expected to represent that of a resident individual.

Home Range

I estimated the size of bobcat summer home ranges and core areas using the minimum convex polygon (MCP; Mohr 1947) and adaptive kernel (ADK; Worton 1989) methods. I estimated home ranges and core areas using the Home Range Extension for ArcView GIS (Rodgers and Carr 1998). Specifically, I estimated 50% core areas and 100% home ranges using the MCP method for comparison with previous studies. I estimated 50% ADK core areas and 95% ADK home ranges because the adaptive kernel method of home-range estimation is robust to violations of independence (Swihart and Slade 1985a, 1985b, 1997). The MCP estimator of home-range size is perhaps the most common method of depicting range size and shape (Harris et al. 1990). Minimum convex polygon estimates are obtained by connecting the outermost locations of a set of

locations for an individual animal. The only constraint with this method is that the polygon formed remains convex. However, the MCP method has substantial disadvantages despite the simplicity and common usage of the method (White and Garrott 1990). The MCP method does not account for the intensity at which an animal uses different parts of its range (Kenward 2001). Additionally, since animals occasionally make excursions (e.g., to breed) outside of their normal home range, minimum convex polygons often contain large areas which animals never use (Kenward 2001). The ADK estimator, although complex to compute, provides an improved method of home-range estimation. The ADK method is a function based on the density of locations for an individual animal and provides a more representative estimation of how intensively an animal uses different parts of its home range (Worton 1989). Also, since the ADK method allows the contribution of each point location to the overall home-range estimate to be weighted individually based on the density of nearby points, a more accurate depiction of the distribution of locations (i.e., home-range estimate) can be achieved. A disadvantage of the ADK estimator, however, is that it tends to slightly overestimate an animal's peripheral use of its home range (Seaman 1999, Powell 2000). To assess whether home-range estimates achieved stability, I plotted home-range area against number of locations for each adult bobcat (Kenward 2001). Adult bobcats that did not have enough locations to achieve home-range stability were excluded from analysis. I used the Mann-Whitney test ($\alpha = 0.05$) to assess differences in home-range and core-area size of female and male bobcats (Zar 1999).

Habitat Use

I examined bobcat summer use of 7 major habitat aggregations: agriculture/openland, lowland coniferous forest, lowland deciduous forest, non-forested wetland, upland coniferous forest, upland deciduous forest, and urban/transportation (Figure 1). I used theme overlay routines in ArcView 3.2 (Environmental Systems Research Institute, Redlands, California, USA) to estimate the proportion of used habitat within 95% ADK home ranges and 50% ADK core areas compared to available habitat in the study area. I also calculated the proportion of telemetry point locations for each bobcat occurring within each habitat type for comparison with available habitat within 95% ADK home ranges and 50% ADK core areas. Point locations with an error ellipse encompassing more than 1 habitat type were excluded from analysis to avoid assignment of locations to unused habitats. I also refrained from using the proportion of each habitat type occurring within an error ellipse because in some instances use could be heavily weighted toward an unused habitat. For example, a point location with a large error ellipse may be comprised of agriculture/openland and lowland coniferous forest. If the lowland coniferous forest occurred as a thin riparian corridor in the middle of a large agricultural field, the agriculture/openland habitat type would comprise the majority of the error ellipse. But, if the bobcat was using the riparian corridor consisting of lowland coniferous forest and not the agricultural field, then the agriculture/openland habitat type would be falsely weighted in terms of habitat use when identifying used habitat based on the proportion of each habitat type comprising the error ellipse.

I used compositional analysis to investigate landscape-, home range-, and core area-level patterns of habitat selection by bobcats (Aebischer et al. 1993). An advantage

of compositional analysis is that it allows for the assessment of habitat use at different levels of selection. Johnson (1980) identified 4 levels, or orders, of habitat selection: 1) first-order selection is defined as the selection of a geographical range of a species; 2) second-order selection is defined as the selection, or placement, of an individual's home range within a larger landscape; 3) third-order selection pertains to the extent at which an individual uses the various habitat components of its home range; and 4) fourth-order selection pertains to the behavior associated with a particular habitat component (e.g., if third-order selection determines a particular feeding site, the procurement of food items from that feeding site can be termed fourth-order selection). I examined second-order selection by comparing the habitat composition of home ranges and core areas to available habitat in the surrounding landscape (i.e., the study area). I examined third-order selection by comparing the proportion of radio-telemetry locations occurring within each habitat type to available habitat in home ranges and core areas for individual bobcats. I used code provided by Ott and Hovey (1997) to perform compositional analysis in SAS (SAS Institute Inc., Cary, North Carolina, USA). Compositional analysis has several advantages over other types of habitat selection analyses. Compositional analysis treats the animal, rather than the location, as the experimental unit (i.e., independence of radio locations is not required), thereby circumventing problems related to pseudoreplication (Hurlbert 1984, Aebischer et al. 1993). Additionally, compositional analysis overcomes problems pertaining to sampling level (Kenward 1992), non-independence of proportions (i.e., avoidance of 1 habitat type inevitably leads to selection of another), differential use of habitat by groups of individuals (e.g., females may use habitat differently than males), and arbitrary definition of habitat availability (Aebischer

et al. 1993). As recommended by Aebischer et al. (1993), I substituted 0.01% for habitat types that were available but not used by bobcats (natural zeros), whereas structural zeros (unavailable habitat types) were eliminated by excluding these habitat types from further analysis. For a given habitat type, I summed across available habitats the number of positive t-values (i.e., the mean difference in the log-ratio of used and available habitats divided by the standard error). I then ranked habitat types by the number of positive values, where a larger rank value indicated a more preferred habitat.

Results

Trapping

I captured and radio-collared a total of 15 bobcats (Table 1). Thirteen bobcats

Table 1. Capture data for bobcats trapped during a radio-telemetry study of bobcat home-range characteristics and habitat use in the northern Lower Peninsula, Michigan from March 2003 – July 2004.

Bobcat ID	Sex	Weight (kg)	Age	Date Captured	Trap type	Status
F01	F	5.9	Adult	5/20/03	Foot-hold	Active
F02	F	6.4	Adult	6/06/03	Foot-hold	Active
F03	F	6.4	Adult	6/06/03	Foot-hold	Missing
F04	F	7.3	Adult	6/12/03	Foot-hold	Hit by car
F05	F	7.0	Adult	5/08/04	Foot-hold	Active
M01	M	14.1	Adult	5/15/03	Cage	Missing
M02	M	10.9	Adult	5/26/03	Foot-hold	Tx ^a malfunction
M03	M	13.2	Adult	6/16/03	Foot-hold	Active
M04	M	11.7	Adult	5/11/04	Foot-hold	Missing
M05	M	11.7	Adult	5/15/04	Foot-hold	Active
M06	M	8.3	Juvenile	5/20/04	Foot-hold	Tx malfunction
M07	M	6.5	Juvenile	5/22/04	Foot-hold	Active
M08	M	10.6	Adult	5/29/04	Foot-hold	Active
M09	M	10.1	Adult	6/23/04	Foot-hold	Active
M10	M	12.6	Adult	7/07/04	Foot-hold	Active

^a Transmitter

were captured in foot-hold traps during 2,383 trap nights, 1 bobcat was caught in a cage trap during 1,248 trap nights, and 1 bobcat was acquired as an incidental capture by U.S. Department of Agriculture personnel. In 2003, trapping success was 1 bobcat per 270 foot-hold trap nights, whereas cage traps recorded 1 bobcat capture in 1,248 trap nights. In 2004, trapping success was 1 bobcat per 113 foot-hold trap nights. Thirteen (5 females and 8 males) of the 15 bobcats captured and radio collared were classified as adults. Two other males were classified as juveniles.

Radio Telemetry

I obtained 915 locations on 13 adult bobcats from May 2003 through October 2004. Triangulations accounted for 90% of all locations; the remaining 10% of locations were obtained from 2 bearings (8%) and via aerial telemetry (2%). Triangulated locations had an average bearing error of $1.0^\circ \pm 2.6$ ($\bar{x} \pm SD$) and location error polygons of $0.03 \text{ km}^2 \pm 0.18$ ($\bar{x} \pm SD$). The average number of locations per bobcat was 70 (range: 12-145), and bobcats were monitored an average of 230 (range: 14-504) days. Approximately 71% of locations were obtained during diurnal hours (0900 to 1700) with the remaining 29% of locations obtained during crepuscular and nocturnal hours (1700 to 0900). The majority of locations (87%) were obtained during the summer season while 13% of locations were obtained in winter. Eleven of the 13 adult bobcats were monitored through at least 1 summer season; only five adult bobcats (4 females and 1 male) were radio-monitored through 2 summers (1 winter). Consequently, due to sample size concerns, subsequent analyses of home range and habitat use only examine the summer season. Furthermore, males and females were pooled for habitat use analysis.

At the end of the study, 9 bobcats (3 females and 6 males) were active, 1 female had been hit by a car, and the status of 5 individuals was unknown (missing or transmitter malfunction).

Home Range

Investigation of plots of home-range area against number of locations indicated that 11 bobcats (5 females and 6 males) were suitable for use in estimation of home-range and core-area size (Table 2). The number of locations needed to reach home-range stability was 28 ± 7.3 ($\bar{x} \pm SD$). Male bobcat home ranges were >3 times larger than home ranges of females (MCP: $Z = -2.74$, $P = 0.006$; ADK: $Z = -2.56$, $P = 0.011$).

Table 2. Summer (15 May – 14 October) home-range (HR) and core-area (CA) sizes of radio-collared bobcats in the northern Lower Peninsula, Michigan. Home ranges were calculated using the 100% minimum convex polygon (MCP) and 95% adaptive kernel (ADK) methods. Core areas were calculated using the 50% MCP and 50% ADK methods.

Bobcat ID	Sex	Age	Number of days monitored	Number of locations	HR size (km ²)		CA size (km ²)	
					MCP	ADK	MCP	ADK
F01	F	Adult	291	124	11.0	12.7	2.0	1.3
F02	F	Adult	126	110	7.0	8.3	1.8	0.9
F03	F	Adult	122	46	6.2	5.1	0.2	0.6
F04	F	Adult	123	85	19.1	26.9	7.2	3.0
F05	F	Adult	152	89	16.4	19.1	4.0	4.6
M01	M	Adult	58	35	26.2	33.1	3.7	4.2
M02	M	Adult	83	44	77.4	113.8	22.6	12.1
M03	M	Adult	271	117	29.9	26.8	2.9	3.6
M04 ^a	M	Adult	11	10	3.9	13.4	0.2	2.9
M05	M	Adult	151	32	26.7	44.6	3.9	6.1
M06 ^b	M	Juvenile	70	9	9.3	20.9	0.8	4.1
M07 ^b	M	Juvenile	144	97	11.0	9.7	1.8	0.8
M08	M	Adult	132	40	22.8	29.8	2.5	3.7
M09	M	Adult	112	39	36.6	62.9	5.1	10.7
M10 ^a	M	Adult	84	26	11.6	12.3	0.3	1.1

^a Adult bobcat excluded from home-range and core-area analysis.

^b Juvenile bobcat excluded from home-range and core-area analysis.

Minimum convex polygon estimates of mean home-range size for female and male bobcats were $11.9 \text{ km}^2 \pm 5.7 (\bar{x} \pm \text{SD})$ and $36.6 \text{ km}^2 \pm 20.5 (\bar{x} \pm \text{SD})$, respectively. Mean home-range size using 95% ADK contours were $14.4 \text{ km}^2 \pm 8.7 (\bar{x} \pm \text{SD})$ and $51.8 \text{ km}^2 \pm 33.1 (\bar{x} \pm \text{SD})$ for females and males, respectively. Male bobcat core areas were also >3 times larger than female core areas, however that difference was only significant in 50% ADK contours ($Z = -2.19, P = 0.028$), but not for 50% MCP core areas ($Z = -1.10, P = 0.273$). Female and male core-area estimates averaged $3.0 \text{ km}^2 \pm 2.7 (\bar{x} \pm \text{SD})$ and $6.8 \text{ km}^2 \pm 7.8 (\bar{x} \pm \text{SD})$, respectively for 50% MCP estimates, and $2.1 \text{ km}^2 \pm 1.7 (\bar{x} \pm \text{SD})$ and $6.7 \text{ km}^2 \pm 3.8 (\bar{x} \pm \text{SD})$, respectively for 50% ADK estimates.

Habitat Use

I used 695 locations from 11 adult bobcats (5 females and 6 males) to examine summer habitat use. Compositional analysis indicated that habitat composition was nonrandom in 95% home-range contours ($\Lambda = 0.11, F_{6,5} = 7.03, P = 0.025$) and 50% core area contours ($\Lambda = 0.05, F_{6,5} = 14.64, P = 0.005$) relative to availability within the study area. Bobcat home ranges (Table 3) and core areas (Table 4) were comprised of proportionately more lowland forest and non-forested wetland than upland forest, agriculture/openland, and urban habitat. Bobcats also used available habitat within 95% home-range contours in a nonrandom manner ($\Lambda = 0.13, F_{6,5} = 5.48, P = 0.041$). Bobcats used proportionately more lowland forest than other available habitat types within home ranges (Table 5). Bobcat use of available habitat within 50% core-area contours appeared to be random ($\Lambda = 0.30, F_{6,5} = 1.96, P = 0.239$; Table 6).

Table 3. Simplified ranking matrix for radio-collared bobcats comparing habitat composition within 95% adaptive kernel home ranges relative to habitat availability within a 4,253-km² study area in the northern Lower Peninsula, Michigan. Cells in the matrix consist of mean differences in the log-ratios (rows divided by columns) of used and available habitats for all bobcats divided by the standard error. The sign of t-values is indicated with positive or negative signs, where a triple sign signifies nonrandom habitat use at $\alpha = 0.05$. Rank is equal to the sum of positive values in each row. A larger rank value denotes a more preferred habitat type.

Habitat	Habitat							Rank
	Urban	Ag/open	Lowland conifer	Lowland deciduous	Upland conifer	Upland deciduous	Non-forest wetland	
Urban		+	---	---	+	+	---	3
Ag/open	-		---	---	+++	+	---	2
Lowland conifer	+++	+++		+++	+++	+++	+++	6
Lowland deciduous	+++	+++	---		+++	+++	-	4
Upland conifer	---	-	---	---		---	---	0
Upland deciduous	-	-	---	---	+++		---	1
Non-forest wetland	+++	+++	---	+	+++	+++		5

Table 4. Simplified ranking matrix for radio-collared bobcats comparing habitat composition within 50% adaptive kernel core areas relative to habitat availability within a 4,253-km² study area in the northern Lower Peninsula, Michigan. Cells in the matrix consist of mean differences in the log-ratios (rows divided by columns) of used and available habitats for all bobcats divided by the standard error. The sign of t-values is indicated with positive or negative signs, where a triple sign signifies nonrandom habitat use at $\alpha = 0.05$. Rank is equal to the sum of positive values in each row. A larger rank value denotes a more preferred habitat type.

Habitat	Habitat							Rank
	Urban	Ag/open	Lowland conifer	Lowland deciduous	Upland conifer	Upland deciduous	Non-forest wetland	
Urban		-	---	---	-	-	---	0
Ag/open	+		---	---	+	+	---	3
Lowland conifer	+++	+++		+++	+++	+++	+++	6
Lowland deciduous	+++	+++	---		+++	+++	+	5
Upland conifer	+	-	---	---		-	---	1
Upland deciduous	+	-	---	---	+		---	2
Non-forest wetland	+++	+++	---	-	+++	+++		4

Table 5. Simplified ranking matrix for radio-collared bobcats comparing the distribution of radio locations among habitat types within 95% adaptive kernel home ranges in the northern Lower Peninsula, Michigan. Cells in the matrix consist of mean differences in the log-ratios (rows divided by columns) of used and available habitats for all bobcats divided by the standard error. The sign of t-values is indicated with positive or negative signs, where a triple sign signifies nonrandom habitat use at $\alpha = 0.05$. Rank is equal to the sum of positive values in each row. A larger rank value denotes a more preferred habitat type.

Habitat	Habitat							Rank
	Urban	Ag/open	Lowland conifer	Lowland deciduous	Upland conifer	Upland deciduous	Non-forest wetland	
Urban		---	---	---	---	---	---	0
Ag/open	+++		---	-	-	-	-	1
Lowland conifer	+++	+++		+	+	+++	+	6
Lowland deciduous	+++	+	-		+	+++	+	5
Upland conifer	+++	+	-	-		+	-	3
Upland deciduous	+++	+	---	---	-		---	2
Non-forest wetland	+++	+	-	-	+	+++		4

Table 6. Simplified ranking matrix for radio-collared bobcats comparing the distribution of radio locations among habitat types within 50% adaptive kernel core areas in the northern Lower Peninsula, Michigan. Cells in the matrix consist of mean differences in the log-ratios (rows divided by columns) of used and available habitats for all bobcats divided by the standard error. The sign of t-values is indicated with positive or negative signs, where a triple sign signifies nonrandom habitat use at $\alpha = 0.05$. Rank is equal to the sum of positive values in each row. A larger rank value denotes a more preferred habitat type.

Habitat	Habitat							Rank
	Urban	Ag/open	Lowland conifer	Lowland deciduous	Upland conifer	Upland deciduous	Non-forest wetland	
Urban		-	-	-	+	-	-	1
Ag/open	+		-	-	+	-	-	2
Lowland conifer	+	+		+	+++	+	+	6
Lowland deciduous	+	+	-		+	-	+	4
Upland conifer	-	-	---	-		-	-	0
Upland deciduous	+	+	-	+	+		+	5
Non-forest wetland	+	+	-	-	+	-		3

Discussion

Estimates of home-range size in this study differed depending on the type of estimator used. Home-ranges estimated using the 95% ADK method were larger than 100% MCP estimates. This is partially due to the tendency of the ADK estimator to overestimate peripheral home-range use (Seaman 1999, Powell 2000). However, home-range estimates also depend on the shape of the home range (Seaman 1999). In this study, home ranges were typically elongated and linear rather than circular. This may be partially due to the level of habitat fragmentation resulting in linear habitat elements in the landscape. Circular, compact home ranges would likely be estimated more consistently between estimators. This can be evidenced from the core-area estimates from this study where the shapes of both ADK and MCP core areas tended to be circular, and both methods yielded similar estimates.

Average home-range sizes of female and male bobcats in the NLP were smaller than other home-range estimates from the Great Lakes region (Fuller et al. 1985, Lovallo and Anderson 1996a). Annual MCP home ranges of female bobcats averaged 49 km² (range: 14-85 km²) and 32 km² (range: 6-67 km²) for 2 separate study areas in Minnesota (Fuller et al. 1985). Home ranges for male bobcats at those same study areas averaged 46 km² (range: 35-59 km²) and 61 km² (range: 14-156 km²), respectively (Fuller et al. 1985). In Wisconsin, summer MCP home ranges were 20.8 km² ± 2.9 (\bar{x} ± SD) and 45.5 km² ± 7.2 (\bar{x} ± SD), respectively for female and male bobcats (Lovallo and Anderson 1996a). Although, average home-range estimates from Minnesota and Wisconsin were slightly larger than those observed in the NLP, those estimates fell within the range observed in the NLP. Comparisons of bobcat core-area size are difficult to make because core-area

estimates were not reported for other bobcat studies in the Great Lakes region. However, core-area estimates from this study were similar to those reported for bobcats in southern Illinois where female and male bobcat core-area estimates averaged $2.7 \text{ km}^2 \pm 0.5$ ($\bar{x} \pm \text{SE}$) and $7.0 \text{ km}^2 \pm 1.5$ ($\bar{x} \pm \text{SE}$), respectively for 50% MCP estimates, and $2.1 \text{ km}^2 \pm 0.3$ ($\bar{x} \pm \text{SE}$) and $4.9 \text{ km}^2 \pm 0.8$ ($\bar{x} \pm \text{SE}$), respectively for 50% fixed kernel estimates (Nielsen and Woolf 2001).

Fuller et al. (1985) and Lovallo and Anderson (1996a) observed that home ranges of male bobcats in Minnesota and Wisconsin were 2 to 3 times larger than those of females. Similarly, male bobcat home ranges were greater than 3 times larger than female home ranges in the NLP. This difference in male and female bobcat home-range size also appeared to be consistent with intersexual comparisons of bobcat home-range size from Idaho (Bailey 1974), Illinois (Nielsen and Woolf 2001), Maine (Litvaitis et al. 1986), and Oregon (Witmer and DeCalesta 1986), as well as the general conclusion made by Anderson and Lovallo (2003).

Habitats associated with lowland cover types (i.e., lowland coniferous forest, lowland deciduous forest, and non-forested wetland) appear to be relatively important components of a bobcat's home range in the NLP study area, whereas upland, open, and urban habitats appear to be avoided or used less than expected. This corresponds with observations from habitat selection studies in Minnesota (Fuller et al. 1985) and Wisconsin (Lovallo and Anderson 1996a). Fuller et al. (1985) found that bobcats in Minnesota preferred balsam fir, black spruce (*Picea mariana*), and white cedar habitats. In Wisconsin, Lovallo and Anderson (1996a) found that bobcats selected lowland coniferous forests, but avoided upland forests and unforested areas. Female bobcats in

Wisconsin also selected lowland deciduous forests (Lovallo and Anderson 1996a). In the Great Lakes region, lowland habitats, particularly lowland coniferous forests, likely satisfy the food and cover requirements of bobcats. Snowshoe hare (*Lepus americanus*) and white-tailed deer (*Odocoileus virginianus*) are important prey species for bobcats in the northern latitudes (Anderson and Lovallo 2003), and lowland conifer forests are high-quality hare and deer habitat, particularly in the winter (Verme 1965). Additionally, lowland conifer forests provide good thermal cover during the winter season keeping temperatures more moderate and reducing snow depths, which is presumably favorable to bobcats (Rollings 1945, McCord 1974). The thermal cover provided by lowland conifer forests likely reduces the energetic demands of thermoregulation, while reduced snow depths would ease the energetic demands of locomotion. Lowland conifer forests are also important for bobcats in summer. Prey resources are abundant in lowland conifer forests in summer (Lovallo and Anderson 1996a), and the dense understory lends itself well to the hunting method (i.e., ambush/stalking) of bobcats. During this study, the few times which bobcats used upland habitats occurred during spring when many lowland areas flooded from melting snow.

The relatively small sample size, duration of this study, and incidences of collar failure precluded the ability to assess bobcat spatial organization. Numerous bobcat studies have found variation in the degree of intrasexual and intersexual overlap of home ranges. This variation may result from regional differences in climate, habitat, food resources, and population density (Anderson and Lovallo 2003). Generally, in areas with warm climates where prey and cover are abundant and evenly distributed, female bobcat home ranges are small and exclusive, while the home ranges of males are only slightly

larger and exhibit minor overlap (Bailey 1981). Furthermore, areas with more extreme climates where prey and cover are seasonally limiting and unevenly distributed, female home ranges are less exclusive of other females, while the home ranges of males are larger and overlap extensively with those of other males (Anderson and Lovallo 2003). This latter assessment is likely how bobcats are organized spatially in the NLP, but it is unclear to what extent the existing harvest has on bobcat spatial organization.

The identification of habitats that provide for the resource needs of bobcats may aid managers in conserving important habitats. Equally important is the identification of habitats avoided by bobcats. Lovallo and Anderson (1996b) found that bobcats in Wisconsin exhibited an avoidance of paved roads. Bobcats have also been shown to avoid areas of human activity (Tigas et al. 2002). Results on habitat use from the NLP appear to support an avoidance of urban areas by bobcats. Increased human influence due to road development, rural home development, and other forms of habitat fragmentation, in addition to increasing demand for harvest, are likely to intensify pressures on bobcat populations in the NLP. Consequently, it is vital that accurate and efficient methods to monitor bobcat populations be developed and implemented.

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SECTION II

A PREDICTIVE MODEL OF BOBCAT SPATIAL DISTRIBUTION AND RELATIVE ABUNDANCE IN THE NORTHERN LOWER PENINSULA OF MICHIGAN

Abstract

Controversy over the management of bobcats in the northern Lower Peninsula, Michigan (NLP) has stimulated a need for information on the distribution and abundance of Michigan bobcats. From March 2003 – October 2004, I conducted a radio-telemetry and scent-station survey study of bobcats in the NLP. I developed spatial models to predict bobcat distribution and relative abundance and identify areas of suitable habitat in the NLP based on: 1) assessments of bobcat area requirements and habitat use; 2) abundance information from radio-collared bobcats and scent-station surveys; 3) habitat and landscape variables derived from remotely-sensed land-cover data; and 4) a multivariate distance statistic. Habitat throughout the NLP was evaluated relative to habitat characteristics of 11 bobcat core areas using the Penrose distance statistic. Bobcat core areas were comprised of proportionately more lowland forest (51%), non-forested wetlands (9%), and streams (3%) than the surrounding NLP. The NLP was comprised primarily of upland forest (44%) and agriculture/openland (32%). Bobcat distribution was predicted to be relatively patchy throughout the NLP with areas of greatest density in the northeast, central, and southeast regions of the NLP. The majority (75%) of independent bobcat harvest locations ($n = 196$) used to validate the model occurred in areas of the NLP predicted to have greatest bobcat density. This model may be useful in aiding Michigan wildlife management agencies with assessing the status of the NLP

bobcat population by identifying areas important to bobcats and supporting the development of regional strategies for carnivore conservation.

Introduction

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. There is currently a need for the development of efficient and reliable methods to adequately survey and monitor populations of furbearer species, including bobcats (Earle 2001, Rolley et al. 2001). Effective management of wildlife populations requires ecological data pertaining, in part, to abundance, distribution, and habitat use of species, and management of a harvested species requires additional scientific information. Rolley et al. (2001) identified information needs for harvested bobcat populations to include mandatory harvest registration, population indices, population models, user statistics, market-value surveys, and periodic habitat inventories.

Bobcats are a harvested furbearer species in Michigan. In recent years, harvest levels have increased (Cooley et al. 2003); current census and monitoring methods, however, have been unable to accurately assess the status of Michigan's bobcat population. Bobcats can be hunted and trapped during a 128-day season in the Upper Peninsula (Figure 2). In the northern Lower Peninsula (NLP), historically bobcats could only be hunted during a 60-day season in the northern NLP and a 30-day season in the southern NLP (Figure 2). However, due to increasing pressure from furbearer user

groups, an 11-day bobcat trapping season was initiated for the 2004 – 2005 season in the NLP on private land only. Current 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 NLP.

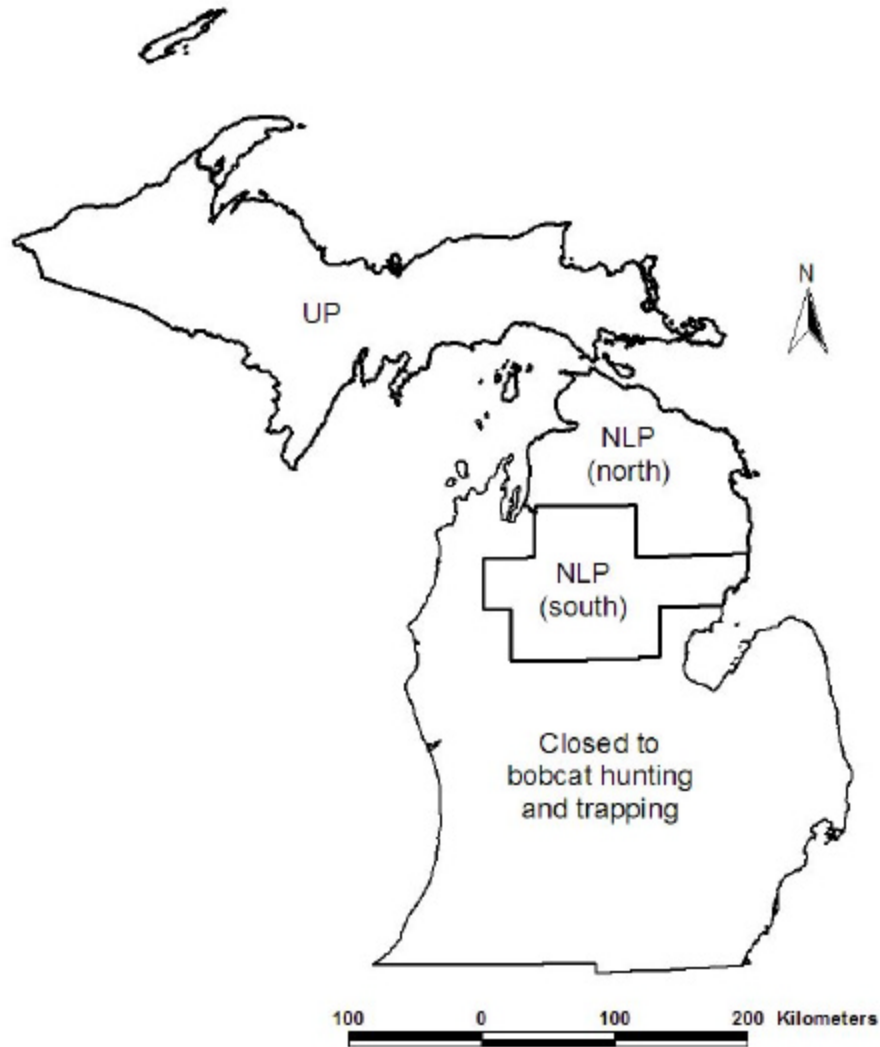


Figure 2. Bobcats can be hunted and trapped in Michigan during a 128-day season in the Upper Peninsula (UP); in the northern Lower Peninsula (NLP), bobcats can be hunted during a 60-day season in the northern NLP and a 30-day season in the southern NLP. An 11-day bobcat trapping season was initiated for the 2004 – 2005 season throughout the NLP on private land only.

Research conducted in Crawford, Missaukee, and Roscommon counties in the NLP from 1991 – 1996 by the Michigan Department of Natural Resources (MDNR) assessed bobcat survival and relative abundance through a capture-mark-recapture study coupled with scent-station surveys (Earle et al. 2003). The results of that study indicated the bobcat population within the study area appeared stable throughout the duration of the study. However, when comparing the age structure of bobcats trapped for research and bobcats harvested by hunters, a higher proportion of yearlings appeared in the harvest (Earle et al. 2003). A high proportion of young animals in the harvest is consistent with heavily harvested (i.e., exploited) populations (Fritts and Sealander 1978, Rolley 1985). Scent-station surveys conducted during the MDNR study detected too few bobcats to identify annual fluctuations in the bobcat population (Earle et al. 2003).

Current biological data on Michigan's NLP bobcat population is acquired through the mandatory registration of harvested bobcats. Data collected from harvested bobcats includes sex, age, date the bobcat was harvested, location where the bobcat was harvested (i.e., County, Township, Range, and Section), and method of harvest (i.e., hunted or trapped). These data provide information on the status (e.g., population trends and relative abundance) of bobcat populations in Michigan (Cooley et al. 2003). Historically, accurate estimates of harvest effort in the NLP were lacking (Earle et al. 2003). However, data collection methods, in the form of mail surveys targeted at bobcat harvesters, to improve estimates of harvest effort were instituted in 2004 (Frawley et al. 2004). The level of harvest effort necessary to harvest 1 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).

Recently, the increased use of geographical 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. Models developed by Lovallo et al. (2001) have resulted in the first harvest of bobcats in Pennsylvania in over 30 years. Nielson and Woolf (2002) developed models that linked habitat and relative abundance to evaluate distribution and abundance of bobcats in southern Illinois. These and similar models were used to assess bobcat status and contributed to the delisting of bobcats as a threatened species in Illinois (Woolf et al. 2002). Integrating demographic data and GIS spatial models can provide a tool to focus management efforts. Furthermore, region-specific models should be developed to more effectively direct bobcat management (Lovallo et al. 2001).

I developed spatial models to identify areas of suitable bobcat habitat and predict bobcat distribution and relative abundance in the NLP of Michigan. I followed a method developed by Nielsen and Woolf (2002) to model bobcat relative abundance. I incorporated data from a radio-telemetry study assessing bobcat home-range and core-area size and habitat use in the NLP (Section 1). These data were linked to habitat and landscape variables using a GIS to model bobcat relative abundance and distribution throughout the NLP. The objective of this study was to predict bobcat distribution and relative abundance based on bobcat area requirements, habitat use, and habitat and landscape variables derived from remotely-sensed land-cover data.

Methods

Study Area

From March 2003 – October 2004, I conducted a radio-telemetry and scent-station survey study of bobcats in a 4,253-km² study area located in the central northern Lower Peninsula, Michigan (Figure 3). The study area included portions of Clare, Crawford, Gladwin, Kalkaska, Missaukee, Ogemaw, Osceola, Oscoda, and Roscommon counties, Michigan. I 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. I reclassified the original 32 cover classes into 8 major cover classes using ArcGIS 8.3 (Environmental Systems Research Institute, Redlands, California, USA). Because some roads and streams were not accounted for in the original land-cover data, I converted vector digital line graph road and stream data (Michigan Center for Geographic Information 2003) to raster format and merged it with the land-cover data.

The study area was comprised of: agriculture/openland (26%), lowland forest (11%), non-forested wetland (4%), open water (4%), streams (1%), transportation (6%), upland forest (47%), and urban (1%) cover types. Forested areas were dominated by oak (*Quercus* spp.), aspen (*Populus* spp.), and mixed pine (*Pinus* spp.) on upland sites and northern white cedar (*Thuja occidentalis*) and balsam fir (*Abies balsamea*) on lowland sites (Leatherberry 1994). I modeled bobcat distribution and relative abundance throughout the 48,518-km² NLP (Figure 4). The NLP was comprised of: agriculture/openland (33%), lowland forest (11%), non-forested wetland (2%), open water (3%), streams (1%), transportation (5%), upland forest (43%), and urban (2%) cover types.

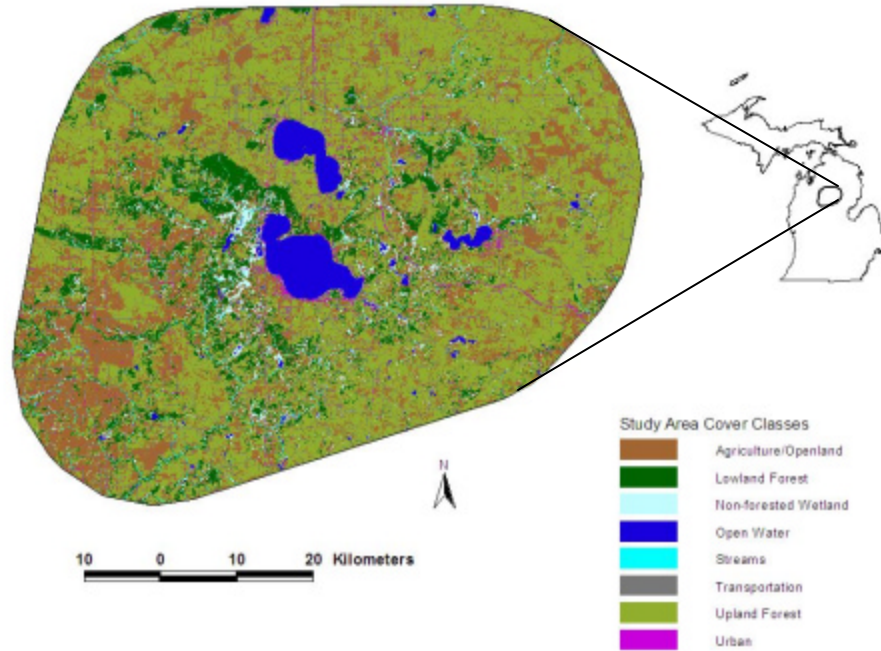


Figure 3. Location of the 4,253-km² study area in the northern Lower Peninsula, Michigan (NLP). A radio-telemetry study was conducted assessing bobcat area requirements and habitat use to aid in spatially modeling bobcat distribution and relative abundance throughout the NLP. The enlarged 30-m resolution study area map displays 8 habitat cover classes.

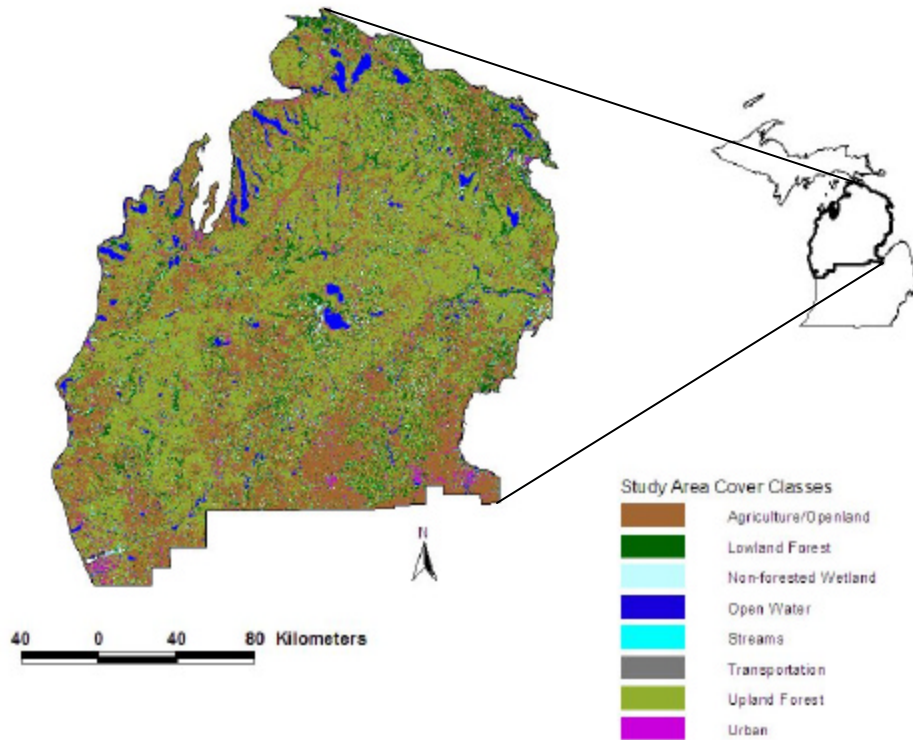


Figure 4. Location of the 48,518-km² northern Lower Peninsula, Michigan (NLP). A model of bobcat distribution and relative abundance was developed for the NLP using 8 habitat cover classes identified in the enlarged 30-m resolution map.

Trapping and Radio-telemetry

I trapped, radio collared, and radio monitored bobcats within the study area in the NLP. Trapping, handling, and radio-telemetry methods are described in Section 1.

Core Area Estimation

I used the Home Range Extension (Rodgers and Carr 1998) for ArcView GIS to estimate 50% core areas of radio-collared adult bobcats using the minimum convex polygon (MCP; Mohr 1947) method. A core area represents an area of the home range where use is more concentrated than in other areas (Samuel et al. 1985, Powell 2000). A core area is probably the most important part of an animal's home range and likely contains den sites, refuges and the most dependable food sources (Samuel et al. 1985). Within the home range of an individual animal, a core area can be defined by using a percentage of locations (e.g., 50%) lower than the total number of locations obtained for that individual (Dixon and Chapman 1980). Using 50% of locations to define the core area of an individual is common for bobcats (Chamberlain and Leopold 2001, Nielsen and Woolf 2001, Benson et al. 2004, Thornton et al. 2004). I modeled at the scale of a core area because core areas of radio-collared bobcats in the NLP would be less likely to exhibit intersexual or intrasexual overlap, whereas home ranges would be more likely to exhibit extensive overlap. Additionally, MCP core-area size did not differ significantly between male and female bobcats (Section 1). I used the MCP estimator because it provides 1 area of use per individual, which was suitable for my analysis (Nielsen and Woolf 2002), and because core areas are estimated more reliably than home ranges (Seaman et al. 1999). To assess whether core areas were adequately estimated, I

developed home-range area accumulation curves. I plotted home-range area against number of locations for each adult bobcat (Kenward 2001). If the home range of an adult bobcat reached stability, I included its core-area estimate in further analyses.

Scent-station Survey

I conducted scent-station surveys to provide presence/absence data in order to supplement radio-telemetry locations for use in relative abundance and distribution modeling. Scent-station surveys were conducted during October – November 2003 and August – September 2004. Surveys were patterned after methods described by Linhart and Knowlton (1975), with modifications by Roughton and Sweeny (1982) and Sargent et al. (1998). Scent stations consisted of a 0.9-m diameter circle of sand with a fatty-acid scent tablet (Pocatello Supply Depot, U.S. Department of Agriculture, Pocatello, Idaho, USA) placed in the center as an olfactory attractant. Seventy transects with 10 stations along each transect were checked for 2 nights. Scent-station transects were placed along paved and unpaved roads and 2-track forest trails throughout and adjacent to the study area (Figure 5). Stations were placed approximately 480 m apart along each transect and transects were located ≥ 5 km from the nearest transect (Sargent et al. 1998). The presence of all tracks was recorded to species whenever possible. Since bobcats and domestic cats were both likely to be encountered in the study area, I identified bobcat tracks as being > 3 cm wide and having a heel pad that was lobed in the rear and concave in front, whereas domestic cat tracks were identified as being < 3 cm wide with a heel pad that was lobed in the rear and not concave in front (Murie 1974, Whitaker 1996). Visitation rates were calculated for the proportion of stations and the proportion of

transects visited by each species. The proportion of stations visited was calculated for each species as the number of stations visited over the 2-night period divided by the total number of stations. However, since individual animals may visit multiple stations along the same transect, thereby introducing pseudoreplication, transect lines rather than stations may be a more appropriate experimental unit (Sargent et al. 1998). The proportion of transects visited was calculated for each species as the number of transects visited over the 2-night period divided by the total number of transects. Stations and transects that detected a species both nights were considered as being visited 1 time. The locations of scent stations visited by bobcats were recorded and merged with radio-telemetry locations for use in distribution and relative abundance modeling.

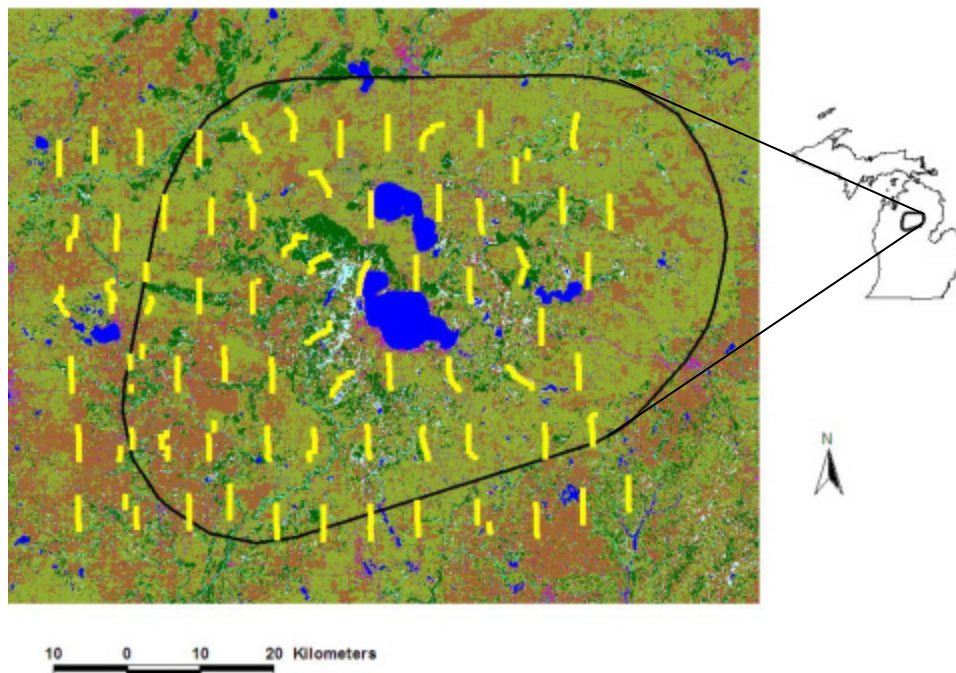


Figure 5. Scent-station surveys were conducted in autumn of 2003 and 2004 to provide presence/absence data in order to supplement radio-telemetry locations for use in relative abundance and distribution modeling. Scent-station transects (represented by yellow lines) were placed along paved and unpaved roads and 2-track forest trails throughout and adjacent to the study area (represented by the black polygon).

Model Variable Selection

I created a grid of 9,113 non-overlapping hexagons and overlaid it on land-cover of the NLP (Figure 6). Each hexagon had an area equal to the average MCP core area of radio-collared adult bobcats.

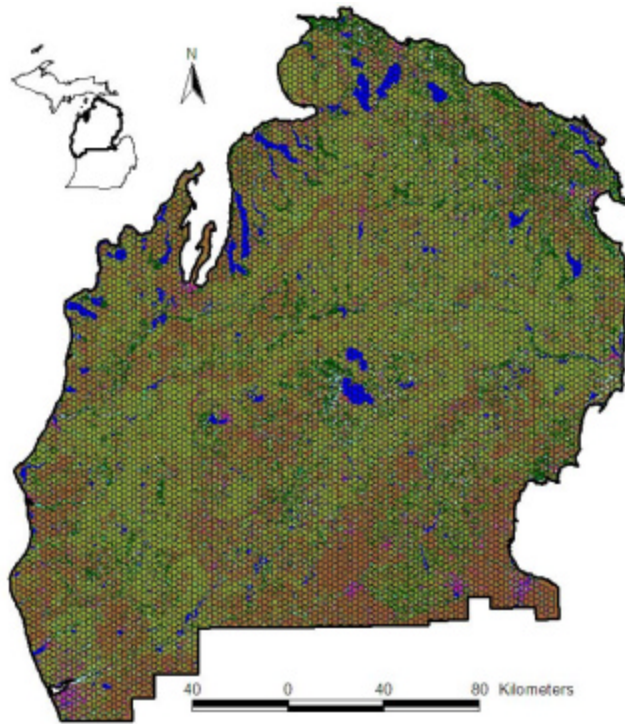


Figure 6. Hexagon grid overlaid on land-cover of the northern Lower Peninsula, Michigan. Habitat and landscape variables were calculated within each 5.1-km² hexagon (i.e., equivalent to the size of an average adult bobcat core area) for modeling bobcat distribution and relative abundance.

Within each hexagon, I calculated 139 habitat and landscape variables from 8 metric groups (Table 7) using the Spatial Statistics by Regions interface of the Patch Analyst Grid 3.0 extension to ArcView GIS 3.2 (Environmental Systems Research Institute, Redlands, California, USA). I \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, Nielsen and Woolf 2002). Habitat proportions were \log_{10} -

Table 7. Habitat (class) and landscape variables calculated for potential use in modeling bobcat distribution and relative abundance in the northern Lower Peninsula, Michigan. Variables were calculated using the Patch Analyst Grid 3.0 extension for ArcView GIS. Class metrics were calculated for agriculture/openland, lowland forest, non-forested wetland, open water, streams, transportation, upland forest, and urban habitats unless noted otherwise.

Calculation	Acronym	Metric (units)
Area Metrics		
Class	%LAND	Percent of landscape (%)
Class-landscape ^a	LPI	Largest patch index (%)
Patch Metrics^b		
Class-landscape	NP	Number of patches (#)
Class-landscape	MPS	Mean patch size (ha)
Class-landscape	PSCV	Patch size coefficient of variation (%)
Edge Metrics^b		
Class-landscape	ED	Edge density (m/ha)
Shape Metrics^b		
Class-landscape	LSI	Landscape shape index
Class-landscape	MSI	Mean shape index
Class-landscape	AWMSI	Area-weighted mean shape index
Class-landscape	DLFD	Double log fractal dimension
Core Area Metrics^{bf}		
Class	C%LAND	Core area percent of landscape (%)
Class-landscape	CAD	Core area density (#/100 ha)
Class-landscape	MCA1	Mean core area per patch (ha)
Class-landscape	CACV1	Patch core area coefficient of variation (%)
Class-landscape	CACV2	Disjunct core area coefficient of variation (%)
Class-landscape	MCA2	Mean area per disjunct core (ha)
Class-landscape	TCAI	Total core area index (%)
Class-landscape	MCAI	Mean core area index (%)
Diversity Metrics^b		
Landscape	SHDI	Shannon's diversity index
Landscape	MSIDI	Modified Simpson's diversity index
Landscape	PR	Patch richness (#)
Landscape	PRD	Patch richness density (#/100 ha)
Landscape	SHEI	Shannon's evenness index
Landscape	MSIEI	Modified Simpson's evenness index
Nearest Neighbor Metrics^b		
Class-landscape	MNN	Mean nearest-neighbor distance (m)
Contagion Metrics^b		
Class-landscape	IJI	Interspersion and juxtaposition index (%)

^a Landscape refers to the total composition of habitats within each hexagon

^b Not calculated for stream and transportation habitat classes

^c Not calculated for the water habitat class

transformed because they would be more likely to obtain a normal distribution than their raw values (Aebischer et al. 1993). I reduced the number of variables for analysis based on the presumed importance of variables to bobcats and univariate statistics. All statistical analyses ($\alpha = 0.05$) were performed in SPSS (SPSS, Inc. 1999). I retained a smaller set of variables for modeling by: 1) retaining the log-transformed proportion of each habitat class; 2) conducting non-parametric Spearman rank correlations within each habitat class for variables within each metric group and determining the number of non-significant correlations per variable; and 3) eliminating 1 of all pairs of correlated variables within each metric group depending on the number of non-significant correlations with other variables in the group. I retained variables in each habitat class most representative of the variables within each metric group. In the case of ties, I retained the variable suspected to be of greater biological importance to bobcats. This resulted in 53 potential variables for modeling.

I further reduced the number of potential variables by correlating the variables within each habitat class. I retained the \log_{10} -transformed proportion of each habitat class, as well as the variable most correlated to others within each habitat class resulting in 15 potential variables for modeling. Since urban land-cover only occurred in 3 of 11 (27%) core areas of radio-collared bobcats, I excluded the 2 variables associated with urban land-cover (proportion of urban and edge density of urban). I also excluded the 2 variables associated with open water (proportion of open water and edge density of open water) because open water only occurred in 4 of 11 (36%) bobcat core areas. This resulted in 11 variables for use in the final modeling of bobcat distribution and relative abundance (Table 8). Because further analysis required data normality, I transformed 2

variables to normal distributions (Wilk-Shapiro statistic = 0.867-0.963). I transformed the proportion of lowland forest by taking the logarithm of the squared value. I also 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 as they were distributed normally (Wilk-Shapiro statistic = 0.867-0.983).

Table 8. The 11 habitat and landscape variables retained for use in the final modeling of bobcat distribution and relative abundance in the northern Lower Peninsula, Michigan.

Variable
Percent of agriculture/openland cover
Percent of lowland forest cover
Percent of upland forest cover
Percent of non-forested wetland cover
Percent of stream cover
Percent of transportation cover
Lowland forest core area percent of landscape
Mean area per disjunct core of landscape
Mean nearest-neighbor of agriculture/openland cover
Mean nearest-neighbor of upland forest cover
Non-forested wetland patch size coefficient of variation

Distribution and Relative Abundance Model

Modeling Habitat Similarity.—I developed an initial model of habitat similarity throughout the NLP based on the habitat characteristics from core areas of radio-collared bobcats. I calculated a mean habitat vector as the mean values of the 11 habitat and landscape variables within bobcat core areas. I 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 grid overlaid on the

NLP. I calculated Penrose distance as: $P_{ij} = \sum_{k=1}^p (\mathbf{m}_{ki} - \mathbf{m}_{kj})^2 / pV_k$; where population i represented core areas of radio-collared 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). Habitat composition within each hexagon of the NLP grid was evaluated relative to the mean habitat vector calculated from bobcat core areas. The habitat and landscape characteristics of hexagons with values close to zero were most similar to the characteristics of core areas of radio-collared bobcats, whereas hexagons with large Penrose distance values had habitat characteristics less similar to those of bobcat core areas. I made 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. I then correlated Penrose distance to each habitat variable to determine the relative importance of each variable in calculating Penrose distance across the NLP.

Modeling Distribution and Relative Abundance.—I developed a spatial model of the distribution of bobcat relative abundance in the NLP. To model relative abundance, I associated Penrose distance for each hexagon with abundance information from radio-collared bobcats and scent-station surveys. I assumed that each hexagon represented 1 bobcat core area. I also assumed that hexagons containing core areas of radio-collared bobcats represented areas of highest relative abundance (1.0 bobcat per hexagon). I calculated mean Penrose distance for hexagons containing core areas of radio-collared bobcats and assumed that all hexagons with a value less than or equal to the mean would contain 1 bobcat. To determine hexagons with zero relative abundance I overlaid bobcat locations from radio-telemetry and scent-station surveys on the Penrose distance map. I

determined the maximum Penrose distance value for hexagons in which bobcats were detected and assumed that hexagons with a Penrose distance value greater than that would contain no bobcats (0 bobcats per hexagon). I estimated intermediate relative abundance (i.e., values between 0 and 1.0 bobcat per hexagon) by calculating frequency distributions of the occurrence of bobcat locations in relation to Penrose distance. I developed a mathematical relationship between the frequency of bobcat locations and Penrose distance to estimate these intermediate relative abundances. The logarithmic curve: $y = -0.69 \ln[x] + 1.5$; where x is Penrose distance and y is bobcat abundance, yielded the greatest R^2 value (0.87). I then quantified the area of land predicted to support 0.51-0.75 and 0.76-1.0 bobcat per hexagon to obtain an estimate of the area of potential habitat suitable to bobcats.

Model Validation.—I validated the relative abundance model by overlaying an independent set of locations ($n = 196$) obtained from harvested bobcats registered with the MDNR during the 2002 – 2003 bobcat hunting season. I then calculated frequency distributions of the percentage of harvested bobcats occurring in each density (i.e., abundance) class of the relative abundance model.

Results

I captured and radio-collared a total of 15 bobcats (5 females and 10 males). Thirteen (5 females and 8 males) of the 15 bobcats captured and radio collared were classified as adults. Two other males were classified as juveniles. I obtained 915 locations on 13 adult bobcats from May 2003 – October 2004. Investigation of plots of home-range area against number of locations indicated that 11 adult bobcats (5 females

and 6 males) were suitable for use in estimation of core-area size. The average core-area size for adult bobcats was $5.1 \text{ km}^2 \pm 6.1 (\bar{x} \pm \text{SD})$.

Bobcats were the third and fourth most detected species at scent stations in 2003 and 2004, respectively, in comparison to other mammal species (Table 9).

Table 9. Station and transect visitation rates for bobcats and selected mammal species detected at scent stations during surveys conducted in autumn of 2003 and 2004.

Species	2003		2004	
	% station visitation	% transect visitation	% station visitation	% transect visitation
Black bear (<i>Ursus americanus</i>)	0.1	1.4	0.6	5.7
Bobcat (<i>Lynx rufus</i>)	7.0	43.0	4.9	42.9
Coyote (<i>Canis latrans</i>)	3.4	22.9	6.1	37.1
Domestic cat (<i>Felis catus</i>)	8.4	44.3	12.9	60.0
Domestic dog (<i>Canis familiaris</i>)	9.7	48.6	8.6	51.4
Gray fox (<i>Urocyon cinereoargenteus</i>)	0.3	1.4	0.4	4.3
Raccoon (<i>Procyon lotor</i>)	4.9	31.4	10.7	58.6
Red fox (<i>Vulpes vulpes</i>)	2.0	15.7	3.3	17.1
Striped skunk (<i>Mephitis mephitis</i>)	3.1	27.1	2.3	17.1
Unknown felid spp. (<i>Felis</i> sp or <i>Lynx</i> sp)	1.3	8.6	1.0	10.0
Weasel spp. (<i>Mustela</i> spp)	0.4	4.3	2.4	18.6

Distribution and Relative Abundance Model

Modeling Habitat Similarity.—Hexagons containing bobcat core areas were comprised of proportionately more lowland forest (51%), non-forested wetlands (9%), and streams (3%) than surrounding NLP hexagons (Table 10). The NLP was comprised primarily of upland forest (44%) and agriculture/openland (32%). All 11 model variables were significantly correlated with Penrose distance (Table 10). Mean area per disjunct core of landscape was most correlated to Penrose distance. Mean nearest-neighbor of

Table 10. Mean values (\pm SE) of 11 habitat variables used for modeling distribution and relative abundance of bobcats in the northern Lower Peninsula, Michigan (NLP), and the correlations between each variable and Penrose distance (PD). Values were calculated from 50% minimum convex polygon core areas of 11 radio-collared bobcats (mean vector) and from within hexagons of a hexagon grid overlaid on the NLP. The mean habitat vector was calculated as the mean values of the 11 habitat and landscape variables within bobcat core areas. All correlations between NLP hexagon variables and Penrose distance were significant ($P \leq 0.05$).

Variable ^a	Mean vector	NLP hexagons	Correlation between NLP hexagons and PD
Percent of agriculture/openland cover	15.8 \pm 2.5	32.4 \pm 0.2	-0.471
Percent of lowland forest cover	51.4 \pm 5.0	10.4 \pm 0.1	0.414
Percent of upland forest cover	17.6 \pm 4.1	43.7 \pm 0.2	-0.439
Percent of non-forested wetland cover	8.6 \pm 1.4	2.3 \pm 0.1	-0.438
Percent of stream cover	3.4 \pm 0.9	0.9 \pm 0.1	-0.223
Percent of transportation cover	3.0 \pm 0.5	5.2 \pm 0.1	-0.425
Lowland forest core area percent of landscape	27.6 \pm 4.5	3.6 \pm 0.1	-0.469
Mean area per disjunct core of landscape	0.7 \pm 0.1	2.6 \pm 0.3	0.922
Mean nearest-neighbor of agriculture/openland cover	50.0 \pm 2.5	44.9 \pm 0.1	0.259
Mean nearest-neighbor of upland forest cover	55.0 \pm 7.6	43.6 \pm 0.3	0.061
Non-forested wetland patch size coefficient of variation	208.3 \pm 28.5	120.1 \pm 0.8	-0.416

^a Percent of habitat cover values are presented as raw percents and not their \log_{10} -transformed equivalents.

upland forest and agriculture/openland cover, as well as proportion of stream cover, appeared least important in determining Penrose distance across the NLP. Mean Penrose distance for bobcat core areas was 2.17 ± 1.5 ($\bar{x} \pm SD$) and ranged from 0.42 to 7.58. Mean Penrose distance for NLP hexagons was 3.54 ± 4.1 ($\bar{x} \pm SD$) and ranged from 0.12 to 76.79. No locations of bobcats occurred in hexagons with Penrose distance value >8.45 . Throughout the NLP, 1,761 of 9,113 (19%) hexagons had a Penrose distance ≤ 2.17 (Figure 7). 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. Areas with low Penrose distance were characterized primarily by lowland forest and non-

forested wetland cover. Habitat characteristics of the west and northcentral areas of the NLP appeared least similar to bobcat core areas. These areas with higher Penrose distances were characterized primarily by upland forest and agriculture/openland habitats.

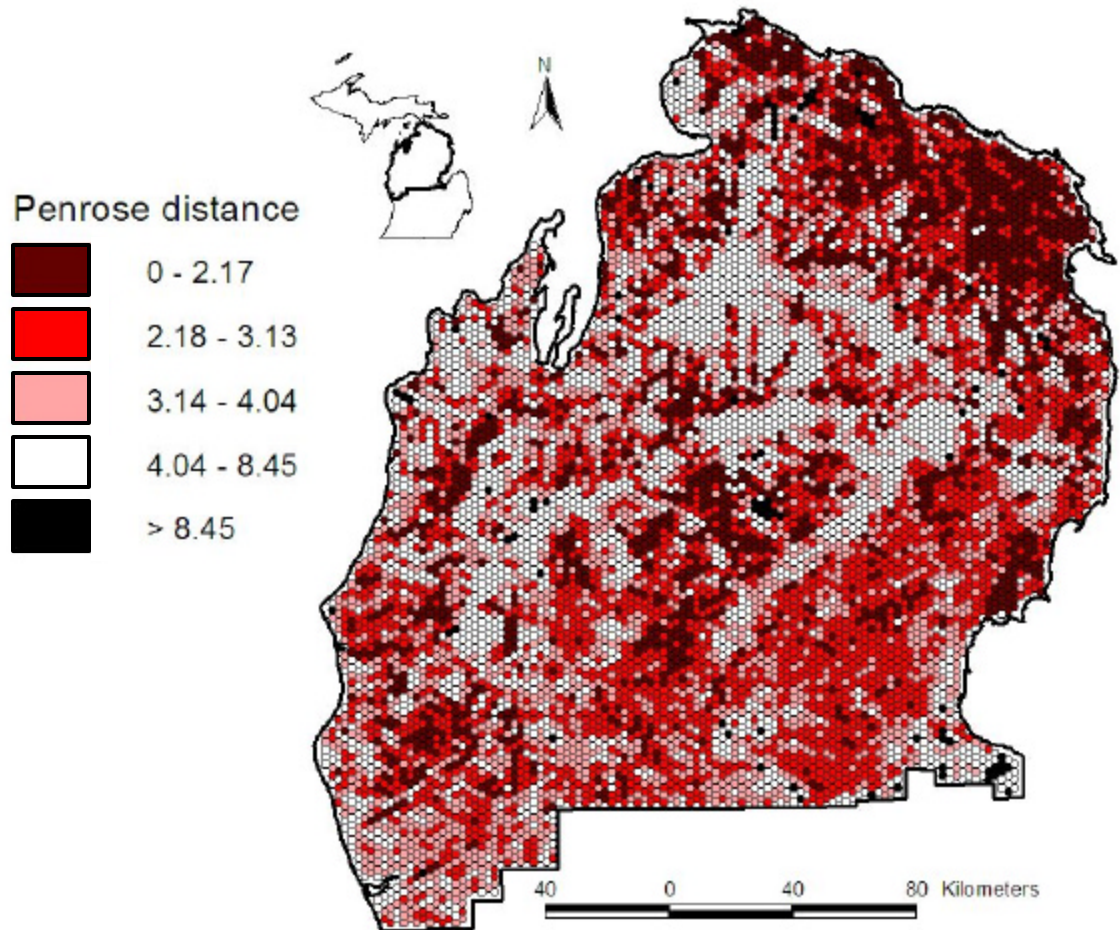


Figure 7. Penrose distance map depicting habitat similarity between core areas of radio-collared adult bobcats and the northern Lower Peninsula, Michigan. Lower Penrose distance values indicate a greater similarity of habitat to bobcat core areas.

Modeling Distribution and Relative Abundance.—Bobcat distribution was predicted to be relatively patchy throughout the NLP (Figure 8). Bobcats were predicted to have greater densities in the northeast, central, and southeast regions of the NLP. Bobcats were predicted to have lowest densities in the northcentral, westcentral, and

extreme southeast regions. A total of 36,556 km² of the NLP (75% of total area) was predicted to be suitable bobcat habitat. Approximately 16,090 km² (33% of total area) and 20,466 km² (42% of total area) of habitat were predicted to support 0.51-0.75 and 0.76-1.0 bobcat per hexagon, respectively.

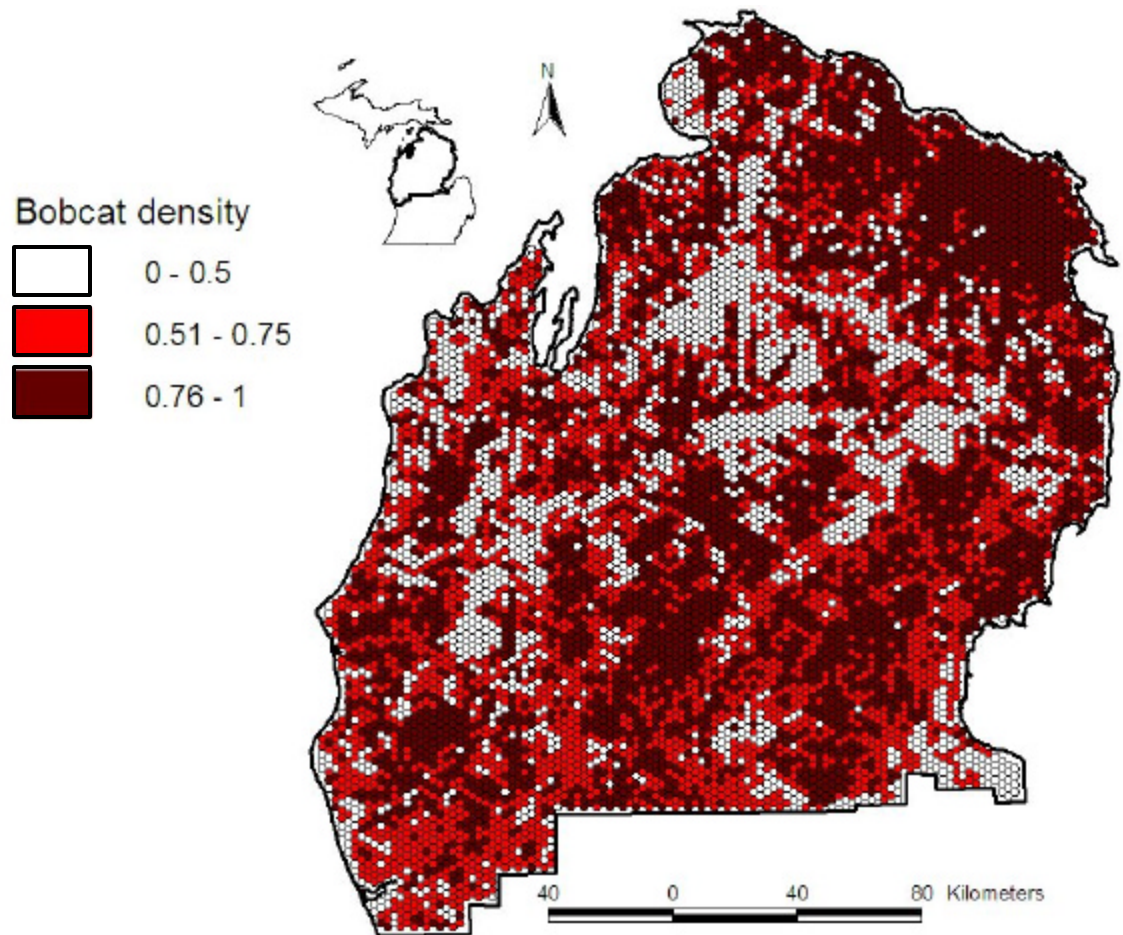


Figure 8. Map of the northern Lower Peninsula, Michigan (NLP) depicting predicted relative abundance of bobcats throughout the region. Bobcat abundance is based on a relationship between the similarity of habitat in the NLP to the habitat characteristics of bobcat core areas and abundance information from radio-collared bobcats and scent-station surveys.

Model Validation.—The majority of independent bobcat harvest locations occurred in areas of the NLP predicted to have greatest bobcat density (Figure 9). Frequency distributions of harvest locations indicated that 75% of locations occurred in

the highest density class (i.e., 0.76-1.0), 19% of locations occurred in the second highest density class (i.e., 0.51-0.75), and 6% of locations occurred in the lowest density class (i.e., 0.0-0.50).

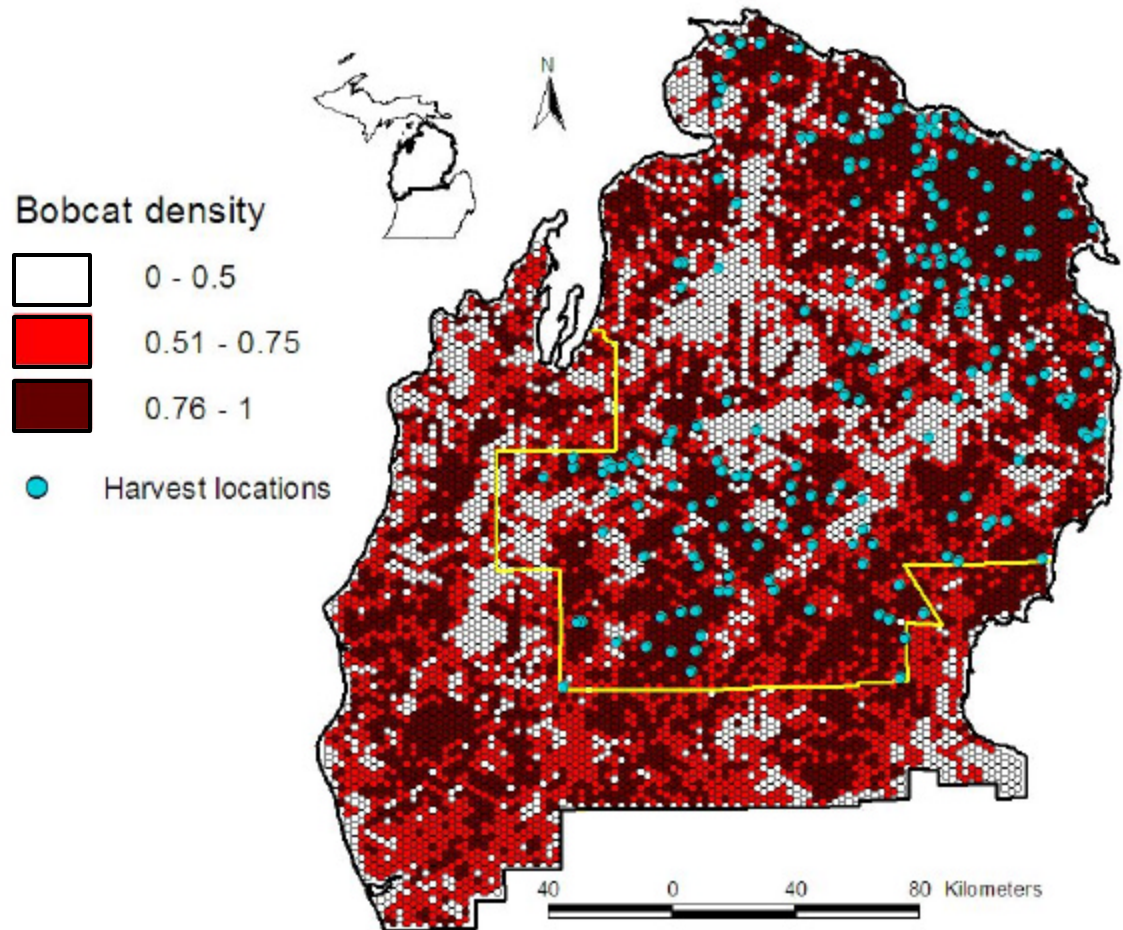


Figure 9. Map of bobcat relative abundance in the northern Lower Peninsula, Michigan with locations of 196 bobcats harvested during the 2002 – 2003 Michigan bobcat hunting season. Locations from harvested bobcats were used for model validation. The area south and west of the yellow line is closed to bobcat hunting.

Discussion

Regional models of habitat suitability have been developed for bobcats (Conner et al. 2001, Lovallo et al. 2001, Nielsen and Woolf 2002), as well as a number of other carnivore species including black bears (*Ursus americanus*, Clark et al. 1993), Canada

lynx (*Lynx canadensis*, Hoving 2001), Florida panthers (*Puma concolor coryi*, Maehr and Cox 1995), and gray wolves (*Canis lupus*, Mladenoff et al. 1995). Additionally, Gehring and Swihart (2003) developed multi-scale models for multiple carnivore species in agricultural landscapes. These models have primarily used logistic regression and distance statistics (e.g., Mahalanobis distance). Lovallo et al. (2001) used logistic regression, the Mahalanobis distance statistic, and a variety of univariate statistics to model bobcat habitat selection in Pennsylvania. Using these statistical methods, habitat selection data from radio-collared bobcats were extrapolated to a statewide model of habitat suitability and were validated with sighting and mortality data from within the districts of wildlife conservation officers. Lovallo et al.'s (2001) model was based on data from within bobcat home ranges but was developed at a scale defined by management zones for use by Pennsylvania state wildlife managers. The model I 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 vertebrate animals tend to perceive their environment at different spatial scales or at different levels of resolution (Zollner and Lima 1997, Gehring 2000, Gehring and Swihart 2003). Therefore, it is important to understand how bobcats interact with the landscape at a scale that may be more meaningful to a bobcat (e.g., a home range or core area).

Nielsen and Woolf (2002) modeled bobcat habitat suitability using a multivariate distance statistic called Penrose distance. Penrose distance has a number of advantages over logistic regression and the Mahalanobis distance statistic. Logistic regression is typically used to predict presence and absence of a species, and generally assumes that used and unused habitats are classified without error. For example, bobcats in Michigan

primarily use lowland conifer forest (Section 1), however, aspen clear-cuts may be an important habitat for procuring prey. If sampling methods (e.g., radio-telemetry, scent-station surveys) for determining bobcat habitat use did not detect bobcats in aspen clear-cuts, logistic regression models would predict bobcats to be absent from that habitat when, in fact, they did occur there (Type I error). Penrose distance does not require the assumption that used and unused habitats are classified without error. The Mahalanobis distance statistic has been shown to provide similar results to Penrose distance (Manly 2005), however there are several differences between these 2 methods. Mahalanobis distance accounts for correlations between variables which Penrose distance does not. In my analysis, I conducted correlation analysis to remove correlated variables before employing the Penrose distance statistic. The Mahalanobis distance equation, however, does not contain squared terms (Manly 2005), which precluded its use in my analysis because the \log_{10} -transformed habitat proportions were often negative.

The model I developed was based on the method implemented in southern Illinois involving the use of data from radio-collared bobcats, remotely-sensed land-cover, and the Penrose distance statistic to develop a habitat-relative abundance relationship for an unharvested bobcat population (Nielsen and Woolf 2002). Nielsen and Woolf (2002) developed this model for use by wildlife managers in Illinois where bobcats had been listed as state threatened until 1999. Similarly, I used data from radio-collared bobcats, remotely-sensed land-cover, and the Penrose distance statistic to model distribution and relative abundance throughout the NLP for a harvested bobcat population. Because radio-telemetry data were collected from relatively few ($n = 11$) bobcats, I conducted scent-station surveys to supplement telemetry data. Scent-station surveys have been

widely used to monitor and index trends in populations of furbearers, including bobcats (Diefenbach et al. 1994). The ability of scent-station surveys to accurately detect trends in bobcat populations has been a subject of some debate. Scent-station surveys have accurately detected fluctuations in some bobcat populations (Conner et al. 1983, Rolley 1985), but have been unsuccessful in indexing trends in other populations of bobcats (Rust 1980). A number of variables, including population density, varying habitat, sampling intensity, and survey duration, can influence the ability of scent-station surveys to detect changes in populations of carnivores (Hatcher and Shaw 1981, Roughton and Sweeny 1982, Turkowski et al. 1983, Earle et al. 2003). According to Sargent et al. (2003), unless surveys are conducted over large spatial scales with large sample sizes and visitation rates to scent stations exceed 10%, scent-station surveys provide little useful data on changes in population size. However, scent-station surveys provide useful information in terms of the presence or absence of a species, and are valuable when used to supplement data from other sources, such as radio-telemetry (Sargent et al. 1998). This was the capacity in which I used scent-station surveys for bobcats in the NLP.

Interpretations of the model I developed for the NLP should be considered cautiously. Population dynamics, particularly in terms of density, can be quite different between harvested (Rolley 1985) and unharvested (Nielsen and Woolf 2001) bobcat populations. The model I developed for the NLP is likely indicative of potential bobcat distribution and relative abundance if the population was not harvested.

Lowland forest and non-forested wetland habitats were 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. The importance of landscape patchiness in determining the similarity of habitat in the NLP to habitat within bobcat core areas is likely indicative 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). A value of zero indicated a high level of patchiness, whereas higher values signified more contiguous habitat patches. Bobcat core areas were characterized by 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 (Section 1). However, the significance of all variables, even with low correlation coefficients, is likely due to the large sample size of NLP hexagons.

No variable pertaining to harvest was included in the NLP model, and it is likely that bobcats in Michigan would use the same habitats regardless of whether or not there is a harvest. However, predicted densities would likely differ depending on the presence or absence of a harvest. Additionally, model data came from a single, albeit large, study area in the center of the NLP and was extrapolated across the NLP. The validation of the model proved to be accurate, however the only independent data obtainable from throughout the NLP were bobcat harvest locations. Since locations of harvested bobcats may be biased, better validation might be achieved from having multiple study areas or conducting regional surveys (e.g., scent-station surveys, snow-track counts) throughout the NLP. 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). Random allocation of surveys in high-density and low-density areas may provide a better model validation. Appropriate and accurate validation is important because many deficiencies in modeling efforts often occur when models are extrapolated to inappropriate spatial scales and when data are collected over a short time frame (Roloff and Kernohan 1999).

The model of bobcat distribution and relative abundance that I developed for the NLP may serve to identify focal areas for the surveying and monitoring of the bobcat population. This may, in turn, lead to a more accurate validation of the NLP model. Additionally, this model may assist wildlife managers in Michigan to quantify the allocation of harvest based on predicted distribution and abundance of bobcats, and, in combination with data on reproduction and survival, may aid in predicting responses to varying levels of harvest. For example, if the majority of harvest pressure is localized in several key areas that are important to bobcats, management agencies may redefine harvest regulations to reduce the pressure on these key areas. This may lead to the delineation of harvest zones and/or the establishment of bobcat harvest quotas based on the spatial patterning of high-quality bobcat habitat (e.g., contiguous patches of lowland forest habitat). Spatially controlling harvest through a mosaic of hunted and unhunted areas can lead to high yields while avoiding overharvest (McCullough 1996). Furthermore, this model may serve as a basis for investigation of potential source-sink dynamics based on the distribution of suitable habitat (Pulliam and Danielson 1991).

Of additional merit, models such as these may be important for landscape planning, particularly in areas experiencing impacts related to urbanization and habitat fragmentation. Habitat fragmentation can have profound effects on wildlife populations.

Bobcats have been shown to be sensitive to levels of habitat fragmentation (Crooks 2002). In particular, 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 wolves and bobcats may be exposed to increased human induced mortality (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. Additionally, in areas experiencing habitat fragmentation, carnivores with large home ranges may be more likely to face declines in population size, or possible extinction, than those with smaller home ranges, regardless of population density (Woodroffe and Ginsberg 1998). 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. 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.

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